JEPPIAAR
INSTITUTE OF TECHNOLOGY
"Self-Belief | Self Discipline | Self Respect"

QUESTION BANK

Regulation	:	2017
Year	:	II
Semester	:	04
Batch	:	2018-2022
Academic Year	:	2019-2020

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

Vision of the Institution:

Jeppiaar Institute of Technology aspires to provide technical education in futuristic technologies with the perspective of innovative, industrial and social application for the betterment of humanity.

Mission of the Institution:

- To produce competent and disciplined high-quality professionals with the practical skills necessary to excel as innovative professionals and entrepreneurs for the benefit of the society.
- To improve the quality of education through excellence in teaching and learning, research, leadership and by promoting the principles of scientific analysis, and creative thinking.
- To provide excellent infrastructure, serene and stimulating environment that is most conducive to learning.
- To strive for productive partnership between the Industry and the Institute for research and development in the emerging fields and creating opportunities for employability.
- To serve the global community by instilling ethics, values and life skills among the students needed to enrich their lives.

Department Vision

To foster contemporary Skills in the field of Electrical and Electronics Engineering with innovatory Skills, Global Understanding and Nation building for the progress of Humankind.

Department Mission

- To Encompass Quality Engineers with skills as persevere to enrich the global technically.
- To engage in research activities leading to innovative application of technology with Industrial approach for the benefit of mankind.
- To provide quality structure and beneficial learning system.
- To enable them as responsible human who value Ethics and environment.

PEO's of the Department

PEO1: To provide students with the fundamental Knowledge, methodologies and use of cutting-edge Technologies.

PEO2: To provide students with an awareness and skills in lifelong learning and self-education.

PEO3: To Cultivate Teamwork, Technical writing and Oral communication skills.

PEO4: To provide students with an appreciation of engineering impact on society and the Professional responsibilities of an engineers.

Program Specific Outcomes (PSO's)

PSO1: Apply the fundamentals of mathematics, Science and Engineering knowledge to identify, formulate, design and investigate complex engineering problems of electric circuits, analog and digital electronics, electrical machines and systems.

PSO2: Apply appropriate technique and modern Engineering hardware and software tools in power systems to engage in life-long learning and to successfully adapt in multi-disciplinary environments.

PSO3: Understand the impact of Professional Engineering solutions in societal and environment context, commit to professional ethical and communicate effectively.

BLOOM’S TAXONOMY

Definition:

Bloom’s taxonomy is a classification system used to define and distinguish different levels of human cognition like thinking, learning, and understanding.

Objectives:

- To classify educational learning objectives into levels of complexity and specificity. The classification covers the learning objectives in cognitive, affective and sensory domains.
- To structure curriculum learning objectives, assessments and activities.

Levels in Bloom’s Taxonomy:

- **BTL 1 – Remember** - The learner recalls, restate and remember the learned information.

- **BTL 2 – Understand** - The learner embraces the meaning of the information by interpreting and translating what has been learned.

- **BTL 3 – Apply** - The learner makes use of the information in a context similar to the one in which it was learned.

- **BTL 4 – Analyze** - The learner breaks the learned information into its parts to understand the information better.

- **BTL 5 – Evaluate** - The learner makes decisions based on in-depth reflection, criticism and assessment.

- **BTL 6 – Create** - The learner creates new ideas and information using what has been previously learned.

TABLE OF CONTENTS

IC8451- CONTROL SYSTEMS

MA8491 NUMERICAL METHODS L T P C
4 0 0 4

OBJECTIVES :

- To introduce the basic concepts of solving algebraic and transcendental equations.
- To introduce the numerical techniques of interpolation in various intervals in real life situations.
- To acquaint the student with understanding of numerical techniques of differentiation and integration which plays an important role in engineering and technology disciplines.
- To acquaint the knowledge of various techniques and methods of solving ordinary differential equations.
- To understand the knowledge of various techniques and methods of solving various types of partial differential equations.

UNITI SOLUTION OF EQUATIONS ANDEIGENVALUEPROBLEMS12

Solution of algebraic and transcendental equations - Fixed point iteration method – Newton Raphson method - Solution of linear system of equations - Gauss elimination method – Pivoting - Gauss Jordan method – Iterative methods of Gauss Jacobi and Gauss Seidel - Eigenvalues of a matrix by Power method and Jacobi's method for symmetric matrices.

UNITII IINTERPOLATION AND APPROXIMATION 12

Interpolation with unequal intervals - Lagrange's interpolation – Newton's divided difference interpolation – Cubic Splines - Difference operators and relations - Interpolation with equal intervals - Newton's forward and backward difference formulae.

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UNITV BOUNDARY VALUE PROBLEMS IN ORDINARY AND PARTIAL DIFFERENTIAL EQUATIONS 12

Finite difference methods for solving second order two - point linear boundary value problems - Finite difference techniques for the solution of two-dimensional Laplace’s and Poisson’s equations on rectangular domain – One dimensional heat flow equation by explicit and implicit (Crank Nicholson) methods – One dimensional wave equation by explicit method.

TOTAL: 60 PERIODS

OUTCOMES:

Upon successful completion of the course, students should be able to:

- Understand the basic concepts and techniques of solving algebraic and transcendental equations.
- Appreciate the numerical techniques of interpolation and error approximations in various intervals in real lifesituations.
- Apply the numerical techniques of differentiation and integration for engineeringproblems.
- Understand the knowledge of various techniques and methods for solving first and second order ordinary differentialequations.
- Solve the partial and ordinary differential equations with initial and boundary conditions by using certain techniques with engineeringapplications.

TEXTBOOKS:

1. Burden, R.L and Faires, J.D, "Numerical Analysis", 9th Edition, Cengage Learning,2016.
2. Grewal, B.S., and Grewal, J.S., "Numerical Methods in Engineering and Science", Khanna Publishers, 10th Edition, New Delhi,2015.

REFERENCES:

1. Brian Bradie, "A Friendly Introduction to Numerical Analysis", Pearson Education, Asia, New Delhi, 2007.
2. Gerald. C. F. and Wheatley. P. O., "Applied Numerical Analysis", Pearson Education, Asia, 6th Edition, New Delhi,2006.
3. Mathews, J.H. "Numerical Methods for Mathematics, Science and Engineering", 2nd Edition, Prentice Hall,1992.
4. Sankara Rao. K., "Numerical Methods for Scientists and Engineers", Prentice Hall of India Pvt. Ltd, 3rd Edition, New Delhi,2007.
5. Sastry, S.S, "Introductory Methods of Numerical Analysis", PHI Learning Pvt. Ltd, 5th Edition, 2015.

REGULATION :2017 **ACADEMIC YEAR : 2019-2020**

Subject Code:MA8491 **Year/Semester: II /04**
Subject Name: Numerical Methods **Subject Handler: Dr. S. Shenbaga Ezhil**

	UNIT I – SOLUTION OF EQUATIONS AND EIGENVALUE PROBLEMS
	Solution of algebraic and transcendental equations – Fixed point iteration method – Newton Raphson method – Solution of linear system of equations – Gauss elimination method – Pivoting – Gauss Jordan method – Iterative methods of Gauss Jacobi and Gauss Seidel – Eigenvalues of a matrix by Power method and Jacobi's method for symmetric matrices.
	PART *A
Q.No.	**Questions**
1.	**Give Newton Raphson iterative formula.** BTL1 $x_{n+1} = x_n - \dfrac{f(x_n)}{f'(x_n)}, n = 0,1,2,.......$
2	**How will you find a negative root of a polynomial equation by Iteration method?**BTL2 Let f(x) =0 be the polynomial. The negative root of this polynomial can be obtained by finding the positive root of f(– x) = 0
3	**State the order (rate) of convergence and convergence condition for NewtonRaphson method**. BTL1 The order of convergence of Newton Raphson method is 2 (quadratic) and convergence condition is $\left\| f(x) f''(x) \right\| < \left[f'(x) \right]^2$.
4	**Show that Newton Raphson formula to find $\sqrt{a}$ can be expressed in the formula.**BTL1 $x_{n+1} = \dfrac{1}{2}\left(x_n + \dfrac{a}{x_n} \right)$ Let x = $\sqrt{a} \Rightarrow x^2 = a$ (i.e.) f(x) = x^2 - a $\Rightarrow f(x_n) = x_n{}^2 - a, f'(x_n) = 2x_n$ By Newton Raphson method,

	$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)} \ = x_n - \frac{(x_n{}^2 - a)}{2x_n}$ $= \frac{x_n{}^2 + a}{2x_n}$ $= \frac{1}{2}\left(x_n + \frac{a}{x_n}\right).$
5	**Derive Newton's algorithm for finding the p^{th} root of a number N.**BTL2 Let x = $N^{1/p}$ $\Rightarrow x^p = N \ \Rightarrow x^p - N = 0$ i.e. f(x) = $x^p - N \Rightarrow f(x_n) = x_n{}^p - N, f'(x_n) = px_n{}^{p-1}$ By Newton Raphson method, $x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)} \ = x_n - \frac{x_n{}^p - N}{px_n{}^{p-1}}$ $= \frac{(p-1)x_n{}^p + N}{px_n{}^{p-1}}.$
6	**Establish an iteration formula to find the reciprocal of a positive number N by Newton Raphson method.**BTL4 Let x = 1/N $\Rightarrow N = \frac{1}{x} \ \Rightarrow \frac{1}{x} - N = 0$ $(i.e.) \ \ f(x) = \frac{1}{x} - N \ \ \Rightarrow f(x_n) = \frac{1}{x_n} - N, f'(x_n) = -\frac{1}{x_n{}^2}$ By Newton Raphson method,

	$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)} = x_n - \frac{\frac{1}{x_n} - N}{-\frac{1}{x_n^{2}}} = x_n + x_n^{2}\left(\frac{1}{x_n} - N\right)$ $= x_n\left(2 - Nx_n\right).$
7	**Derive Newton's formula to find the cube root of a positive number k.** BTL2 Let x = $\sqrt[3]{k}$ f(x) = x^3 – k $\Rightarrow f(x_n) = x_n^{3} - k,\ f'(x_n) = 3x_n^{2}$ By Newton Raphson method, $x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)} = x_n - \frac{x_n^{3} - k}{3x_n^{2}}$ $= \frac{2x_n^{3} + k}{3x_n^{2}}$ $= \frac{1}{3}\left(2x_n + \frac{k}{x_n^{2}}\right).$
8	**State the principle used in Gauss-Jordan method.** BTL1 In the equation AX = B, the matrix A is transformed into an identity matrix.
9	**Give the sufficient condition of convergence of Gauss Seidel method (or) Gauss Jacobi method.** BTL1 The absolute value of the leading diagonal element is greater than the sum of the absolute values of the other elements in that row, which is called diagonally dominant.
10	**Write the conditions for convergence in Gauss Seidel iterative technique. (or) When the method of iteration will be useful?** BTL2 The coefficient matrix should be diagonally dominant.
11	**State Gauss Seidel method.** BTL1 As soon as a new value for a variable is found by iteration it is used immediately in the following equations. This method is called Gauss Seidel method.
12	**Why Gauss Seidel method is a better method than Jacobi's iterative method.** BTL1 Since the immediately calculated values in Gauss Seidel of the unknowns are used, the convergence

in Gauss Seidel method will be more rapid than in Gauss Jacobi method. The rate of convergence of Gauss Seidel method is roughly twice that of Gauss Jacobi method.

13

Write the first iteration values of x, y, z when the equations 7x+6y-z = 85, 6x+15y+2z = 72, x+y+5z = 110 are solved by Gauss Seidel method. BTL4

Here the coefficient matrix is diagonally dominant. Then

$$x = \frac{1}{27}(85 - 6y + z) \text{ …....(1)}$$

$$y = \frac{1}{15}(72 - 6x - 2z) \text{…… (2)}$$

$$z = \frac{1}{5}(110 - x - y) \text{…….(3)}$$

<u>First Iteration</u>

Put y = 0, z = 0 in (1), we get x = 3.148

Put x = 3.148, z = 0 in (2), we get y = 3.451

Put x = 3.148, y = 3.451 in (3), we get z = 20.662

14

Distinguish between direct and iteration method of solving simultaneous equations. BTL4

<u>Direct method</u>	<u>Iterative method</u>
i) We get exact solution	i) Approximate solution
ii) Simple, take less time	ii) Time consuming laborious.

15

Compare Gauss Elimination and Gauss Jordan methods for solving linear systems of the form AX=B. BTL4

In Gauss Elimination method, the coefficient matrix reduced to upper triangular matrix and we get the solution by back substitution whereas in Gauss Jordan method, the coefficient matrix reduces to an unit or identity matrix and we get the solution without using back substitution.

16

Solve 3x+y = 2, x+3y = -2 by Gauss Seidel iteration method. BTL3

In sixth iteration, we get x = 1, y = -1.

17

Find the dominant eigen value of A = $\begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix}$ **by power method.**BTL3

Dominant eigen value = 5.3722.

18

On what type of equations Newton's method can be applicable? BTL1

Newton's method can be applicable to the solution of both algebraic and transcendental equation and can be also used when the roots are complex.

19

By Gauss elimination method solve $x + y = 2 \ \ and \ \ 2x + 3y = 5.$ BTL3

The augmented matrix is

$$[A, B] = \begin{bmatrix} 1 & 1 & 2 \\ 2 & 3 & 5 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & 1 & 2 \\ 0 & 1 & 1 \end{bmatrix} R_2 = R_2 - 2R_1$$

By back substitution, $x + y = 2$ ----(1)

$y = 1$

(1) becomes, $x + 1 = 2$

$x = 1$

Hence x = 1, y = 1.

20

Why Gauss Seidel iteration is a method of successive corrections? BTL1

Because we replace approximations by corresponding new ones as soon the latter have been computed.

21

What are the merits of Newton's method of iteration?BTL1

Newton's method is successfully used to improve the result obtained by other methods. It is applicable to the solution of equations involving algebraical functions as well as transcendental functions.

22

Give two direct methods to solve a system of linear equations.BTL2

Gauss Elimination method and Gauss Jordan method.

23

Compare Gauss Elimination with Gauss Seidel method.BTL4

Gauss Elimination	Gauss Seidel
i.Direct method	Indirect method
ii. Used to find inverse ofequations only	Used to solve system of the matrix also.

iii. Diagonally dominant conditionis insisted.	Diagonally dominant condition is not insisted.

24

Find inverse of A = $\begin{bmatrix}1 & 2\\ 3 & 4\end{bmatrix}$ by Gauss Jordan method.BTL1

$$AI = \begin{bmatrix}1 & 2\\ 3 & 4\end{bmatrix}\begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix}$$

$$= \begin{bmatrix}1 & 3\\ 0 & 1\end{bmatrix}\begin{bmatrix}1 & 0\\ -2 & 1\end{bmatrix}$$

$$= \begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix}\begin{bmatrix}7 & -3\\ -2 & 1\end{bmatrix}$$

$$\text{Hence } A^{-1} = \begin{bmatrix}7 & -3\\ -2 & 1\end{bmatrix}$$

25

Find the real positive root of 3x-cos x – 1=0 by Newton's method correct to 6 decimal places. BTL1

The roots lie between (0,1).

$$x_3 = 0.632$$

Part*B

1

Solve the equation $x\log_{10} x = 1.2$ **using Newton Raphson method. (8M)** BTL5**. (Nov 2013, Apr 2014, Apr2017)**

Answer: Page: 3.12-Dr.G. Balaji

Newton's Formula $x_{n+1} = x_n - \dfrac{f(x_n)}{f'(x_n)}$. **(2M)**

Iteration	x_r	$f(x_r)$
1	2.746	0.00467
2	2.741	0.000309
3	2.741	0.000309

(6M)

2

Find the negative root of the equation $\sin x = 1 + x^3$ by using Newton Raphson method. (8M)BTL5 (Nov 2013, Apr 2014, Apr2017)

Answer: Page: 3.25-Dr.G. Balaji

Newton's Formula $x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)}$ **(2M)**

Iteration	x_r	$f(x_r)$
1	-1.3421	-0.4434
2	-1.2564	-0.0323
3	-1.2491	-0.000209
4	-1.2491	-0.000209

(6M)

3

Solve the following equation by Gauss Elimination method.

$$10x - 2y + 3z = 23$$
$$2x + 10y - 5z = -33.$$ **(8M)** BTL5**(Nov 2013, Apr 2014, Apr2017)**
$$3x - 4y + 10z = 41$$

Answer: Page: 3.41-Dr.G. Balaji

Write the given system of equation in augmented matrix form

$$\begin{bmatrix} 10 & -2 & 3 & 23 \\ 2 & 10 & -5 & -33 \\ 3 & -4 & 10 & 41 \\ & & & \end{bmatrix}$$ **(2M)**

Use back substitution to find the solution to the system**(4M)**

i.e. x=1, y=-2, z=3. **(2M)**

4

Solve the equation by Gauss Jordan method:

$$2x_1 + x_2 + 4x_3 = 4$$
$$x_1 - 3x_2 - x_3 = -5$$ **(8M)BTL5 (Nov 2013, Apr 2014, Apr2017)**
$$3x_1 - 2x_2 + 2x_3 = -1$$

Answer: Page: 3.41-Dr.G. Balaji

Write the given system of equation in augmented matrix form

$$\begin{bmatrix} 2 & 1 & 4 & 4 \\ 1 & -3 & -1 & -5 \\ 3 & -2 & 2 & -1 \end{bmatrix}$$ **(2M)**

To find the solution to the system**(4M)**

i.e. $x_1 = 1,\ x_2 = 2,\ x_3 = 0$ **(2M)**

5

Find the inverse of $\begin{bmatrix} 2 & 2 & 3 \\ 2 & 1 & 1 \\ 1 & 3 & 5 \end{bmatrix}$ **using Gauss Jordan method. (8M)BTL5**

(Nov 2013, Apr 2014, Apr2017).

Answer: Page: 3.97-Dr.G. Balaji

Write the given system of equation in augmented matrix form

$$\begin{bmatrix} 2 & 2 & 3 & 1 & 0 & 0 \\ 2 & 1 & 1 & 0 & 1 & 0 \\ 1 & 3 & 5 & 0 & 0 & 1 \end{bmatrix}$$ **(2M)**

Hence the inverse of given matrix is $\begin{bmatrix} 2 & -1 & -1 \\ -9 & 7 & 4 \\ 5 & -4 & -2 \end{bmatrix}$ **(6M)**

6

Solve by Gauss Seidel method:

$$\begin{aligned} x + y + 54z &= 110 \\ 27x + 6y - z &= 85 \\ 6x + 15y + 2z &= 72 \end{aligned}$$ **. (8M) BTL5 (Nov 2013, Apr 2014, Apr2017)**

Answer: Page: 3.83-Dr.G. Balaji

Interchanging the equations

$$\begin{aligned} 27x + 6y - z &= 85 \\ 6x + 15y + 2z &= 72 \\ x + y + 54z &= 110 \end{aligned}$$ **(2M)**

Iteration	X	Y	Z
1	3.148	3.5408	1.913
2	2.4322	3.572	1.925
3	2.425	3.5728	1.924

4	2.4255	3.573	1.925

(6M)

7

Find the dominant eigen value and the corresponding eigen vector of

A = $\begin{bmatrix} 1 & 6 & 1 \\ 1 & 2 & 0 \\ 0 & 0 & 3 \end{bmatrix}$ **by power method. Find also the least latent root (smallest eigen value) and hence the third eigen value. (8M) BTL5(Nov 2013, Apr 2014, Apr2017)**

Answer: Page: 3.125-Dr.G. Balaji

Let $x_0 = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}$ be an approximate eigenvector

$$x_1 = Ax_0 = \begin{bmatrix} 1 & 6 & 1 \\ 1 & 2 & 0 \\ 0 & 0 & 3 \end{bmatrix}\begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} 1 \\ 1 \\ 0 \end{pmatrix} = 1x_1'.$$ **(2M)**

Therefore, the dominant eigenvalue = 4 and the corresponding eigenvector is $\begin{pmatrix} 1 \\ 0.5 \\ 0 \end{pmatrix}$. **(6M)**

8

Find the numerically largest eigen value of A = $\begin{bmatrix} 25 & 1 & 2 \\ 1 & 3 & 0 \\ 2 & 0 & -4 \end{bmatrix}$ **by power method and the corresponding eigen vector. (8M) BTL5 (Nov 2013, Apr 2014, Apr2017)**

Answer: Page: 3.128-Dr.G. Balaji

Let $x_0 = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}$ be an approximate eigenvector. **(2M)**

$$x_1 = Ax_0 = \begin{bmatrix} 25 & 1 & 2 \\ 1 & 3 & 0 \\ 2 & 0 & -4 \end{bmatrix}\begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} 25 \\ 1 \\ 2 \end{pmatrix} = 25x_1'.$$ **(2M)**

	Therefore, the dominant eigenvalue = 25.182 and the corresponding eigenvector is $\begin{pmatrix}1\\0.045\\0.068\end{pmatrix}$ **.(4M)**
9	**Find the inverse of the coefficient matrix of the system** $\begin{bmatrix}1&1&1\\4&3&-1\\3&5&3\end{bmatrix}\begin{pmatrix}x\\y\\z\end{pmatrix}=\begin{pmatrix}1\\6\\4\end{pmatrix}$ **By the Gauss Jordan method. (8M) BTL5. (Nov 2013, Apr 2014, Apr2017)** **Answer: Page: 3.97-Dr.G. Balaji** Write the given system of equation in augmented matrix form $\begin{bmatrix}2&2&3&1&0&0\\2&1&1&0&1&0\\1&3&5&0&0&1\end{bmatrix}$ **(2M)** Hence the inverse of given matrix is $\begin{bmatrix}2&-1&-1\\-9&7&4\\5&-4&-2\end{bmatrix}$ **(6M)**
10	**Solve the equations by Gauss Jordan method:** **2x+y+4Z=12, 8x-3y+2z=20 , 4x+11y-z=33 . (8M) BTL5 (Nov 2013, Apr 2014, Apr2017)** **Answer: Page: 3.62-Dr.G. Balaji** Write the given system of equation in augmented matrix form $\begin{bmatrix}2&1&4&12\\8&-3&2&20\\4&11&-1&33\end{bmatrix}$ **(4M)** Therefore x=3, y=2, z=1.**(4M)**

	UNIT II- INTERPOLATION AND APPROXIMATION
	Lagrange Polynomials- Divided differences- Interpolating with a cubic spline- Newton's forward and backward difference formulas.
	PART *A
Q.No.	**Questions**
1.	**The n^{th} order difference of a polynomial of n^{th} degree is _____ and $(n+1)^{th}$ order of the same degree is _____** BTL1

Constant and zero

2 **Define the operators E and Δ and show that E = 1+Δ.** BTL 1

$Ef(x) = f(x+h)$ and $\Delta f(x) = f(x+h) - f(x)$

We have $\Delta f(x) = f(x+h) - f(x)$

$= Ef(x) - f(x)$

$= (E - 1)f(x)$

$\Delta = E - 1$ (or) $E = 1 + \Delta$.

3 **What is the relation between the shift operator E and the backward difference operator ∇?** BTL1

$\nabla = 1 - E^{-1}$

4 **What will be the first difference of a polynomial of degree 4?** BTL1

We get a polynomial of degree 3.

5 **$\nabla + E^{-1}$ = ________** BTL1

$\nabla + E^{-1} = 1 - E^{-1} + E^{-1} = 1.$

6 **Given** $u_0 = 1, u_1 = 11, u_2 = 21, u_3 = 28, u_4 = 29. Find \Delta^4 u_0.$ BTL1

x	y = u_x	Δu_x	$\Delta^2 u_x$	$\Delta^3 u_x$	$\Delta^4 u_x$
0	1				
1	11	10	0		
2	21	10	–3	–3	0
3	28	7	–6	–3	
4	29	1			

Hence $\Delta^4 u_0 = 0$.

7 **If** $u_1 = 1, u_3 = 17, u_4 = 43, u_5 = 89.$ **Find the value of u_2.** BTL1

Let the missing term be y_1.

x	y = u_x	Δu_x	$\Delta^2 u_x$	$\Delta^3 u_x$	$\Delta^4 u_x$
1	1				
2	y_1	$y_1 - 1$	$-2y_1 + 18$		
3	17	$17 - y_1$	$y_1 - 43$	$3y_1 - 61$	$-4y_1 + 124$

4	43	26	20	$-y_1+63$	
5	89	46			

By assumption, we have $-4y_1+124=0$, $y_1 = 31$.

8

Define interpolation and extrapolation? BTL1

The process of computing the value of a function inside the given range is called interpolation. The process of computing the value of a function outside the given range is called extrapolation.

9

State Newton's formula on interpolation. When it is used? BTL1

Newton's forward interpolation formula is

$$y = y_0 + u\Delta y_0 + \frac{u(u-1)}{2!}\Delta^2 y_0 + \frac{u(u-1)(u-2)}{3!}\Delta^3 y_0 + \dots\dots\dots\dots\dots\dots$$

where $u = \frac{x-x_0}{h}$

This formula is used mainly for interpolating the values of y near the beginning of a set of tabular values. Newton's backward interpolation formula is

$$y = y_n + u\nabla y_n + \frac{u(u+1)}{2!}\nabla^2 y_n + \frac{u(u+1)(u+2)}{3!}\nabla^3 y_n + \dots\dots\dots\dots\dots\dots$$

where $u = \frac{x-x_n}{h}$

This formula is used mainly for interpolating the values of y near the end of a set of tabular values.

10

State Newton's divided difference formula. BTL1

$$y = y_0 + (x-x_0)\Delta y_0 + (x-x_0)(x-x_1)\Delta^2 y_0 + (x-x_0)(x-x_1)(x-x_2)\Delta^3 y_0$$

+………..

11

State Lagrange's interpolation formula. BTL1

$$y = f(x) = \frac{(x-x_1)(x-x_2)(x-x_3)\dots\dots.(x-x_n)}{(x_0-x_1)(x_0-x_2)(x_0-x_3)\dots\dots.(x_0-x_n)}y_0$$

	$+\frac{(x-x_0)(x-x_2)(x-x_3).......(x-x_n)}{(x_1-x_0)(x_1-x_2)(x_1-x_3).......(x_1-x_n)}y_1$ $+\frac{(x-x_0)(x-x_1)(x-x_3).......(x-x_n)}{(x_2-x_0)(x_2-x_1)(x_2-x_3).......(x_2-x_n)}y_2$ +…………………………….+ $+\frac{(x-x_0)(x-x_1)(x-x_2)(x-x_3).......(x-x_{n-1})}{(x_n-x_0)(x_n-x_1)(x_n-x_2)(x_n-x_3).......(x_n-x_{n-1})}y_n$
12	**What advantage has Lagrange's formula over Newton?** BTL1 Newton's formula can be used only when the values of the Independent variable x are equally spaced. But Lagrange's interpolation formula can be used whether the values of the independent variable x are equally spaced or not. Lagrange's formula can be used for inverse interpolation also, while Newton's formula cannot be used.
13	**What is the disadvantage in practice in applying Lagrange's interpolation formula?** BTL1 It requires close attention to sign and there is always a chance of committing some error due to a number of positive and negative signs in the numerator and denominator.
14	**What is the difference between Newton divided difference Formula and Lagrange's Formula?**BTL1 Lagrange's formula is merely a variant of Newton divided difference formula.
15	**What is inverse interpolation.**BTL1 It is the process of finding the values of x corresponding to a value of y, not present in the table.
16	**What is the Lagrange's formula to find y if three sets of values (x_0, y_0), (x_1,y_1), (x_2,y_2) are given?** BTL1 $y = f(x) = \frac{(x-x_1)(x-x_2)}{(x_0-x_1)(x_0-x_2)}y_0 + \frac{(x-x_0)(x-x_2)}{(x_1-x_0)(x_1-x_2)}y_1$ $+\frac{(x-x_0)(x-x_1)}{(x_2-x_0)(x_2-x_1)}y_2$
17	**Construct a linear interpolating polynomial given the point (x_0,y_0),(x_1,y_1).**(BTL-1)

	$y = f(x) = \frac{(x-x_1)}{(x_0-x_1)} y_0 + \frac{(x-x_0)}{(x_1-x_0)} y_1 = \frac{(y_0-y_1)x+(x_0y_1-x_1y_0)}{x_0-x_1}$
18	**Write the Lagrange's formula for inverse interpolation.**BTL1 $x = f(y) = \frac{(y-y_1)(y-y_2)(y-y_3).......(y-y_n)}{(y_0-y_1)(y_0-y_2)(y_0-y_3).......(y_0-y_n)} x_0$ $+ \frac{(y-y_0)(y-y_2)(y-y_3).......(y-y_n)}{(y_1-y_0)(y_1-y_2)(y_1-y_3).......(y_1-y_n)} x_1$ $+ \frac{(y-y_0)(y-y_1)(y-y_3).......(y-y_n)}{(y_2-y_0)(y_2-y_1)(y_2-y_3).......(y_2-y_n)} x_2$ +………………………………+ $+ \frac{(y-y_0)(y-y_1)(y-y_2)(y-y_3).......(y-y_{n-1})}{(y_n-y_0)(y_n-y_1)(y_n-y_2)(y_n-y_3).......(y_n-y_{n-1})} x_n$
19	**Find the quadratic polynomial that fits y(x) = x^4 at x = 0,1,2.**BTL1 The following data is x : 0 1 2 y=x^4: 0 1 16 By Lagrange's formula $y = f(x) = \frac{(x-x_1)(x-x_2)}{(x_0-x_1)(x_0-x_2)} y_0 + \frac{(x-x_0)(x-x_2)}{(x_1-x_0)(x_1-x_2)} y_1$ $+ \frac{(x-x_0)(x-x_1)}{(x_2-x_0)(x_2-x_1)} y_2$ $y = f(x) = \frac{(x-1)(x-2)}{(0-1)(0-2)}.0 + \frac{(x-0)(x-2)}{(1-0)(1-2)}.1 + \frac{(x-0)(x-1)}{(2-0)(2-1)}.16$

$$y = -x(x-2) + 8x(x-1)$$

y(x) = $7x^2 - 6x$.

20

Use Lagrange's formula to find the quadratic polynomial that takes these values

x : 0 1 3

y : 0 1 0

Then find y (2).BTL3

Solution:

By Lagrange's formula

$$y = f(x) = \frac{(x-x_1)(x-x_2)}{(x_0-x_1)(x_0-x_2)}y_0 + \frac{(x-x_0)(x-x_2)}{(x_1-x_0)(x_1-x_2)}y_1$$

$$+\frac{(x-x_0)(x-x_1)}{(x_2-x_0)(x_2-x_1)}y_2$$

$$y = f(x) = \frac{(x-1)(x-3)}{(0-1)(0-3)}.0 + \frac{(x-0)(x-3)}{(1-0)(1-3)}.1 + \frac{(x-0)(x-1)}{(3-0)(3-1)}.0$$

y(x) = $\frac{x^2-3x}{-2}$

Hence y (2) = 1.

21

Obtain the interpolation quadratic polynomial for the given data by using Newton forward difference formula

X: 0 2 4 6

Y: -3 5 21 45BTL2

Solution: The difference table is

x	y = f(x)	Δy	$\Delta^2 y$	$\Delta^3 y$
0	-3			
		8	8	
2	5			0

		16	8	
4	21			
		24		
6	45			

Newton Forward Interpolation formula is

$$y = y_0 + u\Delta y_0 + \frac{u(u-1)}{2!}\Delta^2 y_0 + \frac{u(u-1)(u-2)}{3!}\Delta^3 y_0 + ...$$

where $u = \frac{x - x_0}{h} = \frac{x-0}{2} = \frac{x}{2}$

$$y = -3 + (x/2)(8) + \frac{(x/2)(x/2-1)}{2!}(8) + 0$$

$$y = -3 + 4x + x(x-2)$$

$y = x^2 + 2x - 3.$

22 **Show that the divided differences are symmetrical in their arguments.** BTL1

$$f(x_0, x_1) = \frac{f(x_1) - f(x_0)}{x_1 - x_0} = \frac{f(x_0) - f(x_1)}{x_0 - x_1} = f(x_1, x_0).$$

23 **What is the nature of nth divided differences of a polynomial of nth degree?** BTL1

The nth divided differences of a polynomial of nth degree is constant.

24 **Find the second divided differences with arguments a, b,c if f(x) = 1/x.**BTL1

The divided difference table is

x	y = 1/x	Δy	$\Delta^2 y$
a	1/a		
		–1/ab	1/abc
b	1/b		
		–1/bc	
c	1/c		

25

If f(x) = 1/x^2, find f(a, b) and f(a,b,c) by using divided difference.BTL1

The divided difference table is

x	y = 1/x^2	Δy	$\Delta^2 y$
a	1/a^2		
b	1/b^2	– (a+b)/a^{2}b^2	(ab+ bc + ca) / a^{2}b^{2}c^2
c	1/c^2	– (b+c)/b^{2}c^2	

Part*B

1

Using Newton's Forward Interpolation formula find the polynomial f(x) satisfying the following data. Hence find f (0.2).

x: 0 1 2 3 4 5 6

f(x): 176 185194 203 212 220 229 (8M) BTL5. (Nov 2013, Apr 2014, Apr2017)

Answer: Page: 4.45-Dr.G. Balaji

The difference table is **(3M)**

X	y = f(x)	Δy	$\Delta^2 y$	$\Delta^3 y$	$\Delta^4 y$	$\Delta^5 y$	$\Delta^6 y$
0	176						
1	185	9	0				
2	194	9	0	0			
3	203	9	0	0	0		
4	212	9	-1	-1	-1	-1	
5	220	8	2	2	3	4	5
6	229	9					

Newton Forward Interpolation formula is

$$y = y_0 + u\Delta y_0 + \frac{u(u-1)}{2!}\Delta^2 y_0 + \frac{u(u-1)(u-2)}{3!}\Delta^3 y_0 + \ldots\ldots\ldots\ldots \text{ (3M)}$$

	where $u = \frac{x-x_0}{h} = \frac{x-0}{2} = \frac{x}{2}$ $y(0.2) = 176 + (0.2)(9) + \frac{(0.2)(0.2-1)}{2!}(0)$ **(2M)** $y(0.2) = 177.8$
2	**Find the polynomial f(x) by using Lagrange's formula and hence find f (3) for** **x: 0 1 2 5** **f(x): 2 3 12 147(8M) BTL5 (Nov 2013, Apr 2014, Apr2017)** **Answer: Page: 4.12-Dr.G. Balaji** The Lagrange's formula is $y(x) = \frac{(x-x_1)(x-x_2)(x-x_3)}{(x_0-x_1)(x_0-x_2)(x_0-x_3)} y_0 + \frac{(x-x_0)(x-x_2)(x-x_3)}{(x_1-x_0)(x_1-x_2)(x_1-x_3)} y_1 + \frac{(x-x_0)(x-x_1)(x-x_3)}{(x_2-x_0)(x_2-x_1)(x_2-x_3)} y_2$ **(2M)** $y(x) = x^3 - 7x^2 + 18x - 12 \quad and \quad f(3) = 4$ **(6M)**
3	**Given** $\log_{10} 654 = 2.8156$, $\log_{10} 658 = 2.8182$, $\log_{10} 659 = 2.8189$, $\log_{10} 661 = 2.8202$ **. Find** $\log_{10} 656$ **by using Lagrange's formula. (8M) BTL5.** **(Nov 2013, Apr 2014, Apr2017)** **Answer: Page: 4.15-Dr.G. Balaji** The Lagrange's formula is $y(x) = \frac{(x-x_1)(x-x_2)(x-x_3)}{(x_0-x_1)(x_0-x_2)(x_0-x_3)} y_0 + \frac{(x-x_0)(x-x_2)(x-x_3)}{(x_1-x_0)(x_1-x_2)(x_1-x_3)} y_1 + \frac{(x-x_0)(x-x_1)(x-x_3)}{(x_2-x_0)(x_2-x_1)(x_2-x_3)} y_2$ **(6M)** $\log_{10} 656 = 2.8167$ **(2M)**

4

Using Lagrange's interpolation formula fit a polynomial to the following data

x:	**–1**	**0**	**2**	**3**
y:	**–8**	**3**	**1**	**12**

and hence find y at x = 1.5. (8M) BTL5(Nov 2013, Apr 2014, Apr2017)

Answer: Page: 4.8-Dr.G. Balaji

The Lagrange's formula is

$$y(x)=\frac{(x-x_1)(x-x_2)(x-x_3)}{(x_0-x_1)(x_0-x_2)(x_0-x_3)}y_0+\frac{(x-x_0)(x-x_2)(x-x_3)}{(x_1-x_0)(x_1-x_2)(x_1-x_3)}y_1$$
$$+\frac{(x-x_0)(x-x_1)(x-x_3)}{(x_2-x_0)(x_2-x_1)(x_2-x_3)}y_2$$

(6M)

$$y(x)=7x^3-31x^2+28x+18$$

(2M)

5

From the following data, estimate the number of persons earning weekly wages between 60 and 70 rupees.

Wage (in Rs.)	**Below 40**	**40 – 60**	**60 – 80**	**80 – 100**	**100 – 120**
No. of person	**250**	**120**	**100**	**70**	**50**

(in thousands) (8M) BTL5 (Nov 2013, Apr 2014, Apr2017)

Answer: Page: 4.54-Dr.G. Balaji

Newton Forward Interpolation formula is

$$y=y_0+u\Delta y_0+\frac{u(u-1)}{2!}\Delta^2 y_0+\frac{u(u-1)(u-2)}{3!}\Delta^3 y_0+\ldots\ldots\ldots\ldots$$ **(4M)**

where $n=\frac{70-40}{20}=\frac{30}{20}=1.5$

$$y(70)=423.5937$$

Therefore, the number of persons whose weekly wages below 70=423.5937

number of persons whose weekly wages below 60=370. **(4M)**

6

Find the value of x when $y = 20$ and $y = 40$ using Lagrange's formula from the following table.

x	1	2	3	4
y	1	8	27	64

(8M) BTL 5

Answer: Page: 2.34 -Dr. Singaravelu.

The Lagrange's formula is

$$y(x) = \frac{(x-x_1)(x-x_2)(x-x_3)}{(x_0-x_1)(x_0-x_2)(x_0-x_3)} y_0 + \frac{(x-x_0)(x-x_2)(x-x_3)}{(x_1-x_0)(x_1-x_2)(x_1-x_3)} y_1$$

$$+ \frac{(x-x_0)(x-x_1)(x-x_3)}{(x_2-x_0)(x_2-x_1)(x_2-x_3)} y_2$$ **(6M)**

$\boldsymbol{x(20) = 2.84675}$ **:**$\boldsymbol{x(40) = 3.01652.}$ **(2M)**

7

Given

x	0	0.1	0.2	0.3	0.4
e^x	1	1.1052	1.2214	1.3499	1.4918

Find the value of y =e^x when x = 0.38. (8M) (Nov 2013, Apr 2015, Apr2016)BTL5**.**

Answer: Page: 4.65-Dr.G. Balaji

Newton backward Interpolation formula is

$$y = y_0 + u\nabla y_0 + \frac{u(u+1)}{2!}\nabla^2 y_0 + \frac{u(u+1)(u+2)}{3!}\nabla^3 y_0 + \ldots\ldots\ldots\ldots$$ **(4M)**

where $n = \dfrac{0.38 - 0.4}{0.1} = -.2$

$y(0.38) = 1.4623$ **(4M)**

8

Construct Newton's forward interpolation polynomial for the following data.

x:	**4**	**6**	**8**	**10**
y:	**1**	**3**	**8**	**16**

Use it to find the value of y for x = 5. (8M) BTL5 (Nov 2013, Apr 2015, Apr2016).

Answer: Page: 4.72-Dr.G. Balaji

Newton Forward Interpolation formula is

$$y = y_0 + u\Delta y_0 + \frac{u(u-1)}{2!}\Delta^2 y_0 + \frac{u(u-1)(u-2)}{3!}\Delta^3 y_0 + \ldots\ldots\ldots\ldots \textbf{(4M)}$$

where $n = \frac{x-4}{2}$

$$\text{y(x)} = \frac{1}{8}\left(3x^2 - 22x + 48\right) \textbf{(4M)}$$

9 **Find $f'(3)$ and $f''(3)$ for the following data:**

x: 3.0 3.2 3.4 3.6 3.8 4.0

f(x): –14 –10.032 –5.296 –0.256 6.672 14(8M) (Nov 2013, Apr 2015, Apr2016)BTL5**.**

Answer: Page: 4.72-Dr.G. Balaji

Newton Forward difference formula is

$$f'(x_0) = \frac{1}{h}[\Delta y_0 - \frac{1}{2}\Delta^2 y_0 + \frac{1}{3}\Delta^3 y_0 - \ldots\ldots\ldots\ldots \textbf{(4M)}$$

$$\text{f}'(3.0) = 18.046$$

$$f''(x_0) = \frac{1}{h^2}[\Delta^2 y_0 - \Delta^3 y_0 + \frac{11}{12}\Delta^4 y_0 \ldots\ldots\ldots\ldots \textbf{(4M)}$$

$$\text{f}''(3.0) = 17.567$$

10 **Evaluate $\int_0^1 \frac{dx}{1+x^2}$ by Simpson's 1/3 rule and dividing the range into four equal parts. (8M) BTL5(Nov 2013, Apr 2015, Apr2016).**

Answer: Page: 4.111-Dr.G. Balaji

By Trapezoidal rule

	$\int_0^1 \frac{dx}{1+x^2} = \frac{h}{2}\left[\left(y_0 + y5\right) + 2\left(y_1 + y_2 + y_3 + y_4\right)\right]$ **(4M)** $\int_0^1 \frac{dx}{1+x^2} = 0.7428$ **(4M)**

Lagrange’s and Newton’s divided difference interpolations – Newton’s forward and backward difference interpolation – Approximation of derivates using interpolation polynomials – Numerical single and double integrations using Trapezoidal and Simpson’s 1/3 rules.

	UNIT III NUMERICAL DIFFERENTIATION AND INTEGRATION
	Differentiation using interpolation formula – Numerical integration by Trapezoidal and Simpson’s$\frac{1}{3}$ and $\frac{3}{8}$rule. Romberg’s method - two- and three-point Gaussian quadrature formula – Double integrations using Trapezoidal and Simpson’s rule.
	PART *A
Q.No.	**Questions**
1	**State the disadvantage of Taylor series method?BTL1** The disadvantage of Taylor series method is the evaluation of higher order derivative which may become tedious for the function which have a complicated algebraical structure.
2	**In the derivation of 4th order Rungekutta formula, why it is called fourth order.**BTL1 The number of parameters = 13. It is called fourth order formula since the parameters are determined such that yn_{+1} obtained by Rungekutta method agrees up to h^4 term in Taylor’s method.
3	**What do you mean by total error in error analysis?**BTL1 The difference between the computed value y_i and the true value $y(x_i)$ at any stage is known as the total error. It is comprised of truncation error and round off error.
4	**State the special advantage of Rungekutta method over Taylor series method. (or) Compare Taylor series and Rungekutta method. (or) Which is better Taylor method or Rungekutta method. BTL1** Rungekutta methods do not require prior calculation of higher derivatives of y(x), as the Taylor method does. Also the Rungekutta formulas involve the computation of f(x,y) at various positions, instead of derivatives and this function occurs in the given equation. Hence Rungekutta method is better method.

5	**Compare Taylor series and Rungekutta method.BTL1** 1. The use of Rungekutta method gives quick convergence to the solutions of the differential equation than Taylor's series method. 2. In Rungekutta method, the derivatives of higher order are not required for calculation as in Taylor's series method.
6	**Write the formula to find k₂, k₄ in R-k method of fourth order.BTL1** $k_2 = hf\left(x_0 + \frac{h}{2}, y_0 + \frac{k_1}{2}\right)$ $k_4 = hf\left(x_0 + h, y_0 + k_3\right)$
7	**Compare Rungekutta method and predictor - corrector method. BTL1** Rungekutta methods are self-starting whereas predictor and corrector method are not self-starting. In Rungekutta method, it is not possible to get any information about truncation error. In predictor and corrector method it is possible to get easily a good estimate of the truncation error. +………..
8	**Write down the error in Milne's method.BTL1** The truncation error in Milne's predictor formula is $\frac{14h^5}{45} y^5(\varepsilon)$ The truncation error in Milne's corrector formula is $\frac{-h^5}{90} y^5(\varepsilon)$
9	**What is a predictor – corrector method?BTL1** Predictor – corrector methods are methods which require the values of y at $x_n, x_{n-1}, x_{n-2}, \ldots\ldots\ldots$ for computing the values of y at x_{n+1}. We first use a formula to find the value of y at x_{n+1} and this is known as a predictor formula. The value of y so got is improved or corrected by another formula is known as corrector formula.
10	**What do you mean by saying that a method is self-starting? Not self-starting ? BTL1** For computing the values of y at x_{n+1} , we do not require the values of y at $x_n, x_{n-1}, x_{n-2}, \ldots\ldots\ldots$ This is called self-starting. If we require the values of y at $x_n, x_{n-1}, x_{n-2}, \ldots\ldots\ldots$ to find y at x_{n+1} then it is called not self-starting.
11	**Write down Milne's predictor and corrector formula.BTL1**

	$y_{n+1,p} = y_{n-3} + \frac{4h}{3}\left[2y_{n-2}' - y_{n-1}' + 2y_n'\right]$ $y_{n+1,c} = y_{n-1} + \frac{h}{3}\left[y_{n-1}' + 4y_n' + y_{n+1}'\right]$
12	**State the Taylor series formula to find y(x_1) for solving** $\frac{dy}{dx} = x^2 y - 1,$ y(x_0) =y_0. **BTL1** $y(x_1) = y_0 + (x - x_0)y'(x_0) + \frac{(x-x_0)^2}{2!}y''(x_0) + \frac{(x-x_0)^3}{3!}y'''(x_0) + ...$
13	**Obtain the finite difference scheme for the differential equation** $2\frac{d^2y}{dx^2} + y = 5.$ **BTL6** Given $2\frac{d^2y}{dx^2} + y = 5.$ $2\left(\frac{y_{i+1} + y_{i-1} - 2y_i}{h^2}\right) + y_i = 5$ $2y_{i+1} + (h^2 - 4)y_i + 2y_{i-1} = 5h^2$
14	**Construct a linear interpolating polynomial given the point (x_0,y_0),(x_1,y_1). BTL6** Explain one-step methods and multi-step methods In one-step methods, we use the data of just one preceding step. In multi-step methods, where in each step, we use data from more than one of the preceding steps.
15	**Find y (1.1) using Euler's method from** $\frac{dy}{dx} = x^2 + y^2,\ y(1) = 1.$ **BTL2** $y_1 = y_0 + h f(x_0, y_0) = 1 + (0.1)[1+1] = 1+0.2 = 1.2$
16	**State the disadvantage of Taylor series method?BTL1** The disadvantage of Taylor series method is the evaluation of higher order derivative which may become tedious for the function which have a complicated algebraical structure.
17	**Which formula is a particular case of Rungekutta formula of the second order.BTL1** Euler's modified formula.

18	**Taylor series and Rungekutta method are single step methods while ________ and ________ are multistep methods. BTL1** Milne's predictor and corrector method and Adam-Bash forth predictor and corrector method
19	**Name the method which is Taylor's method of first order.BTL1** Euler's method.
20	**What are the values of k_1 and l_1 to solve $y''+xy'+y=0, y(0)=1, y'(0)=0$ by Rungekutta method of 4th order.BTL1** Given $y''+xy'+y=0$ $put\ \frac{dy}{dx}=z \quad then \quad \frac{dz}{dx}+xz+y=0$ $\Rightarrow \frac{dz}{dx}=-xz-y$ Also given $x_0 = 0$, $y_0 = 1$, $y'_0 = z_0 = 0$ $k_1 = hf(x_0, y_0,z_0) = hz_0 = 0.$ $l_1 = hg(x_0,y_0,z_0) = h(-x_0z_0 - y_0)$ $= h(0-1)$ $= -h.$
21	**What do you mean by total error in error analysis?BTL1** The difference between the computed value y_i and the true value $y(x_i)$ at any stage is known as the total error. It is comprised of truncation error and round off error.
22	**Write down the error in Milne's method.BTL1** The truncation error in Milne's predictor formula is $\frac{14h^5}{45}y^5(\varepsilon)$ The truncation error in Milne's corrector formula is $\frac{-h^5}{90}y^5(\varepsilon)$
	Part*B

1	**Using Taylor's series find y at x = 0.1 if $\frac{dy}{dx}=x^2y-1,$ y (0) = 1.(8M) BTL5(Nov 2013, Apr 2015, Apr2016)** **Answer: Page: 5.3-Dr.G. Balaji** $y(x_1)=y_0+(x-x_0)y'(x_0)+\frac{(x-x_0)^2}{2!}y''(x_0)+\frac{(x-x_0)^3}{3!}y'''(x_0)+\ldots\ldots\ldots\ldots$ **(4M)** $\mathrm{y}(0.1) == .900305$ **(4M)**
2	**Using R-K method of fourth order, solve $y'=x+y$ with y (0) = 1 at x = 0.2 taking h = 0.1** $y'=x+y\,, \quad i.e \quad f(x,\mathrm{y})=x+y$ **To find y (0.1) using third order Range-Kutta Method. (8M) BTL3(Nov 2013, Apr 2015, Apr2016).** **Answer: Page: 5.48-Dr.G. Balaji** $k_1=hf(x_0,y_0)=0.1$ $k_2=hf(x_0+\frac{h}{2},y_0+\frac{k_1}{2})=0.11$ $k_2=hf(x_0+h,y_0+2k_2-\mathrm{k}_1)=0.122$ **(8M)** $\Delta y=\frac{1}{6}[k_1+4k_2+k_3]$ $\mathrm{y}_1=y_0+\Delta y=1.1103$
3	**Given that $\frac{dy}{dx}=\log_{10}(x+y)$ with the initial condition that y = 1 when x = 0, use Euler's modified method to find y for x = 0.2 and x = 0.5 in more accurate form.(8M) BTL3 (Nov 2013, Apr 2015, Apr2016).** **Answer: Page: 5.37-Dr.G. Balaji** $y_{n+1}=y_n+hf\left(x_n+\frac{h}{2},y_n+\frac{h}{2}f(x_n+y_n)\right)$ ………………. (1)**(4M)** Putting n=0 in 1, we get $y(0.2)=2.0657$ **(4M)**

4	**Solve** $\frac{dy}{dx}=1-y$ **with the initial condition x = 0, y = 0. Using Euler's algorithm, tabulate the solutions at x = 0.1, 0.2, 0.3, 0.4. Get the solutions by Euler's modified method also. (8M) BTL1(Nov 2013, Apr 2014, Apr2012).** **Answer: Page: 5.38-Dr.G. Balaji** $y_{n+1}=y_n+hf\left(x_n+\frac{h}{2},y_n+\frac{h}{2}f(x_n+y_n)\right)$ ………………. (1)**(4M)** Putting n=0 in 1, we get $y(0.1)=0.095$ **(4M)** Putting n=1 in 1, we get $y(0.2)=0.1809$ Putting n=2 in 1, we get $y(0.3)=0.2587$
5	***Us*e Euler's method to approximate y when x = 1.9 given that** $\frac{dy}{dx}=\frac{x-y}{y+x}$ **with y = 1 for x = 2. (8M) BTL5 (Nov 2013, Apr 2015, Apr2012).** **Answer: Page: 5.42-Dr.G. Balaji** $y_{m+1}=y_m+\frac{h}{2}f\left(f(x_m,y_m)+f[x_m+\text{h},y_m,y_n+hf(x_m,y_m))\right)$ ………………. (1) **(4M)** $y_1=y_0+\frac{h}{2}\left(f(x_0,y_0)+f[x_0+\text{h},y_0,y_0+hf(x_0,y_0))\right)$ **(4M)**
6	**Find the value of y (1.1) and y(1.2) from** $\frac{d^2y}{dx^2}+y^2\frac{dy}{dx}=x^3,y(1)=1,y'(1)=1$ **by using Taylor's series method. (8M) (Nov 2013, Apr 2015, Apr2010)**BTL1**.** **Answer: Page: 5.23-Dr.G. Balaji**

	$y_1 = y_0 + hy_0' + \frac{h^2}{2!} y_0'' + \frac{h^3}{3!} y_0''' + \ldots\ldots\ldots\ldots$ **(4M)** $y(1.1) = 1.1002.$ $y_2 = y_1 + hy_1' + \frac{h^2}{2!} y_1'' + \frac{h^3}{3!} y_1''' + \ldots\ldots\ldots\ldots$ **(4M)** $y(1.2) = 1.2015.$
7	**Given** $5x\frac{dy}{dx} + y^2 - 2 = 0, y(4) = 1$, $y(4.1) = 1.0049$, $y(4.2) = 1.0097$ $y(4.3) = 1.0143$ **Compute** $y(4.4)$ **by Milne's Predictor-Corrector Method. (8M) BTL3 (Nov 2012, Apr 2015, Apr2016).** **Answer: Page: 5.91-Dr.G. Balaji** $y_{n+1,p} = y_{n-3} + \frac{4h}{3}\left[2y_{n-2}' - y_{n-1}' + 2y_n'\right]$ ………………… (1) **(4M)** $y_{4,p} = 1.018706$ $y_{n+1,\mathrm{c}} = y_{n-1} + \frac{h}{3}\left[y_{n-1}' + 4y_n' + y_{n+1}'\right]$ **(4M)** $y_{4,\mathrm{c}} = 1.01874$
8	**Given** $\frac{dy}{dx} = x^2 - y, y(0) = 1, y(0.1) = 0.9052,$ $y(0.2) = 0.8213$ **Find** $y(0.3)$ **by modified Euler's method. (8M) BTL3 (Nov 2011, Apr 2015, Apr2017).** **Answer: Page: 5.35-Dr.G. Balaji** $y_{m+1} = y_m + \frac{h}{2} f\left(f(x_m, y_m) + f[x_m + \mathrm{h}, y_m, y_n + hf(x_m, y_m)\right)$ **(4M)** $y_1 = y_0 + \frac{h}{2}\left(f(x_0, y_0) + f[x_0 + \mathrm{h}, y_0, y_0 + hf(x_0, y_0)\right)$ **(4M)**

	$y(0.1) = 0.9055$
09	**If $\frac{dy}{dx} = \frac{y^2 - x^2}{y^2 + x^2}$, y (0)=1 find y(0.2),y(0.4),y(0.6) by Runge-Kutta method . Hence find y (0.8) by Milne's method.** **(8M) BTL4(Nov 2013, Apr 2014, Apr2015).** **Answer: Page: 5.91-Dr.G. Balaji** $k_1 = hf(x_0, y_0) = 0.2$ $k_2 = hf(x_0 + \frac{h}{2}, y_0 + \frac{k_1}{2}) = 0.19672$ $k_3 = hf(x_0 + h, y_0 + 2k_2 - \mathrm{k}_1) = 0.1967$ $k_4 = hf(x_0 + \mathrm{h}, y_0 + \mathrm{k}_3) = 0.1891$ **(8M)** $\Delta y = \frac{1}{6}[k_1 + 4k_2 + k_3 + k_4]$ $\mathrm{y}_1 = y_0 + \Delta y = 1.19598$
10	**Given** $\frac{dy}{dx} = x^2(1+y), \; y(1) = 1, \; y(1.1) = 1.233, \; y(1.2) = 1.548, \; y(1.3) = 1.979$**, evaluate** $y(1.4)$ **by Adam's-Bash forth method. (4M)BTL3(AU/May15)** **Solution:** **1.2,1.6,3.2** **(4M)**

	UNIT IV INITIAL VALUE PROBLEM FOR ORDINARY DIFFERENTIAL EQUATIONS
	Single step methods: Taylor's series method – Euler's method – Modified Euler's method Fourth order Runge-Kutta method for solving first order equations – Multi step methods : Milne's and Adams – Bash forth predictor corrector methods .
	PART *A
Q.No.	**Questions**
1.	**What are the merits and demerits of the Taylor method of solution.** BTL1 Taylor method is very powerful if we can calculate the successive derivative of y in an easy manner. If there is a simple expression for the higher derivatives in terms of the previous derivatives of y, Taylor's method will work very well. But in the differential equation $\frac{dy}{dx} = f(x, y)$, the function f(x,y) may have a complicated algebraically structure. Then the evaluation of higher order derivatives may become tedious. This is the demerit of this method
2	**Taylor series method will be very useful to give some _____ for powerful numerical methods such as Rungekutta method, Milne's method, etc.**BTL-1 Initial starting values.
3	**The use of Taylor series to solve numerically, differential equations is restricted by the labour involved in the determination of________**BTL1 Higher order derivatives.
4	**State the disadvantage of Taylor series method?** BTL1 The disadvantage of Taylor series method is the evaluation of higher order derivative which may become tedious for the function which have a complicated algebraical structure.
5	**In the derivation of 4th order Rungekutta formula, why it is called fourth order.** BTL1 The number of parameters = 13. It is called fourth order formula since the parameters are determined such that yn_{+1} obtained by Rungekutta method agrees up to h^4 term in Taylor's method.
6	**What do you mean by total error in error analysis**BTL1? The difference between the computed value y_i and the true value $y(x_i)$ at any stage is known as the total error. It is comprised of truncation error and round off error.
7	**State the special advantage of Rungekutta method over Taylor series method. (or) Compare Taylor series and Rungekutta method. (or) Which is better Taylor method or Rungekutta method.**BTL1 Rungekutta methods do not require prior calculation of higher derivatives of y(x), as the Taylor

	method does. Also the Rungekutta formulas involve the computation of f(x,y) at various positions, instead of derivatives and this function occurs in the given equation. Hence Rungekutta method is better method.
8	**Compare Taylor series and Rungekutta method.** BTL4 1. The use of Rungekutta method gives quick convergence to the solutions of the differential equation than Taylor's series method. 2. In Rungekutta method, the derivatives of higher order are not required for calculation as in Taylor's series method.
9	**Write the formula to find k₂, k₄ in R-k method of fourth order.** BTL1 $k_2 = hf\left(x_0 + \frac{h}{2}, y_0 + \frac{k_1}{2}\right)$ $k_4 = hf\left(x_0 + h, y_0 + k_3\right)$
10	**Compare Rungekutta method and predictor - corrector method.**BTL4 Rungekutta methods are self-starting whereas predictor and corrector method are not self-starting. In Rungekutta method, it is not possible to get any information about truncation error. In predictor and corrector method it is possible to get easily a good estimate of the truncation error. +………..
11	**Write down the error in Milne's method.** BTL3 The truncation error in Milne's predictor formula is $\frac{14h^5}{45} y^5(\varepsilon)$ The truncation error in Milne's corrector formula is $\frac{-h^5}{90} y^5(\varepsilon)$
12	**What is a predictor – corrector method?** BTL3 Predictor – corrector methods are methods which require the values of y at $x_n, x_{n-1}, x_{n-2}, \ldots\ldots\ldots$ for computing the values of y at x_{n+1}. We first use a formula to find the value of y at x_{n+1} and this is known as a predictor formula. The value of y so got is improved or corrected by another formula is known as corrector formula.
13	**What do you mean by saying that a method is self-starting? Not self-starting ?**BTL1 For computing the values of y at x_{n+1} , we do not require the values of y at $x_n, x_{n-1}, x_{n-2}, \ldots\ldots\ldots$ This is called self-starting. If we require the values of y at

	$x_n, x_{n-1}, x_{n-2}, ...$ to find y at x_{n+1} then it is called not self-starting.
14	**Write down Milne's predictor and corrector formula.** BTL1 $y_{n+1,p} = y_{n-3} + \frac{4h}{3}\left[2y_{n-2}' - y_{n-1}' + 2y_n'\right]$ $y_{n+1,c} = y_{n-1} + \frac{h}{3}\left[y_{n-1}' + 4y_n' + y_{n+1}'\right]$
15	**State the Taylor series formula to find y(x_1) for solving** $\frac{dy}{dx} = x^2y - 1,$ y(x_0) =y_0. BTL1 $y(x_1) = y_0 + (x-x_0)y'(x_0) + \frac{(x-x_0)^2}{2!}y''(x_0) + \frac{(x-x_0)^3}{3!}y'''(x_0) + ...$
16	**Obtain the finite difference scheme for the differential equation** $2\frac{d^2y}{dx^2} + y = 5.$ BTL1 Given $2\frac{d^2y}{dx^2} + y = 5.$ $2\left(\frac{y_{i+1} + y_{i-1} - 2y_i}{h^2}\right) + y_i = 5$ $2y_{i+1} + (h^2 - 4)y_i + 2y_{i-1} = 5h^2$
17	**Construct a linear interpolating polynomial given the point (x_0,y_0),(x_1,y_1).**BTL6 Explain one-step methods and multi-step methods In one-step methods, we use the data of just one preceding step. In multi-step methods, where in each step, we use data from more than one of the preceding steps.
18	**Find y (1.1) using Euler's method from** $\frac{dy}{dx} = x^2 + y^2,\ y(1)=1.$ BTL2 $y_1 = y_0 + h\ f(x_0, y_0) = 1 + (0.1)[1+1] = 1+0.2 = 1.2$
19	**State the disadvantage of Taylor series method?**BTL2 The disadvantage of Taylor series method is the evaluation of higher order derivative

	which may become tedious for the function which have a complicated algebraical structure.
20	**Which formula is a particular case of Rungekutta formula of the second order.** BTL2 Euler's modified formula.
21	**Taylor series and Rungekutta method are single step methods while ________ and ________ are multistep methods.**BTL1 Milne's predictor and corrector method and Adam-Bash forth predictor and corrector method
22	**Name the method which is Taylor's method of first order.** BTL1 Euler's method.
23	**What are the values of k_1 and l_1 to solve $y''+xy'+y=0, y(0)=1, y'(0)=0$ by Rungekutta method of 4thorder.** BTL1 Given $y''+xy'+y=0$ $put \frac{dy}{dx}=z \quad then \quad \frac{dz}{dx}+xz+y=0$ $\Rightarrow \frac{dz}{dx}=-xz-y$ Also given $x_0 = 0$, $y_0 = 1$, $y_0' = z_0 = 0$ $k_1 = hf(x_0, y_0, z_0) = hz_0 = 0.$ $l_1 = hg(x_0,y_0,z_0) = h(-x_0z_0 - y_0)$ $= h(0-1)$ $= -h.$
24	**What do you mean by total error in error analysis?** BTL1 The difference between the computed value y_i and the true value $y(x_i)$ at any stage is known as the total error. It is comprised of truncation error and round off error.
25	**Write down the error in Milne's method.** BTL1 The truncation error in Milne's predictor formula is $\frac{14h^5}{45}y^5(\varepsilon)$ The truncation error

	in Milne's corrector formula is $\frac{-h^5}{90} y^5(\varepsilon)$
	Part*B
1	**Using Taylor's series find y at x = 0.1 if** $\frac{dy}{dx} = x^2 y - 1$, **y (0) = 1.(8M) BTL5(Nov 2013, Apr 2015, Apr2016).** **Answer: Page: 5.3-Dr.G. Balaji** $y(x_1) = y_0 + (x - x_0) y'(x_0) + \frac{(x-x_0)^2}{2!} y''(x_0) + \frac{(x-x_0)^3}{3!} y'''(x_0) + \ldots\ldots\ldots\ldots$ **(4M)** $\mathrm{y}(0.1) = .900305$ **(4M)**
2	**Using R-K method of fourth order, solve** $y' = x + y$ **with y (0) = 1 at x = 0.2 taking h = 0.1** $y' = x + y, \quad i.e \quad f(x, \mathrm{y}) = x + y$ **To find y (0.1) using third order Range-Kutta Method. (8M) BTL3(Nov 2013, Apr 2015, Apr2016).** **Answer: Page: 5.48-Dr.G. Balaji** $k_1 = hf(x_0, y_0) = 0.1$ $k_2 = hf(x_0 + \frac{h}{2}, y_0 + \frac{k_1}{2}) = 0.11$ $k_2 = hf(x_0 + h, y_0 + 2k_2 - \mathrm{k}_1) = 0.122$ **(8M)** $\Delta y = \frac{1}{6}[k_1 + 4k_2 + k_3]$ $\mathrm{y}_1 = y_0 + \Delta y = 1.1103$
3	**Given that** $\frac{dy}{dx} = \log_{10}(x + y)$ **with the initial condition that y = 1 when x = 0, use Euler's modified method to find y for x = 0.2 and x = 0.5 in more accurate form.(8M) BTL3 (Nov 2013, Apr 2015, Apr2016).** **Answer: Page: 5.37-Dr.G. Balaji**

	$y_{n+1} = y_n + hf\left(x_n + \frac{h}{2}, y_n + \frac{h}{2} f(x_n + y_n) \right)$ ………………. (1)**(4M)** Putting n=0 in 1, we get $y(0.2) = 2.0657$ **(4M)**
4	**Solve** $\frac{dy}{dx} = 1 - y$ **with the initial condition x = 0, y = 0. Using Euler's algorithm, tabulate the solutions at x = 0.1, 0.2, 0.3, 0.4. Get the solutions by Euler's modified method also. (8M) BTL1(Nov 2013, Apr 2014, Apr2012).** **Answer: Page: 5.38-Dr.G. Balaji** $y_{n+1} = y_n + hf\left(x_n + \frac{h}{2}, y_n + \frac{h}{2} f(x_n + y_n) \right)$ ………………. (1)**(4M)** Putting n=0 in 1, we get $y(0.1) = 0.095$ **(4M)** Putting n=1 in 1, we get $y(0.2) = 0.1809$ Putting n=2 in 1, we get $y(0.3) = 0.2587$
5	***Us*****e Euler's method to approximate y when x = 1.9 given that** $\frac{dy}{dx} = \frac{x - y}{y + x}$ **with y = 1 for x = 2. (8M) BTL5(Nov 2013, Apr 2015, Apr2012).** **Answer: Page: 5.42-Dr.G. Balaji** $y_{m+1} = y_m + \frac{h}{2} f\left(f(x_m, y_m) + f[x_m + \text{h}, y_m, y_n + hf(x_m, y_m)) \right)$ ………………. (1) **(4M)** $y_1 = y_0 + \frac{h}{2}\left(f(x_0, y_0) + f[x_0 + \text{h}, y_0, y_0 + hf(x_0, y_0)) \right)$ **(4M)**
6	**Find the value of y (1.1) and y(1.2) from** $\frac{d^2y}{dx^2} + y^2 \frac{dy}{dx} = x^3, y(1) = 1, y'(1) = 1$

	by using Taylor’s series method. (8M) BTL1 (Nov 2013, Apr 2015, Apr2010). **Answer: Page: 5.23-Dr.G. Balaji** $y_1 = y_0 + hy_0' + \frac{h^2}{2!}y_0'' + \frac{h^3}{3!}y_0''' + ...$ **(4M)** $y(1.1) = 1.1002.$ $y_2 = y_1 + hy_1' + \frac{h^2}{2!}y_1'' + \frac{h^3}{3!}y_1''' + ...$ **(4M)** $y(1.2) = 1.2015.$
7	**Given** $5x\frac{dy}{dx} + y^2 - 2 = 0, y(4) = 1$, $y(4.1) = 1.0049$, $y(4.2) = 1.0097$ $y(4.3) = 1.0143$ **Compute** $y(4.4)$ **by Milne's Predictor-Corrector Method. (8M) BTL3(Nov 2012, Apr 2015, Apr2016).** **Answer: Page: 5.91-Dr.G. Balaji** $y_{n+1,p} = y_{n-3} + \frac{4h}{3}\left[2y'_{n-2} - y'_{n-1} + 2y'_n\right]$ .... (1) **(4M)** $y_{4,p} = 1.018706$ $y_{n+1,\mathrm{c}} = y_{n-1} + \frac{h}{3}\left[y'_{n-1} + 4y'_n + y'_{n+1}\right]$ **(4M)** $y_{4,\mathrm{c}} = 1.01874$
8	**Given** $\frac{dy}{dx} = x^2 - y, y(0) = 1, y(0.1) = 0.9052,\ y(0.2) = 0.8213$ **Find** $y(0.3)$ **by modified Euler's method. (8M) BTL3 (Nov 2011, Apr 2015, Apr2017).** **Answer: Page: 5.35-Dr.G. Balaji** $y_{m+1} = y_m + \frac{h}{2} f\left(f(x_m, y_m) + f[x_m + \mathrm{h}, y_m, y_n + hf(x_m, y_m)) \right)$ .... (1)\\ **(4M)**

	$y_1 = y_0 + \frac{h}{2}\left(f(x_0, y_0) + f[x_0 + \text{h}, y_0, y_0 + hf(x_0, y_0)) \right)$ **(4M)** $y(0.1) = 0.9055$
09	**If** $\frac{dy}{dx} = \frac{y^2 - x^2}{y^2 + x^2}$ **, y (0)=1 find y(0.2),y(0.4),y(0.6) by Runge-Kutta method . Hence find y (0.8) by Milne's method.** **(8M) BTL4 (Nov 2013, Apr 2014, Apr2015).** **Answer: Page: 5.91-Dr.G. Balaji** $k_1 = hf(x_0, y_0) = 0.2$ $k_2 = hf(x_0 + \frac{h}{2}, y_0 + \frac{k_1}{2}) = 0.19672$ $k_3 = hf(x_0 + h, y_0 + 2k_2 - \text{k}_1) = 0.1967$ $k_4 = hf(x_0 + \text{h}, y_0 + \text{k}_3) = 0.1891$ **(8M)** $\Delta y = \frac{1}{6}[k_1 + 4k_2 + k_3 + k_4]$ $\text{y}_1 = y_0 + \Delta y = 1.19598$

UNIT VBOUNDARY VALUE PROBLEMS IN ORDINARY AND PARTIAL DIFFERENTIAL EQUATIONS

Finite difference methods for solving second order two - point linear boundary value problems - Finite difference techniques for the solution of two-dimensional Laplace's and Poisson's equations on rectangular domain – One dimensional heat flow equation by explicit and implicit (Crank Nicholson) methods – One dimensional wave equation by explicit method.

	PART A
1	**Solve xy″ + y = 0, y(1) = 1, y(2) = 2 with h = 0.5. BTL5**

	Ans: $x_i\frac{[y_{i-1}+y_{i+1}-2y_i]}{h^2}+y_i=0\Rightarrow 4x_i[y_{i-1}+y_{i+1}-2y_i]+y_i=0.$ When i = 1, $y_1 = y(1.5) = 1.6364$
2	**Write the forward, central and backward finite difference for u_xBTL5 (Nov/Dec 2015)** **Ans:** $u_x=\frac{u_{i,j+1}-u_{i,j}}{h}$, $u_x=\frac{u_{i+1,j}-u_{i-1,j}}{2h}$, $u_x=\frac{u_{i,j}-u_{i-1,j}}{h}$
3	**State the central difference approximations for y_1' and y_1'' BTL5** **Ans:** $y_i'=\frac{y_{i+1}-y_{i-1}}{2h}$ and $y_i''=\frac{y_{i+1}-2y_i+y_{i-1}}{h^2}$
4	**State the forward difference approximations for y_1' and y_1'' BTL5 (Nov/Dec 2015)** **Ans:** $y_i'=\frac{y_{i+1}-y_i}{h}$ and $y_i''=\frac{y_{i+2}-2y_{i+1}+y_i}{h^2}$
5	**State the backward difference approximations for y_1' and y_1'' BTL5** **Ans:** $y_i'=\frac{y_i-y_{i-1}}{h}$ and $y_i''=\frac{y_{i+1}-2y_i+y_{i-1}}{h^2}$
6	**State the general form of Poisson's equation in partial derivatives.BTL5** **Ans:** $\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial x^2}=G(x,y)$ or $\frac{u_{i+1,j}-2u_{i,j}+u_{i-1,j}}{h^2}+\frac{u_{i,j+1}-2u_{i,j}+u_{i,j-1}}{k^2}=G(x_i,y_i)$
7	**State Crank-Nicholson's implicit scheme for one dimensional heat equation. BTL5** **Ans:** $\lambda(u_{i+1,j+1}+u_{i-1,j+1})-2(1+\lambda)u_{i,j+1}=$ $2(\lambda-1)u_{i,j}-\lambda(u_{i+1,j}+u_{i-1,j}) \quad where\ \lambda=\frac{ka^2}{h^2}$
8	**Write the explicit formula to solve one dimensional wave equation. BTL5** **Ans:** $u_{i,j+1}=2(1-\lambda^2a^2)u_{i,j}+\lambda^2a^2(u_{i+1,j}+u_{i-1,j})-u_{i,j-1}$ If $\lambda^2=\frac{1}{a^2}\left(i.e., k=\frac{h}{a}\right)$ then $u_{i,j+1}=u_{i+1,j}+u_{i-1,j}-u_{i,j-1}$
9	**Write down the simplest form ofCrank-Nicholson's formula. BTL5** **Ans:** If $\lambda=1\left(i.e., k=\frac{h^2}{a^2}\right)$ then $u_{i,j+1}=\frac{u_{i-1,j+1}+u_{i+1,j+1}+u_{i+1,j}+u_{i-1,j}}{4}$

10	**State Bender-Schmidt formula for solving one dimensional heat equation. BTL5** **Ans:** $u_{i,j+1} = \lambda u_{i+1,j} + (1-2\lambda)u_{i,j} + \lambda u_{i-1,j}$ where $\lambda = \frac{k}{ah^2}$
11	**Write down thesimplest form of Bender-Schmidt formula. BTL5** **Ans:** If $\lambda = \frac{1}{2}\left(i.e., k = \frac{h^2}{2a^2}\right)$ then $u_{i,j+1} = \frac{u_{i+1,j} + u_{i-1,j}}{2}$
12	**Obtain finite difference scheme to solve uxx+ uyy= 0 .BTL5** **Ans:** $\frac{u_{i+1,j} - 2u_{i,j} + u_{i-1,j}}{h^2} + \frac{u_{i,j+1} - 2u_{i,j} + u_{i,j-1}}{k^2} = 0$
13	**Write down the classification of linear seBTLnd order partial differential equation? BTL5** **Ans:** The linear seBTLnd order partial differential equation $Au_{xx} + Bu_{xy} + Cu_{yy} + Du_x + Eu_y + Fu + G = 0$ can be classified as (i) Elliptic if $B^2 - 4AC < 0$ (ii) Parabolic if $B^2 - 4AC = 0$ (iii) Hyperbolic if $B^2 - 4AC > 0$
14	**Classify** $u_{xx} + yu_{xy} + \frac{x}{4}u_{yy} - u_x + u = 0$ **.BTL5** **Ans:** Here $B^2 - 4AC = y^2 - x$. Hence the given i) PDE if Elliptic if $y^2 < x$ ii) PDE is Parabolic if $y^2 = x$ iii) PDE is Hyperbolic if $y^2 > x$
15	**Write down the central finite difference formula for u_{yy}BTL5** **Ans:** $u_{i,j} = \frac{u_{i,j+1} - 2u_{i,j} + u_{i,j-1}}{k^2}$
16	**Write down the Standard five point formula . BTL5** **Ans:** $u_{i,j} = \frac{u_{i,j-1} + u_{i,j+1} + u_{i-1,j} + u_{i+1,j}}{4}$
17	**Write down the Diagonal five point formula. BTL5** **Ans:** $u_{i,j} = \frac{1}{4}\left[u_{i-1,j-1} + u_{i,-1j+1} + u_{i+1,j-1} + u_{i+1,j+1}\right]$
18	**Write down the Liebmann's iteration process formula:BTL5**

Ans: $u_{i,j}^{(n+1)} = \frac{1}{4}\left[u_{i-1,j}^{(n+1)} + u_{i+1,j}^{(n)} + u_{i,j-1}^{(n)} + u_{i,j+1}^{(n+1)}\right]$

19 **Classify $u_{xx} + 2u_{xy} + 4u_{yy} = 0$.BTL5 (Apr/May 2015)**

Ans: Here $B^2 – 4AC = 4 – 16 = –12$

$\Rightarrow$ PDE is Elliptic

20 **Obtain the finite difference scheme for the differential equation 2y″ + y = 5BTL5 (May 2015)**

Ans: $2\left(\frac{y_{i+1} - 2y_i + y_{i-1}}{h^2}\right) + y_i = 5$

$2y_{i+1} + (h^2 - 4)y_i + 2y_{i-1} = 5h^2$

PART B

1 **Solve $(1+x^2)y'' + 4xy' + 2y = 2$ given that y(0) = 0, y(1) = $\frac{1}{2}$ (take h = $\frac{1}{3}$) (16M) BTL5(Nov/Dec 2015)**

Solution:

$x_0 = 0$	$x_1 = 1/3$	$x_2 = 2/3$	$x_3 = 1$
$y_0 = 0$	$y_1 = ?$	$y_2 = ?$	$y_3 = 1/2$

(4M)

Rewrite the equation as $(1+x_1^2)y_i'' + 4x_i y_i' + 2y_i = 2.$

Substitute $y_i'' = \frac{y_{i+1} - 2y_i + y_{i-1}}{h^2}$ & $y_i' = \frac{y_i - y_{i-1}}{h}$ and simplify we get

$9(1+x_i^2)(y_{i+1} - 2y_i + y_{i-1}) + 12x_i(y_i - y_{i-1}) + 2y_i = 2.$

Put i = 1 we get $9(1+x_1^2)(y_2 - 2y_1 + y_0) + 12x_1(y_1 - y_0) + 2y_1 = 2.$ (4M)

$\Rightarrow -26y_1 + 16y_2 = 2$

$\div(-26) \Rightarrow y_1 - 0.6154y_2 = -0.0769 \rightarrow (1)$ (4M)

Put i = 2 we get $9(1+x_2^2)(y_3 - 2y_2 + y_1) + 12x_2(y_2 - y_1) + 2y_2 = 2$

$\Rightarrow 17y_1 - 40y_2 = -10.5$

$\div(17) \Rightarrow y_1 - 2.3529y_2 = -0.61765 \rightarrow (2)$

Solving (1) and (2) we get $y_1 = 0.11455$ and $y_2 = 0.3112$ (4M)

2 **Using the finite difference method, Solve $y'' + y = x$ subject to y(0) = 0, y(1) = 2 at 0.25, 0.5 & 0.75**

(16M) BTL5 (Nov/Dec 2014)

Solution: Page No:121 Singaravelu

Rewrite the equation as $y_i'' + y_i = x_i \,\&\, h = 0.25 = \frac{1}{4}$

Substitute $y_i'' = \frac{y_{i+1} - 2y_i + y_{i-1}}{h^2} \,\&\, y_i' = \frac{y_i - y_{i-1}}{h}$ and simplify we get (4M)

$$y_{i-1} - y_i(2-h^2) + y_{i+1} = h^2 x_i$$

$$y_{i-1} = -\frac{31}{16} y_i + y_{i+1} = \frac{1}{16} x_i$$

Put i = 1 we get

$$y_0 - 1.9375 y_1 + y_2 = 0.0625 x_1$$

$$0 - 1.9375 y_1 + y_2 = 0.0625(0.25)$$

$$-1.9375 y_1 + y_2 = 0.0156 \qquad (1)$$ (4M)

Put i = 2 we get

$$y_1 - 1.9375 y_2 + y_3 = 0.0625 x_2$$

$$y_1 - 1.9375 y_2 + y_3 = 0.0625(0.5)$$

$$y_1 - 1.9375 y_2 + y_3 = 0.0313 \qquad (2)$$ (4M)

Put i = 3 we get

$$y_2 - 1.9375 y_3 + y_4 = 0.0625 x_3$$

$$y_2 - 1.9375 y_3 + 2 = 0.0625(0.75)$$

$$y_2 - 1.9375 y_3 = -1.9531 \qquad (3)$$

Solving (1), (2) and (3) we get $y_1 = 0.5443$, $y_2 = 1.0701$ and $y_3 = 1.5604$ (4M)

3 Solve u$_{xx}$ = u$_t$, given that u(x, 0) = x(4 - x) , u(0, t) = 0, u(4, t) = 0 by Bender Schmidt's formula BTLmpute u up to 5 times steps. (taking h=1, k =1 (16M) BTL5 (Nov/Dec 2015)

Solution:
Bender Schmidt's formula is $u_{i,j+1} = \lambda(u_{i+1,j} + u_{i-1,j}) + (1-2\lambda)u_{i,j}$

(i.e) E = λ(A + C) + (1-2λ)B (4M)

A	B	C
D	E	F

Here $\alpha^2 = 1$, h = 1, k = 1

$$\therefore\ \lambda = \frac{k\alpha^2}{h^2} = 1$$

Put λ = 1 in above formula we get $u_{i,j+1} = (u_{i+1,j} + u_{i-1,j}) - u_{i,j}$ (4M)

(i.e.) E = (A + C) – B

x t	0	1	2	3	4
0	0	3	4	3	0
1	0	1	2	1	6
2	0	1	0	1	0
3	0	-1	2	-1	0
4	0	3	-4	3	0
5	0	-7	10	-7	0

(8M)

4 **Solve $\frac{1}{4}u_t = u_{xx}$, given that $u(x, 0) = \frac{2}{2}(8 - x)$, u(0, t) = 0, u(6, t) = 6 by Bender Schmidt's formula.**

BTLmpute u up to 5 steps. (16M)BTL5 (June 2014)

Solution: Page No: 12.1 Balaji

Here $\alpha^2 = 4$. Since h and k are not known then we use simplest form of Bender Schmidt's formula. For λ = $\frac{1}{2}$ we get the simplest form. Take h and k values such that λ = $\frac{1}{2}$ (i.e) $\frac{k\alpha^2}{h^2}\frac{1}{2}$.(4M)

Take h = 1 and k = $\frac{1}{8}$. Simplest form of Bender Schmidt's

$$u_{i,j+1} = \frac{(u_{i+1,j} + u_{i-1,j})}{2} \quad \text{(i.e.)}\ E = \frac{(A+C)}{2}\ \text{(4M)}$$

A	B	C
D	E	F

x t	0	1	2	3	4	5	6
0	0	3.5	6	7.5	8	7.5	6
1/8	0	3	5.5	7	7.5	7	6
¼	0	2.75	5	6.5	7	6.75	6
3/8	0	2.500	4.625	6.000	6.625	6.500	6
4/8	0	2.313	4.250	5.625	6.250	6.313	6

(8M)

5 **Solve $u_t=u_{xx}$, given that u(x, 0) =0, u(0, t) = 0, u(1, t) = t by Crank Nicholson formula.**

Compute u for 1 time step. (taking $h=\frac{1}{4}$, $k=\frac{1}{8}$) (16M)BTL5(Apr/May 2015)

Solution: Page No:142 Kandasamy and Thilagavathi

x t	0	¼	2/4	¾	1
0	0	0	0	0	0
1/8	0	u_1	u_2	u_3	1/8

(4M)

Crank Nicholson formula is

$$\lambda(u_{i-1,j}+u_{i+1,j}+u_{i-1,j+1}+u_{i+1 j+1}) = 2\lfloor(\lambda-1)u_{i,j}+(\lambda+1)u_{i,j+1}\rfloor$$

$$\lambda(A+C+D+F) = 2[(\lambda-1)B+(\lambda+1)E]$$

Here $\alpha^2 = 1$, h = 1/4, k = 1/8 $\therefore \lambda = \frac{k\alpha^2}{h^2} = 2$ (4M)

Put λ = 2 in above formula we get $(u_{i-1,j}+u_{i+1,j}+u_{i-1,j+1}+u_{i+1 j+1}) = u_{i,j}+3u_{i,j+1}$

i.e) $(A+C+D+F) = B+3E$

To find u_1 : Apply formula we get $0+0+0+u_2 = 0+3u_1 \Rightarrow -3u_1+u_2 = 0$ (1) (4M)

To find u_2 : Apply formula we get $0+0+u_1+u_3 = 0+3u_2 \Rightarrow u_1-3u_2+u_3 = 0$ (2)

To find u_3 : Apply formula we get $0+0+u_2+1/8 = 0+3u_3 \Rightarrow 8u_2-24u_3 = -1$ (3)

Solving (1), (2) and (3) we get $u_1 = 0.0059$, $u_2 = 0.0178$, $u_3 = 0.04762$ (4M)

6 Solve 16u_t=u_{xx}, given that u(x, 0) =0, u(0, t) = 0, u(1, t) = 100 t by Crank Nicholson formula. Compute u for 2-time step. (16M)BTL5 (May/June 2014)

Solution: Page No 149 Kandasamy and Thilagavathi

Here α^2 = 1/16. Since h and k are not known then we use simplest form of Crank Nicholson formula.

For λ = 1 we get the simplest form. Take h and k values such that λ = 1 i.e) $\frac{k\alpha^2}{h^2} = 1$. (4M)

Take $h = \frac{1}{4}$ and k = 1.

Simplest form of Crank Nicholson formula is $u_{i,j+1} = \frac{u_{i-1,j} + u_{i+1,j} + u_{i-1,j+1} + u_{i+1j+1}}{4}$ (4M)

A	B	C
D	E	F

i.e) $E = \frac{(A+C+D+F)}{4}$

x t	0	1/4	2/4	¾	1
0	0	0	0	0	0
1	0	u_1	u_2	u_3	100
2	0	u_4	u_5	u_6	200

To find u_1 : Apply formula we get $4u_1 - u_2 = 0$ (1) (4M)

To find u_2 : Apply formula we get $u_1 - 4u_2 + u_3 = 0$ (2)

To find u_3 : Apply formula we get $u_2 - 4u_3 = -100$ (3)

Solving (1), (2) and (3) we get $u_1 = 1.785$, $u_2 = 7.1428$, $u_3 = 26.78$

To find u_4 : Apply formula we get $4u_4 - u_5 = 7.1428$ (4)

To find u_5 : Apply formula we get $-u_4 + 4u_5 - u_6 = 28.565$ (5)

To find u_6 : Apply formula we get $-u_5 + 4u_6 = 307.1428$ (6)

Solving (4), (5) and (6) we get $u_4 = 9.438$, $u_5 = 30.61$, $u_6 = 84.43$ (4M)

7 **Solve $u_t = u_{xx}$ in $0 < x < 5$, $t \geq 0$ given that $u(x,0) = 20$, $u(0,t) = 0$, $u(5,t)=100$, with h=1 by Crank-Nicholson method. (16M)BTL5 (Nov/Dec 2014)**

Crank-Nicholson formula is

$$\lambda(u_{i-1,j} + u_{i+1,j} + u_{i-1,j+1} + u_{i+1j+1}) = 2\lfloor(\lambda - 1)u_{i,j} + (\lambda + 1)u_{i,j+1}\rfloor \qquad \text{(4M)}$$

$$\lambda(A + C + D + F) = 2[(\lambda - 1)B + (\lambda + 1)E]$$

A	B	C
D	E	F

Here a = α^2 = 1 Choose λ = 1, $\lambda = \dfrac{k}{ah^2}$ (4M)

h = 1 gives k = 1

Put λ = 1 in above formula we get $u_{i,j+1} = \dfrac{1}{4}(u_{i-1,j+1} + u_{i+1,j+1} + u_{i-1,j} + u_{i+1j})$

i.e) $(A + C + D + F)/4 = E$

t \ x	0	1	2	3	4	5
0	0	20	20	20	20	100
1	0	u_1	u_2	u_3	u_4	100

(4M)

To find u_1 : Apply formula we get $4u_1 - u_2 = 20$ (1)

To find u_2 : Apply formula we get $u_1 - 4u_2 + u_3 = -40$ (2)

To find u_3 : Apply formula we get $u_2 - 4u_3 + u_4 = -40$ (3)

To find u_4 : Apply formula we get $u_3 - 4u_4 = -220$ (4)

Solving (1), (2), (3) and (4) we get $u_1 = 10.05$, $u_2 = 20.2$, $u_3 = 30.72$, $u_4 = 62.68$ (4M)

8 **Solve $u_{xx} = 32u_t$, h = 0.25 for $t \geq 0$, $0 < x < 1$, $u(x,0) = 0$, $u(0,t) = 0$, $u(1,t) = t$. (16M)BTL5 (May/June 2013)**

	Solution:Page No:5.12 Sakthivel

The range for x is (0, 1); h = 0.25 and a = 32

$$k = \frac{ah^2}{2} = 1$$

$$u_{i,j+1} = \frac{(u_{i+1,j} + u_{i-1,j})}{2} \quad \text{i.e)} \quad E = \frac{(A+C)}{2}$$ (4M)

A	B	C
D	E	F

(2M)

i j	0	0.25	0.5	0.75	1
0	0	0	0	0	0
1	0	0	0	0	1
2	0	0	0	0.5	2
3	0	0	0.25	1	3
4	0	0.125	0.5	1.625	4
5	0	0.25	0.875	2.25	5

(10M)

9 **Solve 4u$_{tt}$ = u$_{xx}$, given that u(x,0) = x(4-x) , u(0,t)=0, u(4,t) = 0 and ut(x,0) = 0 by Explicit formula. (Take h=1 and upto t = 4). (16M)BTL5 (May/June 2013)**

Solution:

Explicit formula is $u_{i,j+1} = 2(1-\lambda^2\alpha^2)u_{i,j} + \lambda^2\alpha^2(u_{i-1,j} + u_{i+1,j}) - u_{i,j} - 1$ (2M)

The given wave equation is 4u$_{tt}$ = u$_{xx}$

$$u_{tt} = \frac{1}{4}u_{xx}$$

$$u_{tt} = a^2 u_{xx}$$ (4M)

$$a^2 = \frac{1}{4} \Rightarrow a = \frac{1}{2}$$

Let h = 1, $k = \frac{h}{a} = \frac{1}{(1/2)} = 2$

t = 0, 2, 4

h = 0, 1, 2, 3, 4

$u_{i,j+1} = (u_{i+1,j} + u_{i-1,j}) - u_{i,j}$ i.e) H = (D + F) – B

BTLndition $u_t(x, 0) = 0$ is equivalent to $E = \frac{(A+C)}{2}$.

x / t	0	1	2	3	4
0	0	3	4	3	0
2	0	2	3	2	0
4	0	0	0	0	0

(10M)

10 **Solve $25u_{xx} - u_{tt} = 0$, given u(0,t) = 0 = u(5,t), $u_t(x,0) = 0$, u(x,0) =** $\begin{cases} 2x & for\ 0 \le x \le 2.5 \\ 10-2x & for\ 2.5 \le x \le 5 \end{cases}$

Compute u up to one half period of oscillation, taking h=1.(16M)BTL5

Solution: Page No 5.32 Sakthivel

Explicit formula is $u_{i,j+1} = 2(1-\lambda^2\alpha^2)u_{i,j} + \lambda^2\alpha^2(u_{i-1,j} + u_{i+1,j}) - u_{i,j} - 1$

i.e) $H = 2(1-\lambda^2\alpha^2)E + \lambda^2\alpha^2(D+F) - B$

Here $\alpha^2 = 25$, h = 1 $\therefore \lambda^2 = \frac{1}{\alpha^2} = \frac{1}{25}$ (4M)

One period of oscillation $= \frac{2l}{\alpha} = \frac{2(5)}{5} = 2\,\text{sec}.$

$\therefore$ One period of oscillation = 1 sec. Hence k = 1/5 (i.e. Do up to t = 1) (4M)

Put λ = 1/5 in above formula we get the simplest form

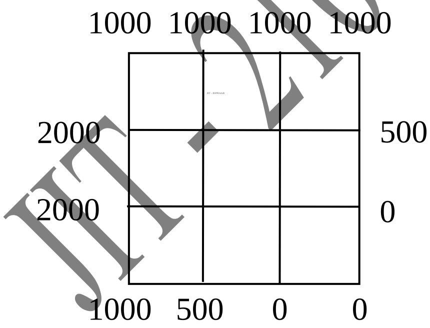
$u_{i,j+1} = (u_{i+1,j} + u_{i-1,j}) - u_{i,j}$ i.e) H = (D+F)–B

BTLndition $u_t(x,0) = 0$ is equivalent to $E = \frac{(A+C)}{2}$. (4M)

x t	0	1	2	3	4	5
0	0	2	4	4	2	0
1/5	0	2	3	3	2	0
2/5	0	1	1	1	1	0
3/5	0	-1	-1	-1	-1	0
4/5	0	-2	-3	-3	-2	0
1	0	-2	-4	-4	-2	0

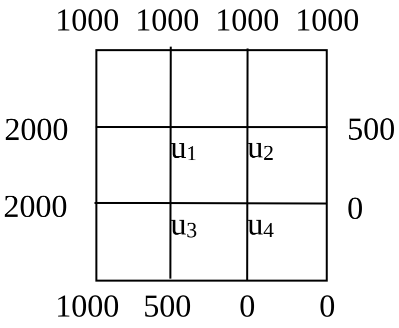
(4M)

11 **Evaluate the function u(x,y) satisfying $\nabla^2 u = 0$ at the lattice points given the boundary values as follows. (16M)BTL5 (Nov/Dec 2015)**



Solution:

Let the Lattice points be u_1, u_2, u_3 and u_4



SFPF is $u_{i,j} = \frac{1}{4}\left[u_{i-1,j} + u_{i+1,j} + u_{i,j-1} + u_{i,j+1}\right]$

To find u1: By SFPF $u_1 = \dfrac{2000+1000+u_2+u_3}{4} \Rightarrow 4u_1 - u_2 - u_3 = 3000$ (1) (4M)

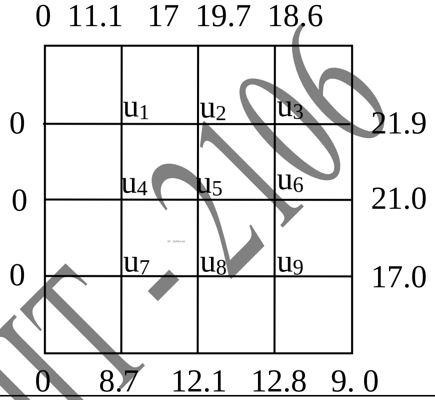
To find u2: By SFPF $u_2 = \dfrac{500+1000+u_1+u_4}{4} \Rightarrow u_1 - 4u_2 + u_4 = -1500$ (2) (4M)

To find u3: By SFPF $u_3 = \dfrac{500+2000+u_1+u_4}{4} \Rightarrow u_1 - 4u_3 + u_4 = -2500$ (3) (4M)

To find u4: By SFPF $u_4 = \dfrac{0+0+u_2+u_3}{4} \Rightarrow u_2 + u_3 - 4u_4 = 0$ (4) (2M)

Solving (1), (2), (3) and (4) we get $u_1 = 1208.4$, $u_2 = 791.7$, $u_3 = 1041.7$, $u_4 = 458$ (2M)

12 **Find by the Liebmann's method the values at the interior lattice points of a square region of the harmonic function u whose boundary values are as shown in the following figure.(16M)BTL5**



Solution: Page No 163 Singaravelu

Rough values:

Applying SFPF $u_{i,j} = \frac{1}{4}\left[u_{i-1,j} + u_{i+1,j} + u_{i,j-1} + u_{i,j+1}\right]$ for the grid points us, we get u5 = 12.5

Applying DFPF $u_{i,j} = \frac{1}{4}\left[u_{i-1,j-1} + u_{i-1,j} + u_{i+1,j-1} + u_{i+1,j+1}\right]$ for the grid points u1, u3, u7, u0 we get

$u_1 = 7.4$, $u_3 = 17.3$, $u_7 = 6.2$, $u_0 = 13.7$ (4M)

Applying SFPF $u_{i,j} = \frac{1}{4}\left[u_{i-1,j} + u_{i+1,j} + u_{i,j-1} + u_{i,j+1}\right]$ for the grid points u2, u4, u6, u8 we get,

$u_2 = 13.6$, $u_4 = 6.5$, $u_6 = 16.1$, $u_8 = 11.1$ (4M)

We will now improve the values by using always SFPF

$$u_{i,j} = \frac{1}{4}\left[u_{i-1,j} + u_{i+1,j} + u_{i,j-1} + u_{i,j+1}\right]$$

First Iteration values: u_1 = 7.8, u_2 = 13.7, u_3 = 17.9, u_4 = 6.6, u_5 = 11.9, u_6 = 16.1, u_7 = 6.6, u_8 = 11 & u_0 = 14.3

Second Iteration values: u_1 = 7.9, u_2 = 13.7, u_3 = 17.9, u_4 = 6.6, u_5 = 11.9, u_6 = 16.3, u_7 = 6.6, u_8 = 11.2 &
u_0 = 14.3 (4M)

Third Iteration values: u_1 = 7.9, u_2 = 13.7, u_3 = 17.9, u_4 = 6.6, u_5 = 11.9, u_6 = 16.3, u_7 = 6.6, u_8 = 11.2 & u_0 = 14.3. Second and third iteration values are same.

Final values: u_1 = 7.9, u_2 = 13.7, u_3 = 17.9, u_4 = 6.6, u_5 = 11.9, u_6 = 16.1, u_7 = 6.6, u_8 = 11.2 & u_0 = 14.3 (4M)

13 Solve u_{xx}+ u_{yy}= 0 over the square mesh of sides 4 units satisfying the following boundary Conditions

u(x,0)= 0, u(x,4) = 8 + 2x, 0 ≤ x ≤ 4, u(0,y) = $\frac{1}{2}$ y^2, 0 ≤ x ≤ 4 and u(4,y) = y^2, 0 ≤ y ≤ 4. (16M) BTL5

(May/June 2013)

Solution:

Given 0 ≤ x ≤ 4 &0 ≤ y ≤ 4

Let x = 0, 1, 2, 3, 4

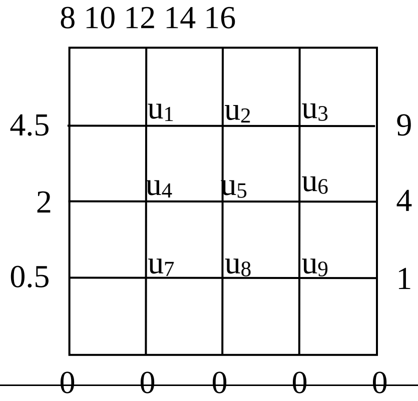
y = 0, 1, 2, 3, 4

u(x,4) = 8+2x

u(0,4) = 8; u(1,4) = 10; u(2,4) = 12; u(3,4) = 14; u(4,4) = 16;

u(0,y) = $\frac{1}{2}$ y^2

u(0,0) = 0; u(0,1) = 0.5; u(0,2) = 2; u(0,3) = 4.5; u(0,4) = 8;



Rough values:

Applying SFPF $u_{i,j}=\frac{1}{4}\left[u_{i-1,j}+u_{i+1,j}+u_{i,j-1}+u_{i,j+1}\right]$ for the grid point u_5, we get $u_5 = 4$

Applying DFPF $u_{i,j}=\frac{1}{4}\left[u_{i-1,j-1}+u_{i-1,j}+u_{i+1,j-1}+u_{i+1,j+1}\right]$ for the grid points u_1, u_3, u_7, u_9 we get $u_1 = 6.5$, $u_3 = 9$, $u_7 = 1.5$, $u_9 = 2$

Applying SFPF $u_{i,j}=\frac{1}{4}\left[u_{i-1,j}+u_{i+1,j}+u_{i,j-1}+u_{i,j+1}\right]$ for the grid points u_2, u_4, u_6, u_8 we get $u_2 = 7.86$, $u_4 = 3.5$, $u_6 = 4.75$, $u_8 = 1.875$

We will now improve the values of using always SFPF

$$u_{i,j}=\frac{1}{4}\left[u_{i-1,j}+u_{i+1,j}+u_{i,j-1}+u_{i,j+1}\right]$$ (8M)

First Iteration values: $u_1 = 6.46$, $u_2 = 7.86$, $u_3 = 8.9$, $u_4 = 3.49$, $u_5 = 4.49$, $u_6 = 4.85$, $u_7 = 1.46$, $u_8 = 1.99$ &

$u_9 = 1.96$

SeBTLnd Iteration values: $u_1 = 6.46$, $u_2 = 7.96$, $u_3 = 8.95$, $u_4 = 3.6$, $u_5 = 4.6$, $u_6 = 4.88$, $u_7 = 1.52$, $u_8 = 2.02$ &

$u_9 = 1.97$

Third Iteration values: $u_1 = 6.51$, $u_2 = 8.01$, $u_3 = 8.97$, $u_4 = 3.66$, $u_5 = 4.64$, $u_6 = 4.89$, $u_7 = 1.54$, $u_8 = 2.04$ &

$u_9 = 1.98$

Fourth Iteration values: $u_1 = 6.54$, $u_2 = 8.04$, $u_3 = 8.98$, $u_4 = 3.68$, $u_5 = 4.66$, $u_6 = 4.90$, $u_7 = 1.55$, $u_8 = 2.05$ &

$u_9 = 1.99$

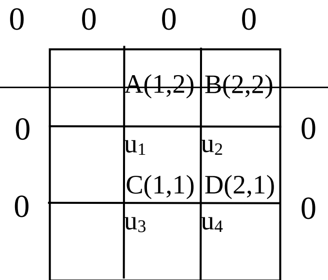
Fifth Iteration values: $u_1 = 6.55$, $u_2 = 8.05$, $u_3 = 8.99$, $u_4 = 3.69$, $u_5 = 4.67$, $u_6 = 4.91$, $u_7 = 1.56$, $u_8 = 2.06$ &

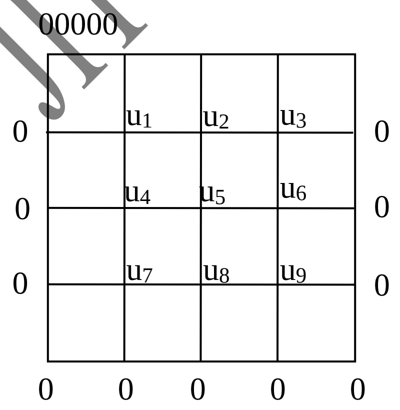
$u_9 = 1.99$. Fourth and Fifth iteration values are almost same.

Final values: $u_1 = 6.5$, $u_2 = 8$, $u_3 = 8.9$, $u_4 = 3.6$, $u_5 = 4.6$, $u_6 = 4.9$, $u_7 = 1.5$, $u_8 = 2.0$ & $u_9 = 1.99$ (8M)

14 **Solve the Poisson's equation $\nabla^2 u = -10(x^2 + y^2 + 10)$ over the square mesh with sides x = 0, y = 0, x = 3 and y = 3 with u = 0 on the boundary and mesh length is 1.(16M)BTL5 (Apr/May 2015)**

Solution:



	Here h = 1 and $f(x,y) = -10(x^2 + y^2 + 10)$. Since f(x,y) is symmetrical about the line x = y, we get $u_1 = u_4$ ∴ It is enough to find u_1, u_2 and u_3 $u_{i-1,j} + u_{i+1,j} + u_{i,j-1} + u_{i,j+1} - 4u_{i,j} = h^2 f(ih, jh) = -10(i^2 + j^2 + 10)$ Put i = 1 and j = 2 in above formula we get, $-4u_1 + u_2 + u_3 = -150$ (1) (6M) Put i = 2 and j = 2 in above formula we get, $u_1 - 4u_2 + u_4 = -180$ (2) (2M) Put i = 1 and j = 1 in above formula we get, $u_1 - 4u_3 + u_4 = -120$ (3) (2M) Put i = 2 and j = 1 in above formula we get, $u_2 + u_3 - 4u_4 = -150$ (4) (2M) Solving (1), (2), (3) and (4) we get $u_1 = 75 = u_4$, $u_2 = 82.5$ and $u_3 = 67.5$ (4M)
15	**Solve $\nabla^2 u = 8x^2 y^2$ over the square with x = –2, x = 2, y = –2, y = 2with u = 0 on the boundary and mesh length 1. (16M)BTL5 (May/June 2013)**
	Solution: Page No:186 Kandasamy and Thilagavathi 2`  Here h = 1 and $f(x,y) = 8x^2y^2$ Since f(x,y) is symmetrical about x and y axes and also about the line x = y, we get (2M) $u_1 = u_3 = u_7 = u_9$& $u_2 = u_4 = u_6 = u_8$ ∴ It is enough to find u_1, u_2 and u_5 $u_{i-1,j} + u_{i+1,j} + u_{i,j-1} + u_{i,j+1} - 4u_{i,j} = h^2 f(ih, jh) = 8i^2j^2$ Put i = –1 and j = –1 in above formula we get, $u_2 - 2u_1 = 4$ (1) (6M)

	Put i = 0 and j = 1 in above formula we get, $2u_1 - 4u_2 + u_5 = 0$ (2) (2M) Put i = 0 and j = 0 in above formula we get, $u_2 - u_5 = 0$ (3) Solving (1), (2) and (3) we get $u_1 = -3$, $u_2 = -2$ and $u_5 = -2$ $u_1 = u_3 = u_7 = u_9 = -3$ & $u_2 = u_4 = u_6 = u_8 = -2$ & $u_5 = -2$ (6M)

EE8401 **ELECTRICAL MACHINES – II** **L T P C**
2 2 0 3

OBJECTIVES:

To impart knowledge on the following Topics

- Construction and performance of salient and non – salient type synchronous generators.
- Principle of operation and performance of synchronous motor.
- Construction, principle of operation and performance of induction machines.
- Starting and speed control of three-phase induction motors.
- Construction, principle of operation and performance of single phase induction motors and special machines.

UNIT I SYNCHRONOUS GENERATOR 6+6

Constructional details – Types of rotors –winding factors- emf equation – Synchronous reactance – Armature reaction – Phasor diagrams of non-salient pole synchronous generator connected to infinite bus--Synchronizing and parallel operation – Synchronizing torque -Change of excitation and mechanical input- Voltage regulation – EMF, MMF, ZPF and A.S.A methods – steady state power-angle characteristics– Two reaction theory –slip test -short circuit transients - Capability Curves

UNIT II SYNCHRONOUS MOTOR 6+6

Principle of operation – Torque equation – Operation on infinite bus bars - V and Inverted V curves – Power input and power developed equations – Starting methods – Current loci for constant power input, constant excitation and constant power developed-Hunting – natural frequency of oscillations – damper windings- synchronous condenser.

UNIT III THREE PHASE INDUCTION MOTOR 6+6

Constructional details – Types of rotors –- Principle of operation – Slip –cogging and crawling- Equivalent circuit – Torque-Slip characteristics - Condition for maximum torque – Losses and efficiency – Load test - No load and blocked rotor tests - Circle diagram – Separation of losses – Double cage induction motors –Induction generators – Synchronous induction motor.

UNIT IV STARTING AND SPEED CONTROL OF THREE PHASE INDUCTION MOTOR 6+6

Need for starting – Types of starters – DOL, Rotor resistance, Autotransformer and Star-delta starters – Speed control – Voltage control, Frequency control and pole changing – Cascaded connection-V/f control – Slip power recovery scheme-Braking of three phase induction motor: Plugging, dynamic braking and regenerative braking.

UNIT V SINGLE PHASE INDUCTION MOTORS AND SPECIAL MACHINES 6+6

Constructional details of single phase induction motor – Double field revolving theory and operation – Equivalent circuit – No load and blocked rotor test – Performance analysis – Starting methods of single-phase induction motors – Capacitor-start capacitor run Induction motor- Shaded pole induction motor - Linear induction motor – Repulsion motor - Hysteresis motor - AC series motor- Servo motors- Stepper motors - introduction to magnetic levitation systems.

TOTAL: 60 PERIODS

OUTCOMES:

- Ability to understand the construction and working principle of Synchronous Generator
- Ability to understand MMF curves and armature windings.
- Ability to acquire knowledge on Synchronous motor.
- Ability to understand the construction and working principle of Three Phase Induction Motor

- Ability to understand the construction and working principle of Special Machines
- Ability to predetermine the performance characteristics of Synchronous Machines.

TEXT BOOKS:

1. A.E. Fitzgerald, Charles Kingsley, Stephen. D. Umans, 'Electric Machinery', Mc Graw Hill publishing Company Ltd, 2003.
2. Vincent Del Toro, 'Basic Electric Machines' Pearson India Education, 2016.
3. Stephen J. Chapman, 'Electric Machinery Fundamentals'4th edition, McGraw Hill Education Pvt. Ltd, 2010.

REFERENCES

1. D.P. Kothari and I.J. Nagrath, 'Electric Machines', McGraw Hill Publishing Company Ltd, 2002.
2. P.S. Bhimbhra, 'Electrical Machinery', Khanna Publishers, 2003.
3. M.N. Bandyopadhyay, Electrical Machines Theory and Practice, PHI Learning PVT LTD., New Delhi, 2009.
4. B.R.Gupta, 'Fundamental of Electric Machines' New age International Publishers,3rd Edition ,Reprint 2015.
5. Murugesh Kumar, 'Electric Machines', Vikas Publishing House Pvt. Ltd, 2002.
6. Alexander S. Langsdorf, 'Theory of Alternating-Current Machinery', McGraw Hill Publications, 2001.

	Subject Code: EE8401 Year/Semester: II/04 **Subject Name: Electrical Machines – II Subject Handler: Mr. A.Antony Charles**
	UNIT I - SYNCHRONOUS GENERATOR
	Constructional details – Types of rotors –winding factors- emf equation – Synchronous reactance – Armature reaction – Phasor diagrams of non-salient pole synchronous generator connected to infinite bus--Synchronizing and parallel operation – Synchronizing torque - Change of excitation and mechanical input- Voltage regulation – EMF, MMF, ZPF and A.S.A methods – steady state power angle characteristics– Two reaction theory –slip test - short circuit transients - Capability Curves
	PART * A
Q. No	**Questions**
1	**List the essential parts for generating emf in alternators. (Nov/Dec 2014)** BTL 1 ➢ Magnetic field ➢ Armature system ➢ Relative motion between the above two.
2	**Write the EMF equation of a three-phase alternator.** BTL 1 The emf equation of alternator is $E = 4.44\ K_c\ K_d \Phi\ f\ T$ volts Where E = Induced emf per phase K_c = Pitch factor

	K_d= Distribution factor T = No of turns connected in series in each phase.
3	**Two reaction theory is applied only to salient pole machines. State the reason. (Nov/Dec 2014) (APR/MAY 2019)**BTL 1 According to two reaction theory, the armature mmf Fa is resolved in to two components, one along the d-axis and another along q-axis. d-axis reactance can be obtained from occ and scc. $\bar{E}_f = \bar{V}_t + \bar{I}_a R_a + jX_d \bar{I}_d + jX_q \bar{I}_q$ The current I_a lags terminal voltage V_t by Φ. Then add $I_a R_a$ in phase with I_a to V_t. The drop $I_d X_d$ leads I_d by 90° as in case purely reactive circuit current lags voltage by 90° i.e. voltage leads current by 90° . Similarly the drop $I_q X_q$ leads X_q by 90° . The total e.m.f. is E_f.
4	**List the advantages of salient pole type construction used for Synchronous machines.**BTL 1 Advantages of salient-pole type construction are: ➢ The pole faces are so shaped that the radial air gap length increases from the pole center to the pole tips so that the flux distribution in the air-gap is sinusoidal in shape which will help the machine to generate sinusoidal emf. ➢ Due to the variable reluctance the machine develops additional reluctance power which is independent of excitation. ➢ They allow better ventilation.
5	**How does electrical degree differ from mechanical degree?** BTL 1 Mechanical degree is the unit for accounting the angle between two points based on their mechanical or physical placement. Electrical degree is used to account the angle between two points in rotating electrical machines. Since all electrical machines operate with the help of magnetic fields, the electrical degree is accounted with reference to the magnetic field. 180 electrical degree is accounted as the angle between adjacent North and South poles. 1 degree electrical = (P/2) mechanical degree. where P = No. of poles
6	**Why short pitch winding is preferred over full-pitch winding?** BTL 2 ➢ Waveform of the emf can be approximately made to a sine wave and distorting harmonics can be reduced or totally eliminated. ➢ Conductor material, copper is saved in the back and front-end connections due to less coil-span. ➢ Fractional slot winding with fractional number of slots/phase can be used which in turn reduces the tooth ripples. ➢ Mechanical strength of the coil is increased.
7	**Why Alternators rated in kVA and not in kW? (APR/MAY 2019)**BTL 2 The continuous power rating of any machine is generally defined as the power of the machine or apparatus can deliver for a continuous period so that the losses incurred in the machine gives rise to a steady temperature rise not exceeding the limit prescribed by the insulation class. Apart from the constant loss incurred in Alternators is the copper loss, occurring in the 3 –phase winding which depends on I^2 R, the square of the current delivered by the generator. As the current is directly related to apparent – power delivered by the generator, the Alternators have only their apparent power ratings in VA/kVA/MVA.

8	**Write short note on "single layer" and "double layer" winding. (Nov/Dec 2011)** BTL 2 In single layer winding, there- is only one coil side per slot- But in double layer winding, in each slot there are two coil sides namely upper coil side and lower coil side. Hence, in single layer winding, the number of coils is half the number of slots, but in double layer winding, the number of coils is equal to the number of slots.
9	**Where the damper windings are located? What are their functions? (Nov/Dec 2011)** BTL 3 Damper windings are provided in the pole shoes of the salient pole rotor. Slots or holes are provided in the pole shoes. Copper bars are inserted in the slots and the ends of all the bars in both the sides are short circuited by copper end rings to have a closed circuit. These windings are useful in preventing the hunting in alternators; they are also needed, in synchronous motor to provide the starting torque.
10	**List the causes of changes in terminal voltage of Alternators when loaded. (Nov/Dec 2012)** BTL 1 Variations in terminal voltage in Alternators on load condition are due to the following three causes: ➢ Voltage drop due to the resistance of the winding, IR. ➢ Voltage drop due to the leakage reactance of the winding, IX_l. ➢ Voltage variation due to the armature reaction effect, IX_a.
11	**What is meant by armature reaction in Alternators? (Nov/Dec 2013)** BTL 2 The effect of armature flux on the flux produced by the field ampere turns is called as armature reaction.
12	**Define synchronous reactance.** BTL2 Synchronous reactance $X_s= (X_l + Xa)$ The value of leakage reactance X_l is constant for a machine based on its construction. X_l depends on saturating condition of the machine. Xa, which represent the armature reaction effect between two synchronously acting magnetic fields. The sum of leakage flux and armature reaction reactance makes the total reactance X_S to be called synchronous reactance.
13	**What is meant by synchronous impedance of an Alternator? (APR/MAY 2019)**BTL 2 The complex addition of resistance, R and synchronous reactance, jXs can be represented together by a single complex impedance Zs called synchronous impedance. In complex form $Zs = (R + jXs)$ In polar form $Zs = \| Zs \| \angle\Theta$ Where $\Theta= \tan^{-1} (Xs /R)$.
14	**Define load angle of an Alternator.** BTL 1 The phase angle introduced between the induced emf phasor, E and terminal voltage phasor (V), during the load condition of an Alternator is called load angle.
15	**Define the term voltage regulation of Alternator. (Nov/Dec 2013)**BTL 1 The voltage regulation of an Alternator is defined as the change in terminal voltage from no-load to load condition expressed as a fraction or percentage of terminal voltage at load condition; the speed and excitation conditions remaining same.
16	**Why the synchronous impedance is called as pessimistic method? (APR/MAY 2019)** BTL 2 Compared to other methods, the value of voltage regulation obtained by the synchronous impedance method is always higher than the actual value and therefore this method is called

	the pessimistic method.

17	**Why the MMF method is called as the optimistic method?** BTL 2 Compared to the EMF method, MMF method, involves more number of complex calculation steps. Further the OCC is referred twice, SCC is referred once while predetermining the voltage regulation for each load condition. Reference of OCC takes care of saturation effect. As this method require more effort, the final result is very close to the actual value. Hence this method is called optimistic method.
18	**State the condition for connecting two alternators in parallel.** BTL 1 The following are the three conditions that is to be satisfied by synchronizing the additional alternator with the existing one or the common bus-bars. ➢ The terminal voltage magnitude of the incoming Alternator must be made equal to the existing Alternator or the bus-bar voltage magnitude. ➢ The phase sequence of the incoming Alternator voltage must be similar to the bus-bar voltage. ➢ The frequency of the incoming Alternator voltage must be the same as the bus-bar voltage.
19	**List the factors that affect the load sharing in parallel operating generators.**BTL 1 The total active and reactive power delivered to the load, connected across the common bus-bars, are shared among Synchronous generators, operating in parallel, based on the following three factors ➢ Prime-mover characteristic/input ➢ Excitation level and ➢ Percentage synchronous impedance and its R/X ratio
20	**State briefly about infinite bus-bars.(May/June 2014)** BTL 2 The source or supply lines with non-variable voltage and frequency are called infinite bus-bars. The source lines are said to have zero source impedance and infinite rotational inertia.
21	**What is meant by armature reaction? (Nov/Dec 2013)** BTL 2 The load currents flowing in the stator winding usually generate a magnetic field which opposes the magnetic field generated by the excitation (field) winding, reducing the total airgap field and the terminal voltage. In order to**counteract** this reaction effect from the stator currents, the field current has to be adjusted (usually increased).
22	**Why the field system of an alternator made as a rotor? (April/May 2012)** BTL 2 Number of brush, voltage drop across the brush, number of phases of windings in rotor and weight of rotor are reduced.
23	**What is synchronizing power of an alternator? (April/May 2012)** BTL 2 When two alternators are operated parallel after synchronism, suppose due to change in input parameter of second alternator it acts as motor, first alternator supplies power to second alternator. That power is called as synchronous power.
24	**How will you distinguish between the two types of large synchronous generator from their appearance? (May/June 2014)** BTL 4 ➢ Salient pole type, the pole is projected out from the surface of the rotor and are characterized by large diameters and short axial length ➢ Non-salient type, the poles are non-salient (i.e.) they do not project out from the surface of the rotor.

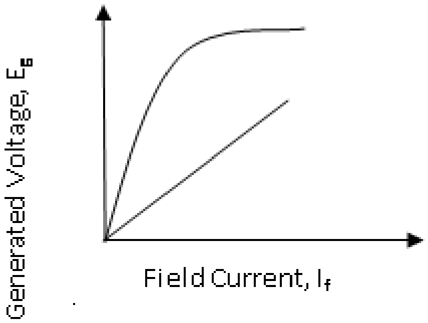
25

Distinguish the use of salient pole and round rotor synchronous machines. (May/June 2015) BTL 4

salient pole	round rotor
Rotor poles are projected	Smooth cylindrical type rotor
Mechanical strength is low	Mechanical strength is high
It has large diameter and small axial length	It has small diameter and large axial length
This type of rotor used for low speed applications	This type of rotor used for high speed applications
Operating noise is high	Operating noise is low
Non uniform airgap between stator and rotor	Uniform airgap between stator and rotor

26

Draw typical open circuit and short circuit characteristics of synchronous machine. (May/June 2015) BTL 1



PART * B

1

Explain the construction and working principle of synchronous generator with neat diagram.(Nov 2018, May 2018) (APR/MAY 2019) (13M) BTL 1

Answer: Page 1.3 to 1.5 - J. Gnanavadivel

Construction:

Principle:(2M)

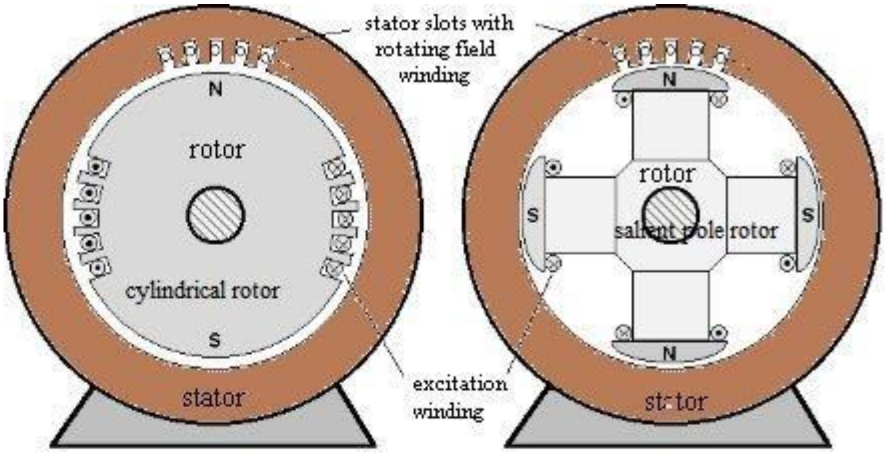
- Conductor cuts magnetic flux.
- Dynamically induced emf is produced.
- Faraday’s laws of Electromagnetic Induction.
- Current flow in the conductor.

Construction: (5 M)

Stator

- Stator stationary member.
- Cylinder inside which rotor rotates.
- Air gap between the stator and the rotor.
- Armature windings are housed in the slots cut the stator

Diagram: (3M)



Rotor

- Two types of rotor.
- Cylindrical type rotor and salient pole.
- Cylindrical pole rotor has dc field winding.
- Cylindrical rotor provides greater mechanical strength
- Used in high speed turbo generators.
- Salient pole rotors have projecting poles.
- Projecting poles lessen its mechanical strength.
- Used for low speed applications.
- Larger in diameter and smaller in length.

Principle of operation: (3 M)

- DC excitation provided to the rotor
- Rotor produces a stationary flux in the air gap
- Which links stator winding.
- Generator converts mechanical energy into electrical energy.
- Rotor is rotated produces a sinusoidalflux in air gap.
- links the armature windings and induces sinusoidally alternating emf in it.
- The frequency of the induced emf.

$f = PN_s/120$

Where

P = number of stator poles.

N_s = Speed of the rotor in rpm.

2 **Derive the emf equation of alternator. (Nov/Dec 2011 & 2012 & 2013, Nov 2017 Nov 2018 &2014) (8M)**BTL 1

Answer: Page No. 1.11- J. Gnanavadivel

	Let Φ = Flux per pole, in Wb P = Number of poles N_s = Synchronous speed in r.p.m. f = Frequency of induced e.m.f. in Hz Z = Total number of conductors Z_{ph} = Conductors per phase connected in series ∴ Z_{ph} = Z/3 as number of phases = 3.(2M) The average value of e.m.f. induced in a conductor = dΦ/dt Total flux cut in one revolution is Φ x P Time taken for one revolution is $60/N_s$ seconds. e_{avg} per conductor = 2 f Φ volts ∴ e.m.f. per turn = 2 x (e.m.f. per conductor) = 4 f Φ volts ∴ Average E_{ph} = T_{ph} x (Average e.m.f. per turn) ∴ Average Eph = T_{ph} x 4 f Φ K_f = (R.M.S.)/Average = 1.11 .... for sinusoidal (3 M) E = 4.44 x f Φ T_{ph} volts ....(2) $T_{ph} = Z_{ph}/2$ Actual available voltage/phase=4.44$k_c k_d$ ø fT in Volts (3 M)
3.	**Explain the condition for parallel operation of 3 phase alternator. (Nov/Dec 2012) (APR/MAY 2019) (5M)** BTL 2 **Answer: Page -1.73- J. Gnanavadivel** **Condition** :(5 M) **Conditions for Paralleling Alternator with Infinite Busbars** ➢ An alternator connected to infinite busbars is synchronizing. ➢ Induced e.m.f. is zero at standstill and a short-circuit will result. **Condition:** ➢ Terminal voltage must be same as busbars voltage. ➢ Frequency must be equal to the busbars frequency. ➢ Phase sequence of the voltage should be the same as that of the busbars.
4	**Explain the procedure for POTIER method to calculate voltage regulation of alternator. (April/May 2012, May 2018) (13M)** BTL 5 **Answer: Page -1.66 to 1.68 - J. Gnanavadivel** ➢ Separation of armature leakage reactance and armature reaction. ➢ Armature leakage reactance X_L is called Potier reactance. ➢ To determine armature leakage reactance and armature reaction m.m.f. separately. ➢ Two tests are performed. • Open circuit test • Zero power factor test (3 M) **Open Circuit Test**

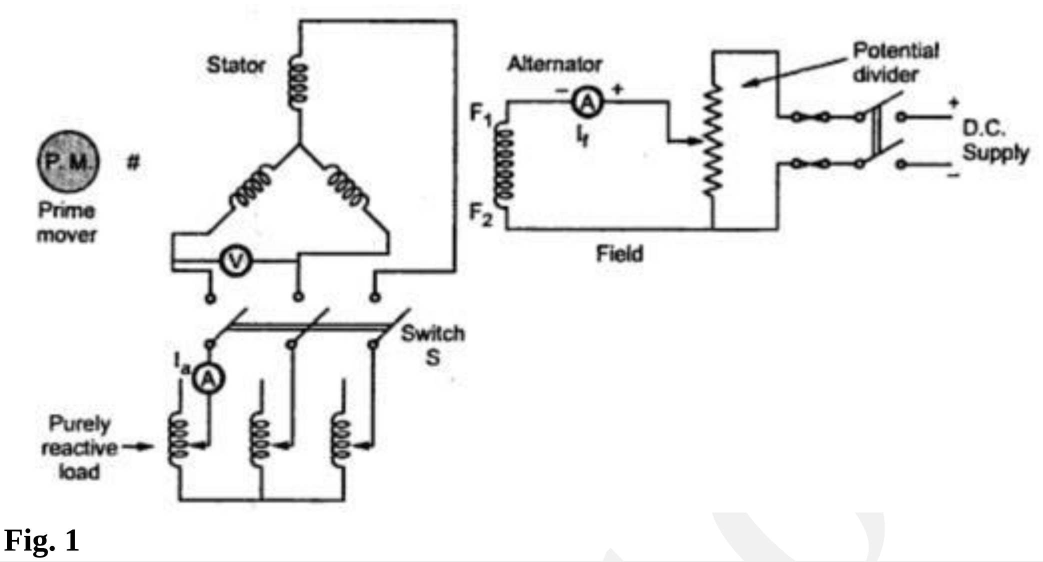


Fig. 1

The steps to perform open circuit test are,

- Switch S is kept open.
- Alternator is driven by its prime mover at its synchronous speed.
- Excitation is varied with the help of potential divide.
- Field current and open circuit voltage noted.
- Draw open circuit characteristics. (3 M)

Zero Power Factor Test

- Switch S is kept closed.
- Purely inductive load gets connected to an alternator through an ammeter.
- Speed is maintained constant at its synchronous value.
- An alternator will always operate at zero p.f. lagging.
- Plot open circuit characteristics on graph as shown in the Fig. 2. (3 M)

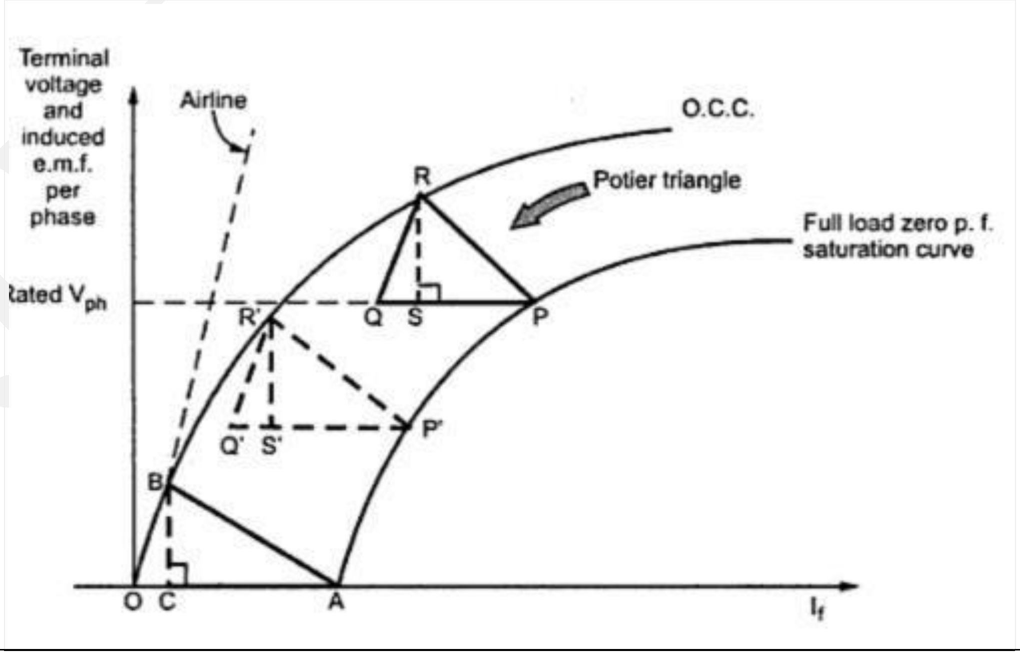
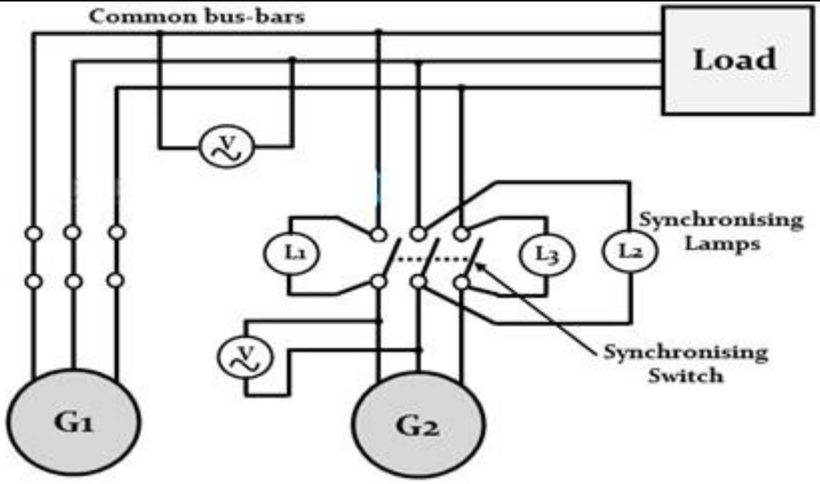


	Fig. 2 ➢ Draw tangent to O.C.C. through origin which is line OB ➢ Draw the horizontal line PQ parallel and equal to OA. ➢ Triangle PQR is called potier triangle. ➢ From point R, drop a perpendicular on PQ to meet at point S. ➢ Perpendicular RS gives the voltage drop due to the armature leakage reactance. ➢ Length PS gives field current to overcome de-magnetizing effect. ∴ $\boxed{\bar{E}_{lph} = \bar{V}_{ph} + \overline{I_{ph} R_{aph}} + \overline{I_{ph} X_{Lph}}}$ Once E_{ph} is known, the regulation of an alternator can be predicted as, $\% R = \frac{E_{ph} - V_{ph}}{V_{ph}} \times 100$ (4 M)

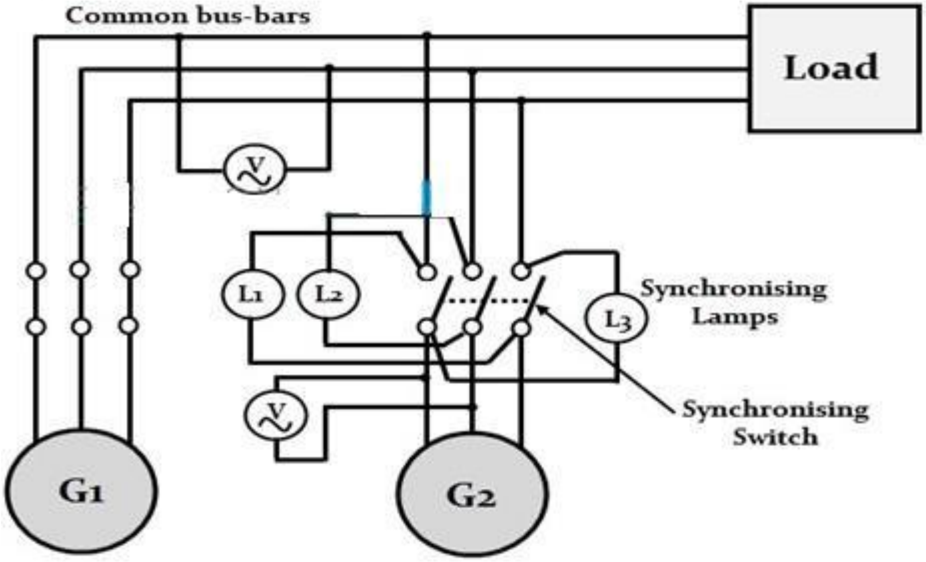
5	**Explain about the various methods of Synchronization. (April/May 2012, Nov 2017) (13M)** BTL 2
	Answer: Page No. 1.73 to 1.76 - J. Gnanavadivel
	➢ Connecting an alternator to busbars is synchronization.
	➢ Methods of synchronization.
	    ➢ Three Lamp (one dark, two bright) method (5M)
	    ➢ Dark Lamp method (5 M)
	    ➢ By synchroscope(3M)
	Three Dark Lamps Method
	➢ Alternator connected to rated voltage and frequency.
	➢ Three lamps are connected across the switches.
	➢ Speed close to the synchronous speed.
	➢ Decided by the bus bar frequency and number of poles of the alternator.
	➢ Field current of the generator-2 is increased.
	➢ Machine terminals is equal to the bus bar voltage.
	➢ If lamps go ON and OFF concurrently.
	➢ Indicating that the phase sequence of alternator-2.
	➢ If they ON and OFF one after another, incorrect phase sequence.
	➢ By changing the connections of any two leads, phase sequence can be changed.



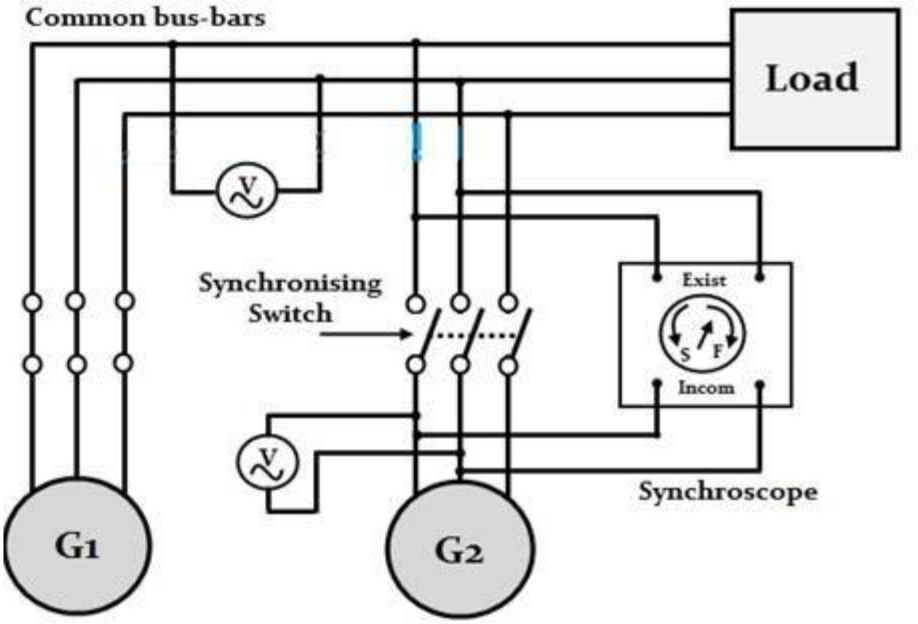
- Rate of flickering has to be reduce.
- Adjusting the speed of alternator by its prime mover control.
- Lamps become dark and synchronizing switch can be closed.
- Synchronize alternator-2 with alternator-1.

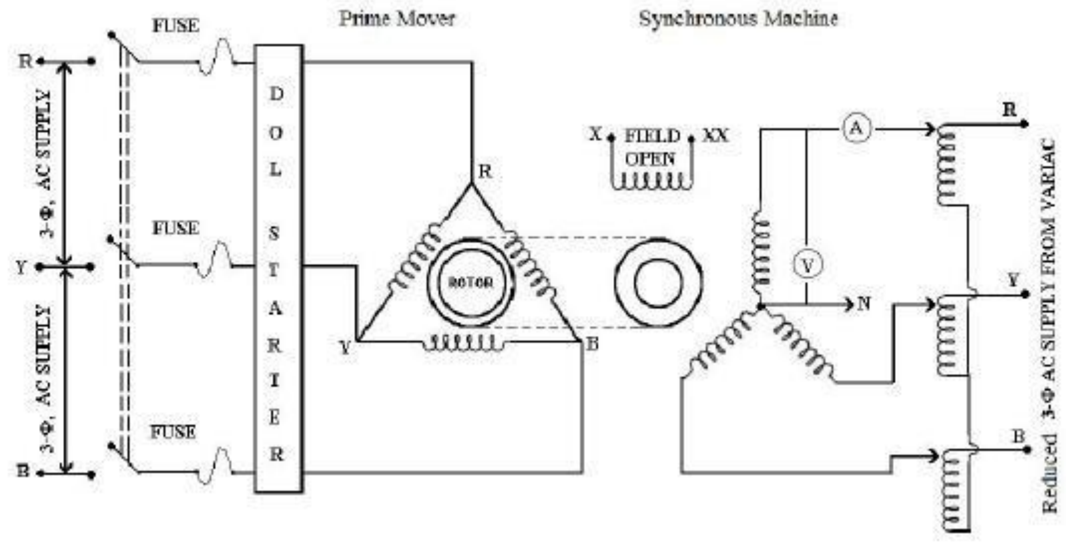
Two Bright and One Dark Lamp Method

- Lamp L2 is connected across the pole in the middle line.
- Lamps L1 and L3 are connected in a transposed manner.
- Voltage condition checking is similar to the previous method.
- Lamps glow bright and dark one after another.
- Frequency is determined by the sequence in which the lamps become dark and bright.



- Bright and dark L1- L2 – L3 indicates frequency is higher than bus bar frequency.
- Alternator speed has to be reduced till flickering rate is small.
- Flickering L1- L3 – L2 indicates frequency is less than that of bus bar.
- Speed of the alternator is increased till flickering is small as possible.
- The synchronizing switch is then closed.
- Lamps L1 and L3 are equally bright and lamp L2 is dark.

	Synchroscope Method ➢ Better accuracy of synchronization. ➢ It consists of two pairs of terminals. ➢ One pair of terminals connected across the bus bar terminals. ➢ Other pair of terminals connected across incoming alternator. ➢ It has circular dial. ➢ Rotating in clockwise and anticlockwise directions.  ➢ Pointer rotates indicates difference of frequency ➢ Frequency is higher or lower than bus bar frequency. Pointer moves either fast or slow. ➢ Correction to be made to control the speed of alternator.
6	**Explain how you will determine the d and q axis reactance of a synchronous machine in your laboratory. (Nov/Dec 2011, Nov 2017)(May/June 2014) (13 M)** BTL 2 **Answer: Page -1.98 to 1.100- J. Gnanavadivel** ➢ From this test Xd and Xq are determined. ➢ Field winding remains unexcited. ➢ Machine is run less than the synchronous speed. **Diagram –** (3 M)

	 **Explanation** (10 M) ➢ Voltage V applied to stator terminal. ➢ Current I flow causing a stator mmf. ➢ Stator mmf induced an emf in the field circuit. ➢ Stator mmf moves slowly relative to poles. ➢ Axis of the pole and axis of the armature reaction mmf wave coincide. ➢ Armature mmf acts field magnetic circuit. ➢ Voltage is constant, air-gap flux would be constant. ➢ Minimum air-gap offers minimum reluctance. ➢ Current required in armature for constant air-gap flux must be minimum. ➢ d-axis synchronous reactance is given by • *Xd*= Maximum armature terminal voltage per phase / Minimum armature current per phase. • *Xq* = Minimum armature terminal voltage per phase / Maximum armature current per phase.
7	**A four pole alternator has an armature with 25 slots and 8 conductors per slot and rotates at 1500 rpm and the flux per pole is 0.05Wb. Calculate the emf generated, if winding factor is 0.96 and all the conductors are in series. (Nov/Dec 2012). (5M)** BTL 4 **Answer: Page1.12- J. Gnanavadivel** Frequency, f=(PN)/120=(4*1500)/120=50Hz (2 M) Generated emf/phase, $E=4.44f\Phi K_wT=4.44*50*0.05*0.96*100=1065.6$ V (3 M)
8	**Explain the EMF method of determining the regulation of an alternator. (Nov/Dec 2012 & 2014) (13 M)** BTL 5 **Answer: Page -1.38 to 1.41- J. Gnanavadivel** ➢ Also known as synchronous impedance method. ➢ Magnetic circuit is assumed to be unsaturated. ➢ MMFs (fluxes) produced by rotor and stator. ➢ Replaced by equivalent emf. ➢ Determine armature resistance /phase of the alternator, open circuit and short circuit

characteristics.

Determination of synchronous impedance Zs: Diagram – (3 M)

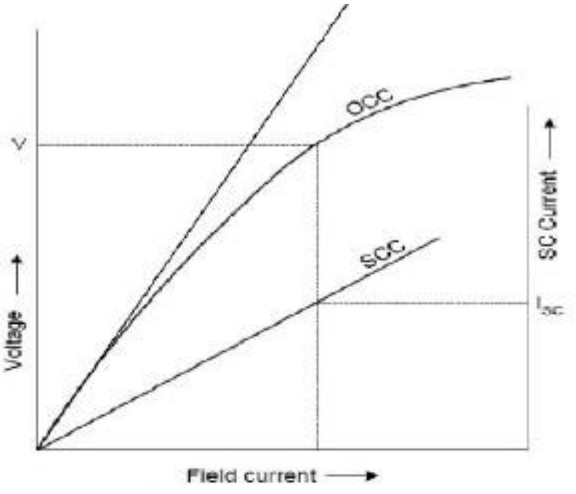


Fig: 1.16 OCC and SCC of alternator

Explanation (7M)

- Terminals of stator are short circuited in SC test.
- Impedance can be estimated form OC and SC characteristics.
- Synchronous impedance Zs = (open circuit voltage per phase)/(short circuit current per phase) for same If Hence Zs = (Voc) / (Isc).
- synchronous impedance Zs = V/Isc

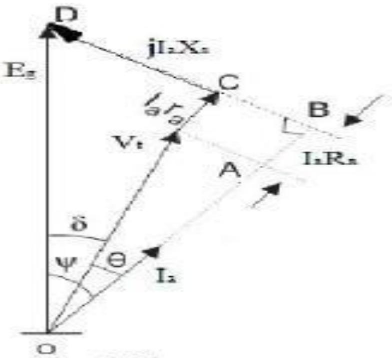


Fig: 1.17

- $Zs = \sqrt{[(Ra)^2 + (XS)^2]}$ and Synchronous reactance $Xs = \sqrt{[(Zs)^2 - (Ra)^2]}$
- Induced emf per phase $Eg = \sqrt{[(Vt \cos + IaRa)^2 + (Vt \sin \pm IaXS)^2]}$
  where Vt = phase voltage per phase = Vph,
  Ia = load current per phase
  \+ sign is for lagging power factor
  \- sign is for leading power
- *V* % Regulation = (Eg – Vt) / Vt
  - where Eg = no-load induced emf /phase,
  - Vt = rated terminal voltage/phase
- It gives approximate results.

- This method is called pessimistic method.

Phaser Diagram (3M)

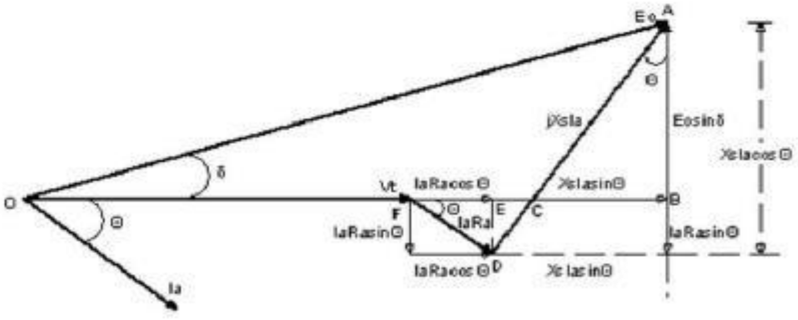


Fig: 1.18

9

Explain the phenomenon of armature reaction in alternator for different load power factors.(April/May2012) (Nov/Dec2015) (APR/MAY 2019) (13 M) BTL 2

Answer: Page No. 1.31 to 1.33 - J. Gnanavadivel

- Alternator is running at no-load.
- No current flowing through the armature winding.
- Flux produced in air-gap.
- Alternator is loaded, three-phase currents produce a magnetic field in air-gap.
- Air-gap flux is changed from no-load condition.
- Effect of armature flux is called armature reaction.
- First, armature flux and flux produced by rotor ampere-turns.
- Rotate at the same speed and same direction.
- Two fluxes are fixed in space relative to each other.
- Power factor which determines whether armature flux distorts, opposes or helps the flux.
- To illustrate this important point:
  - When load p.f. is unity
  - When load p.f. is zero lagging
  - When load p.f. is zero leading (3 M)

When load p.f. is unity(3 M)

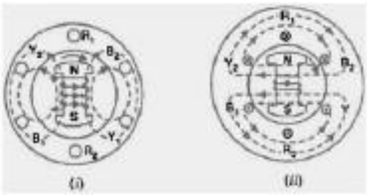


Fig: 1 (c)

- Armature is on open-circuit, there is no stator current.
- Flux due to rotor current is distributed in air-gap as shown in Fig: 1 (d).
- Direction of the rotor is assumed clockwise, the generated e.m.f. in phase.
- No armature flux is produced since no current flows in the armature winding.

- When a resistive load (unity p.f.) is connected across the terminals.
- Armature flux is clockwise due to currents in the top conductors.
- Anti-clockwise due to currents in the bottom conductors.
- Armature flux is at 90° to the main flux and is behind the main flux.
- In this case, the flux in the air-gap is distorted but not weakened.
- Unity p.f., the effect of armature reaction is merely to distort the main field.
- No weakening of the main field and the average flux practically remains the same.
- Since the magnetic flux due to stator currents.

When load Power Factor is Zero lagging :(3 M)

- Pure inductive load is connected across the terminals.
- Current in phase R1R2 will not reach its maximum.
- Armature flux is from right to left and field flux is from left to right.
- All the flux produced by armature current opposes be field flux.
- Therefore, weakens it.
- Armature reaction is directly demagnetizing.
- Hence at zero p.f. lagging, armature reaction weakens the main flux.
- Causes a reduction in the generated e.m.f.

When load Power Factor is Zero leading (4 M)

- Capacitive load (zero p.f. leading) is connected across the terminals.

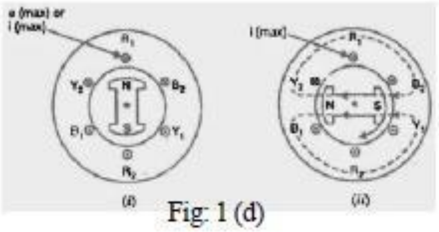


Fig: 1 (d)

- Effect of armature reaction will be reverse that for pure inductive load.
- Armature flux now aids the main flux and the generated e.m.f. is increased.
- Note that e.m.f. as well as current in phase R1R2 is maximum.
- Maximum current in R1R2 will occur 90° electrical.
- Armature flux is now in same direction as field flux.
- Therefore, strengthens it.
- Causes an increase in generated voltage.
- Hence at zero p.f. leading, armature reaction strengthens the main flux.

PART * C

1 **A 11 kV, 1000 kVA, 3-phase, star connected alternator has a resistance of 2 Ω per phase. The open-circuit and full load zero power factor characteristics are given below. Find the voltage regulation of the alternator for full load current at 0.8 pf lagging by potier method.(15 M)** BTL 4

Field current (A)	**40**	**50**	**110**	**140**	**180**

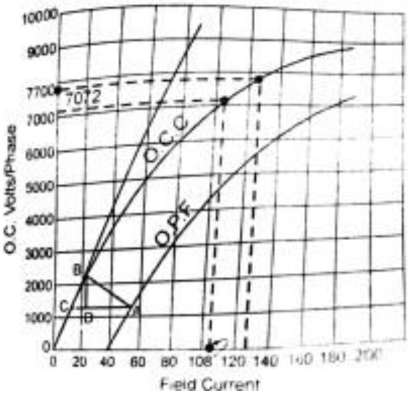
OCC line voltage	**5800**	**7000**	**12500**	**13750**	**15000**
Line volt zero p.f	**0**	**1500**	**8500**	**10500**	**12500**

Answer: Page –1.68 - J. Gnanavadivel

The OCC and full load zero power factor curve for phase voltage are drawn figure. The corresponding phase voltages are

Field current (A)	40	50	110	140	180
OCC phase voltage	3350	4040	7220	7940	8660
Phase volt zero p.f	0	866	4900	6060	7220

- Full load current = $(1000 * 10^3) / (\sqrt{3} * 11000) = 52.5$ A
- Phase voltage = $11000 / \sqrt{3} = 6350$ V
- In potier triangle ABC, AC = 40 A, CB is parallel to the tangent to the initial portion of the OCC and BD is perpendicular to AC.
- BD = Leakage reactance drop $IX_L = 1000$ V by measurement
- AD = 30 A – field current required to overcome demagnetizing effect armature reaction on full load.
- From the figure,
  OA = 6350, AB = IRa = 52.5 * 2 = 105 V
- IX_L = BC = 1000 V
- OC = $\sqrt{[(V \cos \varphi + I Ra)^2 + (V \sin \varphi + IX_L)^2]}$(5 M)



(3 M)

- E = $\sqrt{[(6350*0.8 + 105)^2 + (6350 * 0.6 + 1000)^2]}$
  = 7072 V (5 M)
- As seen from OCC field current required for 7072 V is 108 A. Vector OD represents 108 A and is drawn perpendicular to OC. DF represents 30 A and is draw parallel to OI or at (90 + 36.86 = 126.86) with OD. The total field current is OF.

- OF = √[$108^2 + 30^2 + 2*108*30*\cos 53.14$] = 128 A
- From OCC it is found that the emf corresponding to this field current is 7700 V.
- Eg = 7700 V
- % Regulation = (7700 – 6350) * 100 / 6350
  = 21.3 %(5 M)

2

A 3-Phase,star-connected,1000KVA,11,000V alternator has rated current of 52.5A.The ac resistance of the winding per phase is 0.45Ω.The test results are given below:

OC Test: field current = 12.5A,voltage between lines = 422V.

SC Test: field current = 12.5A, line current = 52.5A

Determine the full load voltage regulation of the alternator

(i) 0.8 pf lagging and (ii) 0.8 pf leading.(May/June 2014) (15 M) BTL 4

Answer: Page - J. Gnanavadivel

(i) Answer: For 0.8 lagging $E_o = \sqrt{(V\cos\Phi + IR_a)^2 + (V\sin\Phi + IX_s)^2}$ (2 M)

(ii) Voltage regulation = 19.96 % (6 M)

(iii) For 0.8 leading $E_o = \sqrt{(V\cos\Phi + IR_a)^2 + (V\sin\Phi - IX_s)^2}$ (2 M)

(iv) Voltage regulation = - 11. 276 % (5 M)

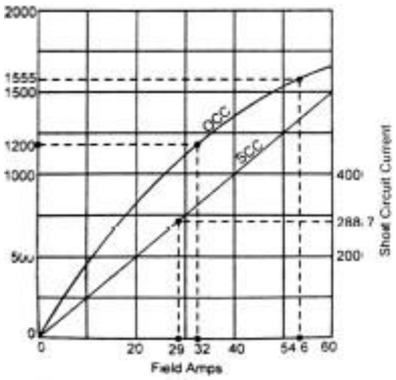
3

A three phase, star connected,1000 kVA, 2000V, 50Hzalternator gave the following open circuit and short circuit test readings:

Field current(A):	**10**	**20**	**25**	**30**	**40**	**50**
O.C. voltage(V):	**800**	**1500**	**1760**	**2000**	**2350**	**2600**
S.C.armature current(A):	**-**	**200**	**250**	**300**	**-**	**-**

The armature effective resistance per phase is 0.2Ω. Draw the characteristic curves and determine the full load percentage regulation at i.0.8 p.f lagging, ii. 0.8 p.f leading by MMF method.(15 M) BTL 4

Answer: Page - 1.61 to 1.62- Dr. Gananvadivel



(a)

Graph (5 M)

- The phase voltages are: 462, 866, 1016, 1357, 1502
- Full load phase voltage = 2000/√3 = 1155 V
- Full load current = 1000000/(2000*√3) = 288.7 A
- Voltage/phase at full load at 0.8 pf

  =V + IRa cos φ

  = 1155 + (288.7 * .02 * 0.8) = 1200 V
- From open circuit curve, it is found that field current necessary to produce this voltage = 32 A.
  - From short circuit characteristics it is found that field current necessary to produce full load current 288.7 A s 29 A From figure AB = 32 A, BC = 29 A and is at an angel of (90 + 36.86) = 126.86 with AB
  - The total field current at full load 0.8 pf lagging is AC = 54.6 A
  - Open circuit volt corresponding to a field current of 54.6 A is = 1554 V
  - % Regulation = (1555 -1155)*100 / 1155
- Cos φ = 0.8, φ = 36.86

  % Voltage regulation = 34.6 % (5 M)
- As power factor is leading, BC is drawn with AB at an angle of 90 – 36.86 = 53.14 A
- AC = 27.4 A
- Open circuit voltage corresponding to 27.4 A of field excitation is 1080 V
- % Regulation = (1080 – 1155) * 100 / 1155
- % Voltage regulation = - 6.4 % (5 M)

4

Explain the MMF method of evaluating the voltage regulation of alternator. (May/June 2015, Nov 2018, Nov 2017) (15 M) BTL 6

Answer: page - 1.38 to 1.4 - J. Gnanavadivel

Explanation – (10M)

- This method is also known as amp - turns method.
- Emfs produced by rotor and stator are replaced by their equivalent.
- Assumed that magnetic circuit is unsaturated.
- Reactance drops are replaced by their equivalent mmfs.
- Emf method OC and SC characteristics are used for determination of regulation by mmf method.

Phasor Diagram (3 M)

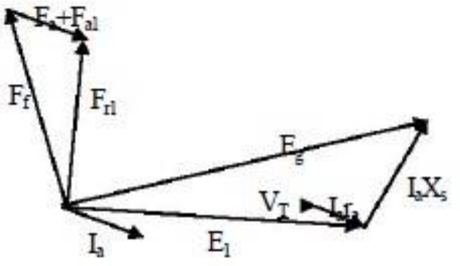


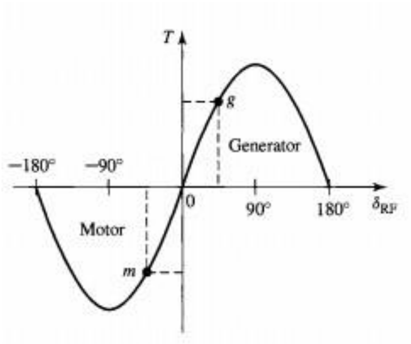
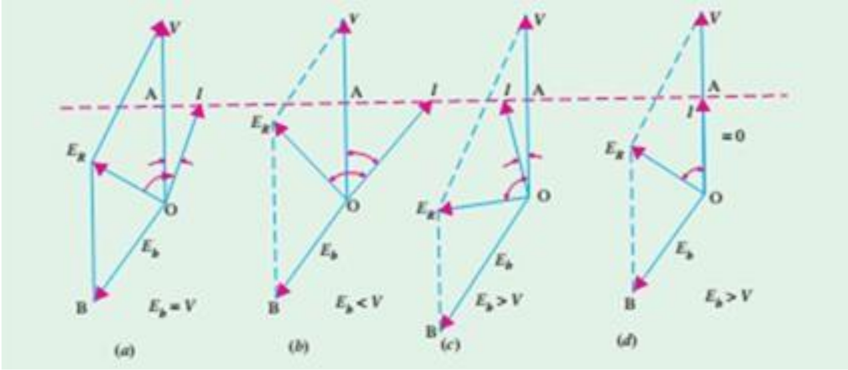
Fig: 1.19

	➢ From phasor diagram mmf required to produce emf E1= (V + IRa) is FR1. ➢ Large machines resistance drop may neglected. ➢ Mmf required to overcome reactance drops is (Fa+Fal). ➢ Mmf (Fa+Fal) can be found from SC characteristic Following procedure can be used for determination of regulation by mmf method. ➢ By conducting OC and SC test plot OCC and SCC. ➢ From OCC find field current *If1* required to produce voltage, E1= (V + IRa). ➢ From SCC find magnitude of field current *If2* (Fa+Fal) to produce armature current. ➢ Fa+Fal can also found from ZPF characteristics. ➢ Draw *If2* at angle (90+) from *If1*. ➢ If current is leading, take the angle of *If2* as (90-). ➢ Determine resultant field current, *If* and mark its magnitude on the field current axis. ➢ From OCC. find voltage corresponding to *If,* which will be *E0.* ➢ Find regulation.

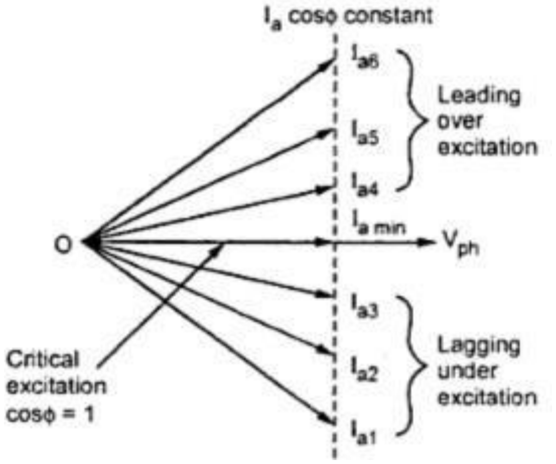
	UNIT II SYNCHRONOUS MOTOR
	Principle of operation – Torque equation – Operation on infinite bus bars - V and Inverted V curves – Power input and power developed equations – Starting methods – Current loci for constant power input, constant excitation and constant power developed-Hunting – natural frequency of oscillations – damper windings- synchronous condenser.
	PART * A
Q.No.	**Questions**
1	**Name the methods of starting a synchronous motor. (May/June 2014) (APR/MAY 2019)**BTL 1 ➢ By an extra 3 phase induction motor ➢ By providing damper winding in pole shoes ➢ By operating the pilot exciter as a dc motor
2	**Why a synchronous motor is called as constant speed motor? (April/May 2012)** BTL 1 Synchronous motor work on the principle of force developed due to the magnetic attraction established between the rotating magnetic field and the main pole feed. Since the speed of rotating magnetic field is directly proportional to frequency the motor operates at constant speed.
3	**State V and inverted V curves of synchronous motor.(Nov/Dec 2011)** BTL 1 The variation of magnitude of line current with respect to the field current is called V curve. The variation of power factor with respect to the field current is called inverted V curve.
4	**What happens when the field current of a synchronous motor is increased beyond the normal value at constant input?** BTL 2 Increase in emf causes the motor to have reactive current in the leading direction. The additional leading reactive current causes the magnitude of line current, accompanied by the decrease in power factor.
5	**Distinguish between synchronous phase modifier and synchronous condenser.** BTL 4 A synchronous motor used to change the power factor or power factor in the supply lines is called synchronous phase modifier. A synchronous motor operated at no load with over excitation condition to draw large leading reactive current and power is called a synchronous condenser.
6	**How does the synchronous motor can be used as synchronous condenser? (Nov/Dec 2011& 2012 & 2014)** BTL 2 Synchronous motor is operated on over excitation so as to draw leading reactive current and power from the supply lines. This compensates the lagging current and power requirement of the load making the system power factor to become unity. The motor does the job of capacitors and hence called as synchronous condenser.

7	**Mention the methods of starting of 3-phase synchronous motor. (May/June 2014)** BTL 2 ➢ A D.C motor coupled to the synchronous motor shaft. ➢ A small induction motor coupled to its shaft ➢ Using damper windings as a squirrel cage induction motor.
8	**What is meant by hunting of synchronous motor? (April/May 2012) & (Nov/Dec 2013)** BTL 1 When the load applied to the synchronous motor is suddenly increased or decreased, the rotor oscillates about its synchronous position with respect to the stator field. This action is called hunting.
9	**Write important differences between a 3-phase synchronous motor and a 3-phase induction motor. (May/June 2014)** BTL 1 ➢ Synchronous motor is a constant speed motor whereas induction motor speed will decrease on load. ➢ Synchronous motor requires A.C and D.C supplies whereas induction motor requires only A.C supply. ➢ Synchronous motor can be worked under various power factors such as lagging, leading and unity. But induction motor can be run with lagging power factor only.
10	**What could be the reasons if a 3-phase synchronous motor fails to start? (Nov/Dec 2014& May/June2015)** BTL 4 It is usually due to the following reasons ➢ Voltage may be too low. ➢ Too much starting toad. ➢ Open circuit in one phase or short circuit. ➢ iv. Field excitation may be excessive.
11	**How does a change of excitation affect its power factor? (APR/MAY 2019)** BTL 4 When the excitation is reduced, the motor draws a lagging current and when the excitation is increased, the armature current is leading the applied voltage. It may also happen for some value of excitation, that current may be in phase with the voltage i.e. power factor is unity.
12	**Define phase swinging.**BTL 1 Phase swinging is otherwise called as hunting. When the load on the synchronous motor is varying or the supply frequency is pulsating the speed of the machine will fluctuate causing vibration on the rotor, which is called hunting or phase swinging.
13	**Which condition a synchronous motor will fail to pull in to step?** BTL 2 ➢ No field excitation. ➢ Excessive load. ➢ Excessive load inertia.
14	**Write the applications of synchronous motor.** BTL 1 ➢ Used for power factor improvement in sub-stations and in Industries. ➢ Used in industries for power applications- ➢ Used for constant speed drives such as motor -generator set, pumps and compressors.
15	**Why a synchronous motor is a constant speed motor?** BTL 4 It runs always with a constant speed called synchronous speed N =120 f/P. where f is the supply frequency and P is the no- of poles.

16	**How the synchronous motor is made self-starting?** BTL 2 By providing damper windings in the pole face's, it will start and run like a squirrel cage induction motor.
17	**State the characteristic features of synchronous motor.** BTL 1 ➢ The motor is not inherently self-starting ➢ The speed of operation is always in synchronous with the supply frequency irrespective of load conditions. ➢ The motor is capable of operating at any power factor.
18	**How the synchronous motor is differed from other motors?** BTL 4 All dc and ac motors work on the same principle. Synchronous motor operates due to magnetic locking taking place between stator and rotor magnetic fields.
19	**Why a 3-phase synchronous motor always runs at synchronous speed?** BTL 2 Because of the magnetic coupling between the stator poles and rotor poles the motor runs exactly at synchronous speed.
20	**What are the uses of damper winding in synchronous motor? (Nov/Dec 2013)** BTL 1 ➢ Starting of synchronous motor ➢ Reduce the Oscillations
21	**What is the effect on speed if the load is increased on a 3-phase synchronous motor?** BTL 1 The speed of operation remains constant from no load to maximum load if the motor operated constant frequency supply.
22	**What is the phasor relation between induced emf and terminal voltage of a 3-phase synchronous motor? (APR/MAY 2019)** BTL 1 The rotating magnetic field is initially established by the prime source of supply V. The main field then causes an emf (e) to get induced in the 3- phase winding. Hence when the machine operates as a synchronous motor the emf phasor always lags the terminal voltage phasor by the load/torque angle δ.
23	**What is meant by pull out torque?** BTL 2 When the load on the motor is increased, the load angle is also increased, i.e. the rotor goes on progressively falling back in phase and draws more current. If we increase the load further, then the motor pulls out of synchronism and stops. The torque developed at pull out point is called pull out torque.
24	**How will you reverse the direction of rotation of a 3-phase synchronous motor?** BTL 2 By Inter changing two phases of the 3-phase supply connections the direction of rotation can be reversed.
25	**Give some merits and demerits of synchronous motor.** BTL 1 Merits ➢ This motor runs at constant speed (synchronous speed) even at full load. ➢ Can be operated with leading power factor, for power factor improvement. Demerits ➢ Two sources of supply are necessary ➢ Since damper-winding resistance is low, it takes large currents, from supply mains.

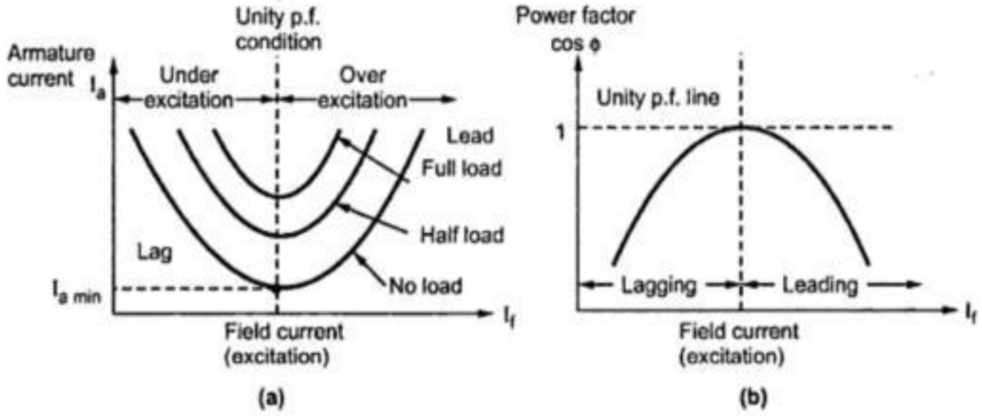
26	**When synchronous motor receives 100% excitation? (Nov/Dec 2015)** BTL 1 The value of excitation for which back emfE_b is equal (in magnitude) to applied voltage V is known as 100% excitation.
27	**Draw the typical torque angle characteristics of synchronous machine. (May/June2015)** BTL 1 
	PART * B
1	**Explain the working of synchronous motor with different excitations. (May/June 2014) (13 M)** BTL 4 **Answer: Page – 2.19 – J. Gnanavadivel** ➢ Excitation for which back e.m.f. Eb is equal to oltage V is known as 100% excitation. ➢ Motor is either over-excited or under-excited. ➢ Consider a synchronous motor in which the mechanical load is constant.  (6 M) ➢ Fig. 38.47 (a) shows for 100% excitation i.e., when Eb = V. ➢ Armature current I lags behind V by a small angle f. ➢ Angle q with ER is fixed by stator constants i.e. tan q = X S / Ra. ➢ In Fig. 38.47 (b)* excitation is less than 100% i.e., Eb < V. ➢ It lags behind ER by fixed angle q. ➢ Magnitude of I is increased but its power factor is decreased. ➢ Fig. 38.47 (c) represents for overexcited motor i.e. when Eb > V. ➢ Now motor is drawing a leading current. ➢ Current I may be in phase with V i.e., p.f. is unity. ➢ At that time, the current drawn by the motor would be minimum. (7 M)

2	**List out the main characteristic features of synchronous motor. (APR/MAY 2019) (8 M)** BTL 4 **Answer: Page - 2.53- J. Gnanavadivel** Some salient features of a synchronous motor are: ➢ A synchronous motor runs at synchronous speed. ➢ Its speed is constant at all loads. ➢ To change its speed is to alter the supply frequency (Ns = 120 f/P). ➢ It can be made to operate over a wide range of power factors (lagging, unity or leading). ➢ By adjustment of its field excitation. (4 M) ➢ To carry the mechanical load at constant speed and at the same time improve the pf. ➢ Synchronous motors are generally salient pole type ➢ synchronous motor is not self-starting. ➢ An auxiliary means be used for starting it. (4 M)
3	**A 5kW,3 phase Y-connected 50 Hz,440 V, cylindrical rotor synchronous motor operates at rated condition with 0.8 pf leading. The motor efficiency excluding field and stator losses is 95% and X_s=2.5 Ω. Calculate** **1.Mechanical power developed** **2.armature current** **3.back emf** **4.power angle** **5.maximum or pull out torque of the motor. (13 M)** BTL 3 **Answer: Page – 38 -Class Notes** Solution: ➢ Mechanical power developed =78950W (3 M) ➢ Armature current =129A (2 M) ➢ Back emf=516V (2 M) ➢ Power angle=-30^0(3 M) ➢ Maximum or pull out torque of the motor =1000Nm (3 M)
4	**Explain V-curves and inverted V-curves. (Nov/Dec 2011)& (Nov/Dec 2012)& (Nov/Dec 2013, Nov 2018 & 2014) (13 M)** BTL 4 **Answer: Page-2.18 - J. Gnanavadivel** ➢ If excitation is varied from very low to very high value, then current Ia decreases. ➢ minimum at unity p.f. and then again increases. ➢ initial lagging current becomes unity and then becomes leading.



(3 M)

- Excitation can be increased by increasing the field current.
- graph of armature current drawn by Ia against field current (If) is plotted,
- then its shape looks like V curve.

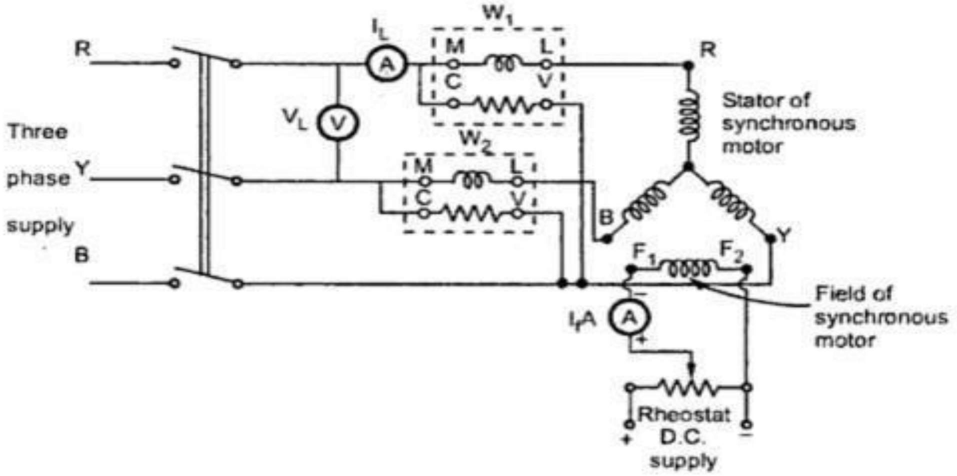


(a) (b)

(3 M)

Experimental Setup to Obtain V-Curves

- Stator is connected top three phase supply through wattmeters and ammeter.
- two wattmeter method is used to measure input power of motor.
- ammeter is reading line current which is same as armature (stator) current.
- Voltmeter is reading line voltage.



- A rheostat in a potential divider arrangement is used in the field circuit.
- By controlling the voltage by rheostat, the field current can be changed.
- Hence motor can be subjected to variable excitation condition to note down the readings. (3 M)

Observation Table :

Sr. No.	V_L (V)	I_L (A)	W_1 (W)	W_2 (W)	I_f excitation (A)
1					
2					
:					

Now IL = Ia, per phase value can be determined, from the stator winding connections.

IL =Iaph for stator connection

IL/√3 = Iaph for delta connection

power factor can be obtained as

$$\cos\phi = \cos\left\{\tan^{-1}\left[\frac{\sqrt{3}\,(W_1 - W_2)}{(W_1 + W_2)}\right]\right\}$$

The result table can be prepared as :

Sr. No.	I_f (A)	I_a (A)	cos ϕ p.f.	Nature of p.f.
1				
2				
:				

The graph can be plotted from this result table.

- Ia Vs If → V-curve
- cosΦ Vs If → Inverted V-curve (4 M)

5.

Explain the various starting methods of a synchronous motor. (Nov/Dec 2012 & 2014) (13 M) BTL 4

Answer: Page – 2.14-2.15 - J. Gnanavadivel

Types: (2 M)

- Using pony motors
- Using damper winding
- As a slip ring induction motor
- Using small d.c. machine coupled to it.

Using pony motors(2 M)

- Rotor is brought to the synchronous speed.
- Some external device like small induction motor.
- Such an external device is called 'pony motor'.
- Rotor attains the synchronous speed, the d.c. excitation to the rotor is switched on.
- Synchronism is established pony motor is decoupled.
- Motor iscontinues to rotate as synchronous motor.

Using Damper Winding(3 M)

- Additional winding consisting of copper bars
- Placed in slots of pole faces.
- Bars are short circuited with help of end rings.
- Such an additional winding on the rotor is called damper winding.
- Winding as short circuited.

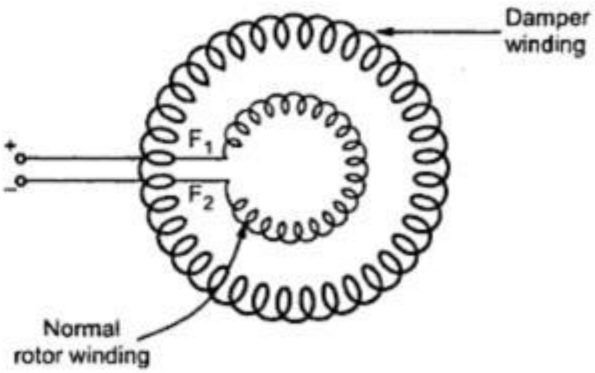


Fig . 1 Starting as a squirrel cage I.M.

- Rotor is excited by a three phase supply
- Motors starts rotating as an induction motor at sub synchronous speed.
- D.C supply is given to field winding.
- At a instant motor gets pulled into synchronism and starts rotating at a synchronous speed.
- As rotor rotates at synchronous speed,
- Relative motion between damper winding and rotating magnetic field is zero.
- Motor is running as synchronous motor, there can not be any induced e.m.f. indamper winding.
- Damper winding is active only at start

As a Slip Ring Induction Motor(3 M)

- Three ends of this winding are brought out through slip rings.
- An external rheostat then can be introduced in series with the rotor circuit.
- When stator is excited, motor starts as a slip ring induction motor
- Due to resistance added in the rotor provides high starting torque.
- Resistance is then gradually cut off, as motor gathers speed.

- Motor attains speed near synchronous. d.c. excitation is provided to rotor,
- then motors gets pulled into synchronism and starts rotating at synchronous speed.
- damper winding is shorted by shorting the slip rings.
- initial resistance added in rotor not only provides high starting torque
- but also limits high inrush of starting current.
- Hence it acts as a motor resistance starter.

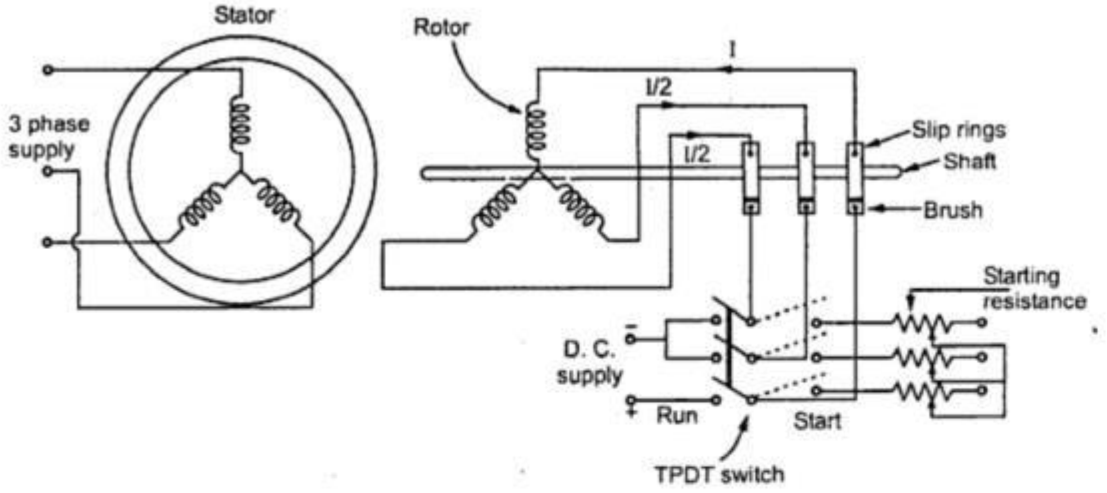


Fig. 2 Starting as a slip ring I.M.

Using Small D.C. Machine(3 M)

- Synchronous motor is provided with a coupled d.c. Machine.
- Machine is used as a d.c. Motor to rotate the synchronous motor at a synchronous speed.
- Excitation to the rotor is provided.
- Once motor starts running as a synchronous motor,same d.c. Machine acts as a d.c exciter.
- Field ofsynchronous motor is then excited by this exciter itself.

6

Explain effect of changing field current excitation at constant load.
(i) Under excitation (ii) Normal excitation (iii) Over excitation (Nov/Dec 2011)& (April/May 2012, May 2018) (13 M) BTL 6

Answer: Refer Page No. 2.18to 2.19 - J. Gnanavadivel

Under Excitation(3M)

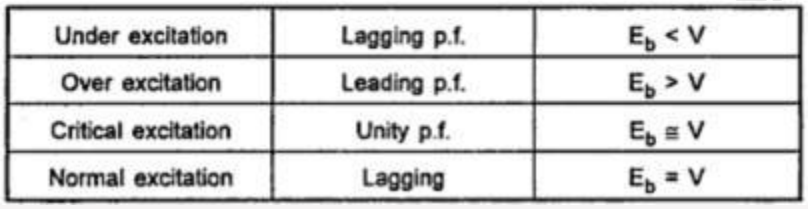
- Magnitude of induced e.m.f. Is less than the applied voltage ($e_b < v$)
- Due to this, e_r increases in magnitude.
- Constant z_s, current drawn by the motor increases.
- But e_r phase shifts in such a way that, phasor $i_a$also shifts (as $e_r \wedge i_a = \theta$) to keep $i_a \cos \varphi$ constant.
- Under excited condition, current drawn by the motor increases.
- The p.f. cos Φ decreases and becomes more and more lagging in nature.

Normal Excitation(3M)

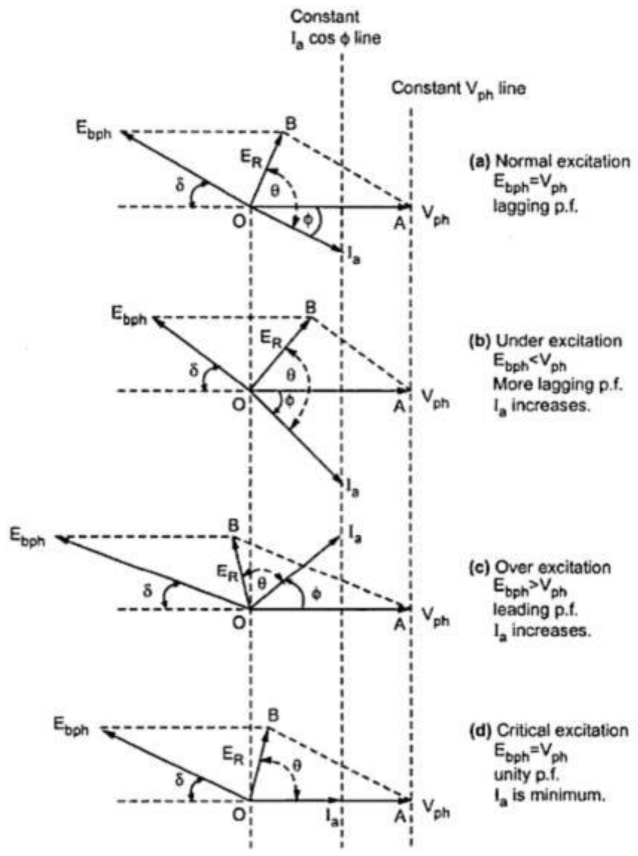
- where excitation is adjusted to get $E_b = V$ i.e. induced e.m.f. is equal to applied voltage.
- Such an excitation is called Normal Excitation of the motor.
- Motor is drawing certain current from the supply and power input to the motor is say P_{in}.
- The power factor of the motor is lagging in nature.

Over Excitation (3M)

- The induced e.m.f. Becomes greater than applied voltage ($e_b < v$), is called over excitation.
- Increased magnitude of e_b, e_r also increases in magnitude.
- But the phase of e_r also changes. Now = $e_r \wedge i_a = \theta$ is constant, hence i_a also changes its phase.
- Φ changes.
- I_a increases to keep $i_a \cos \varphi$ constant
- Phase of e_r changes so that i_a becomes leading with respect to v_{ph}in over excited condition.
- So power factor of the motor becomes leading in nature.
- Overexcited synchronous motor works on leading power factor.
- Power factor decreases as over excitation increases but it becomes more and more leading in nature.

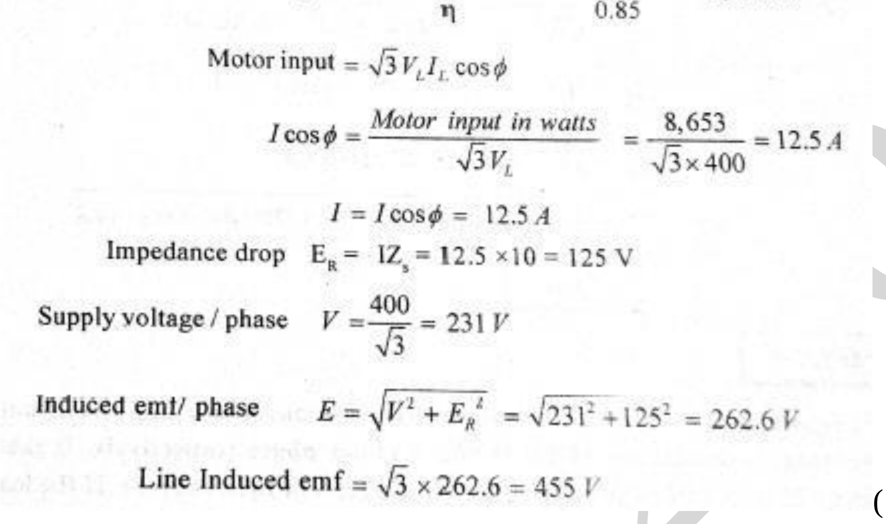
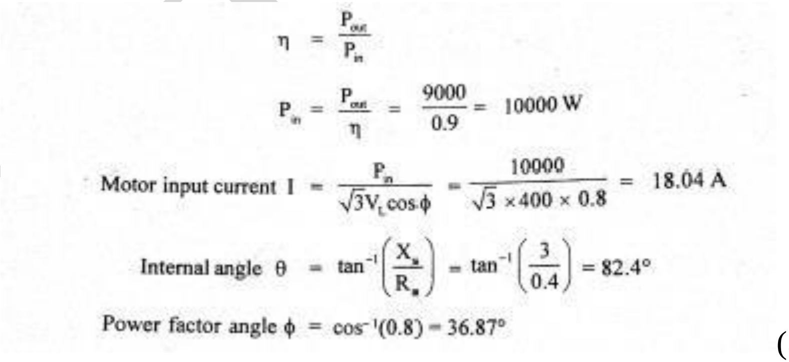


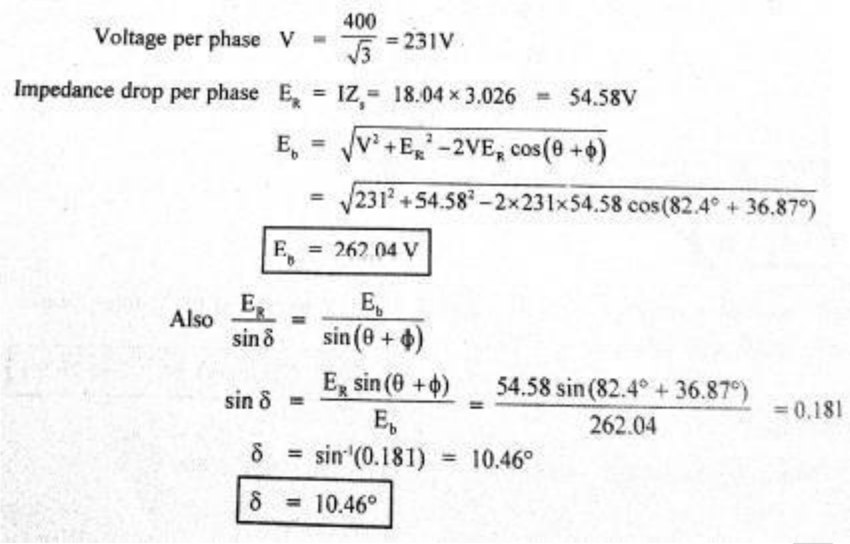
Under excitation	Lagging p.f.	$E_b < V$
Over excitation	Leading p.f.	$E_b > V$
Critical excitation	Unity p.f.	$E_b \cong V$
Normal excitation	Lagging	$E_b = V$



(4 M)

7	**Illustrate the phenomenon of hunting and the use of damper winding with the help of dynamic equations. (May/June 2015) (13 M)** BTL 3 **Answer: Page No. 2.19 to 2.20- J. Gnanavadivel** **Causes of Hunting in Synchronous Motor (6 M)** ➢ Sudden change in load. ➢ Sudden change in field current. ➢ A load containing harmonic torque. ➢ Fault in supply system. **Effects of Hunting in Synchronous Motor (7 M)** ➢ It may lead to loss of synchronism. ➢ Produces mechanical stresses. ➢ Increases machine losses and cause temperature rise. ➢ Cause greater surges in current and power flow.
8.	**Explain how synchronous motor can be used as a synchronous condenser. Draw the phasor diagram. (April/May 2012, Nov 2017) (13 M)** BTL 2 **Answer: Refer Page No. 2.27- J. Gnanavadivel** ➢ When synchronous motor is over excited it takes leading p.f. current. ➢ If synchronous motor is on no load, where load angle δ is very small. ➢ It is over excited ($E_b > V$) then power factor angle increases almost upto 90^o. ➢ Motor runs with zero leading power factor condition. ➢ This characteristic is similar to a normal capacitor. ➢ Which takes leading power factor current. ➢ Over excited synchronous motor operating on no load condition is as synchronous condenser. (6 M) <u>Use of Synchronous Condenser in Power Factor Improvement</u> ➢ Low power factor increases the cost of generation, distribution and transmission. ➢ Low power factor needs to be corrected. ➢ Such power factor correction is possible by connecting synchronous motor. ➢ V_{ph} is the voltage applied and I_{1ph} is the current lagging V_{ph} by angle Φ_1. ➢ This power factor Φ_1 is very low, lagging. ➢ Motor acting as a synchronous condenser. ➢ It draws a leading current of I_{2ph}. ➢ Total current drawn fromsupply is now phasor of I_{ph} and I_{2ph}. ➢ This total current I_T now lags V_{ph} by smaller angle Φ. ➢ Due to which effective power factor gets improved. (7 M)
	Part * C
1.	**A 2.3 kV, 3 phase star connected synchronous motor has Zs = (0.2 + j 2.2) ohm per phase. The motor is operating at 0.5 PF leading with a line current of 200 A. Determine the generated emf per phase. (15 M)** BTL 3 **Answer: Page – 2.29-J. Gnanavadivel** ➢ Input current I =200 A ➢ Supply voltage per phase = 2.3 * 1000 / $\sqrt{3}$ =1328 V (3 M) ➢ Internal angel $\theta = \tan^{-1}$Xs/Ra = 84.8 (3 M)

	➢ PF = $\cos^{-1}(0.5) = 60$ ➢ $Zs = \sqrt{}(Ra^2 + Xs^2) = 2.29$ (3 M) ➢ $E_R = I\ Zs = 200 * 2.209 = 441.8$ V (3 M) ➢ $E_b^2 = V^2 + E_R^2 - 2VE \cos(\varphi + \theta) = 1708$ V (3M)
2.	**A 400 V, 10 HP, 3 phase synchronous moto has negligible armature resistance and synchronous reactance of 10 ohm per phase. Determine the minimum current and the corresponding induced emf for full load condition. Assume an efficiency of 85 %. (15**  Motor input $= \frac{\text{Output power}}{\eta} = \frac{10 \times 735.5}{0.85} = 8{,}653$ W Motor input $= \sqrt{3} V_L I_L \cos\phi$ $I\cos\phi = \frac{\textit{Motor input in watts}}{\sqrt{3} V_L} = \frac{8{,}653}{\sqrt{3} \times 400} = 12.5\ A$ $I = I\cos\phi = 12.5\ A$ Impedance drop $E_R = IZ_s = 12.5 \times 10 = 125$ V Supply voltage / phase $V = \frac{400}{\sqrt{3}} = 231\ V$ Induced emf/ phase $E = \sqrt{V^2 + E_R^2} = \sqrt{231^2 + 125^2} = 262.6\ V$ Line Induced emf $= \sqrt{3} \times 262.6 = 455\ V$ (15 M)
3.	**A 9 kW, 400 V, 3 phase star connected synchronous motor has synchronous impedance per phase of (0.4 + j3) ohm. Find the angle of retard and the voltage to which the motor must be excited to give a full load output at 0.8 leading pf. Assume in efficiency of 90%.**  $\eta = \frac{P_{out}}{P_{in}}$ $P_{in} = \frac{P_{out}}{\eta} = \frac{9000}{0.9} = 10000$ W Motor input current $I = \frac{P_{in}}{\sqrt{3} V_L \cos\phi} = \frac{10000}{\sqrt{3} \times 400 \times 0.8} = 18.04$ A Internal angle $\theta = \tan^{-1}\left(\frac{X_s}{R_s}\right) = \tan^{-1}\left(\frac{3}{0.4}\right) = 82.4°$ Power factor angle $\phi = \cos^{-1}(0.8) = 36.87°$ (5 M)



Voltage per phase $V = \frac{400}{\sqrt{3}} = 231V$

Impedance drop per phase $E_R = IZ_s = 18.04 \times 3.026 = 54.58V$

$$E_b = \sqrt{V^2 + E_R^2 - 2VE_R\cos(\theta + \phi)}$$

$$= \sqrt{231^2 + 54.58^2 - 2\times 231 \times 54.58\cos(82.4° + 36.87°)}$$

$$\boxed{E_b = 262.04\ V}$$

5 M)

Also $\frac{E_R}{\sin\delta} = \frac{E_b}{\sin(\theta+\phi)}$

$$\sin\delta = \frac{E_R\sin(\theta+\phi)}{E_b} = \frac{54.58\sin(82.4° + 36.87°)}{262.04} = 0.181$$

$$\delta = \sin^{-1}(0.181) = 10.46°$$

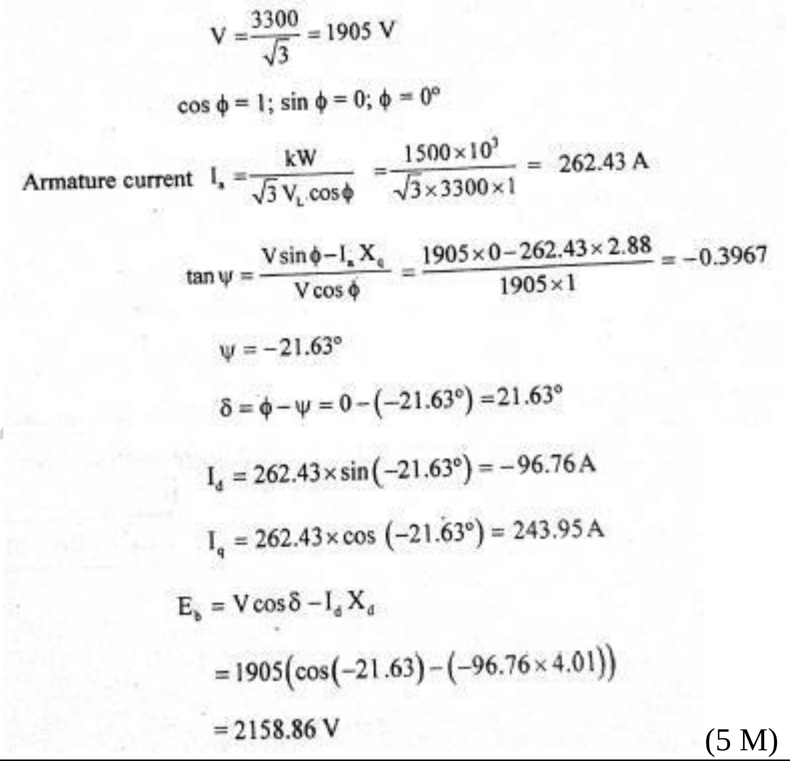
$$\boxed{\delta = 10.46°}$$

(5 M)

4.

A 1500 kW, 3 phase, star connected, 3.3 kV synchronous motor has reactance of Xd = 4.01 ohm and Xq = 2.88 ohm per phase. All losses may be neglected. Calculated the excitation emf when the motor is supplying rated load at unity PF. Also calculate the maximum mechanical power that the motor can supply with excitation held fixed at this value. (15 M) BTL 3

Answer: Page – 2.45 -J. Gnanavadivel.



$$V = \frac{3300}{\sqrt{3}} = 1905\ V$$

$$\cos\phi = 1;\ \sin\phi = 0;\ \phi = 0°$$

Armature current $I_a = \frac{kW}{\sqrt{3}V_L\cos\phi} = \frac{1500\times10^3}{\sqrt{3}\times3300\times1} = 262.43\ A$

$$\tan\psi = \frac{V\sin\phi - I_a X_q}{V\cos\phi} = \frac{1905\times0 - 262.43\times2.88}{1905\times1} = -0.3967$$

$$\psi = -21.63°$$

$$\delta = \phi - \psi = 0 - (-21.63°) = 21.63°$$

$$I_d = 262.43\times\sin(-21.63°) = -96.76A$$

$$I_q = 262.43\times\cos(-21.63°) = 243.95A$$

$$E_b = V\cos\delta - I_d X_d$$

$$= 1905(\cos(-21.63) - (-96.76\times4.01))$$

$$= 2158.86\ V$$

(5 M)

$$P_m = \frac{E_b V}{X_d}\sin\delta + \frac{V^2 (X_d - X_q)}{2X_d X_q}\sin 2\delta$$

$$= \frac{2158.86 \times 1905}{4.01}\sin\delta + \frac{1905^2 (4.01 - 2.88)}{2 \times 4.01 \times 2.88}\sin 2\delta$$

$$= 1025.59 \times 10^3 \sin\delta + 177.54 \times 10^3 \sin 2\delta$$

(5 M)

If developed power has to achieve maximum value, then

$$\frac{dP_m}{d\delta} = 1025.59 \times 10^3 \cos\delta + 2 \times 177.54 \times 10^3 \cos 2\delta = 0$$

$$\therefore\ 1025.59 \times 10^3 \cos\delta + 355.08 \times 10^3 (2\cos^2\delta - 1) = 0$$

or $$710.16 \times 10^3 \cos^2\delta + 1025.59 \times 10^3 \cos\delta - 355.08 \times 10^3 = 0$$

$$\cos\delta = \frac{-1025.59 \times 10^3 \pm \sqrt{(1025.59 \times 10^3)^2 + 4 \times 710.16 \times 10^3 \times 355.08 \times 10^3}}{2 \times 710.16 \times 10^3}$$

$$= \frac{-1025.59 \times 10^3 \pm 1435.44 \times 10^3}{1420.32 \times 10^3} = 0.288$$

$$\delta = 73.22^\circ$$

Maximum $P_m = 1025.59 \times 10^3 \sin(73.22^\circ) + 177.54 \times 10^3 \sin(2 \times 73.22^\circ)$

$$P_m = 1080\ \text{kW}$$

Maximum Power developed for three phases $= 3 \times P_m$

$$= 3 \times 1080 = 3240\ \text{kW}$$

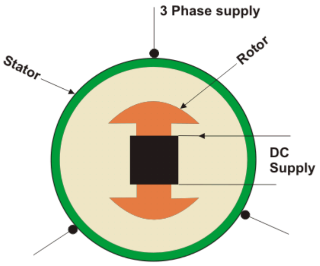
(5 M)

5.

Explain the working principle of synchronous motor. (Nov 2017)

Answer: Page – 2.1 -J. Gnanavadivel

Construction of Synchronous Motor (7 M)



Synchronous Motor

Main Features of Synchronous Motors

- **Synchronous motors** are inherently not self starting.
- They require some external means to bring their speed close to synchronous speed to before they are synchronized.
- The speed of operation of is in synchronism with the supply frequency.
- This motor has the unique characteristics of operating under any electrical power factor.

- This makes it being used in electrical power factor improvement.

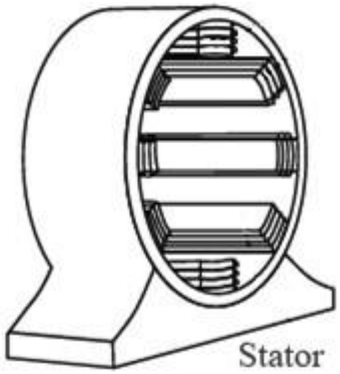
Principle of Operation Synchronous Motor (8 M)

- Synchronous motor is a doubly excited machine, i.e., two electrical inputs are provided to it.
- Its stator winding which consists of a We provide three-phase supply to three-phase stator winding, and DC to the rotor winding.
- The 3 phase stator winding carrying 3 phase currents produces 3 phase rotating magnetic flux.
- The rotor carrying DC supply also produces a constant flux.
- Considering the 50 Hz power frequency, from the above relation we can see that the 3 phase rotating flux rotates about 3000 revolutions in 1 min or 50 revolutions in 1 sec.
- At a particular instant rotor and stator poles might be of the same polarity (N-N or S-S) causing a repulsive force on the rotor and the very next instant it will be N-S causing attractive force.
- But due to the inertia of the rotor, it is unable to rotate in any direction due to that attractive or repulsive force, and the rotor remains in standstill condition.
- Hence a synchronous motor is not self-starting.
- Here we use some mechanical means which initially rotates the rotor in the same direction as the magnetic field to speed very close to synchronous speed.
- On achieving synchronous speed, magnetic locking occurs, and the synchronous motor continues to rotate even after removal of external mechanical means.

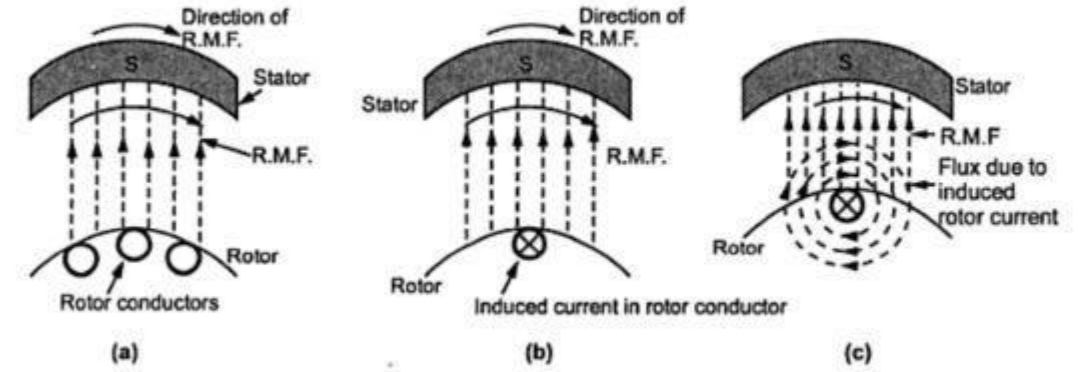
	UNIT III - THREE PHASE INDUCTION MOTOR
	Constructional details – Types of rotors –- Principle of operation – Slip –cogging and crawling- Equivalent circuit – Torque-Slip characteristics - Condition for maximum torque – Losses and efficiency – Load test - No load and blocked rotor tests - Circle diagram – Separation of losses – Double cage induction motors –Induction generators – Synchronous induction motor.
	PART * A
Q.No.	**Questions**
1	**State the principle of 3 phase IM.**BTL 1 While starting, rotor conductors are stationary, and they cut the revolving magnetic field and so an emf is induced in them by electromagnetic induction. This induced emf produces a current if the circuit is closed. This current opposes the cause by Lenz's law and hence the rotor starts revolving in the same direction as that of the magnetic field.
2	**Why an induction motor is called as 'rotating transformer'?**BTL 2 The rotor receives electric power in exactly the same way as the secondary of a two-winding transformer receiving its power from the primary. That is why an induction motor can be called as a rotating transformer i.e. one in which primary winding is stationary but the secondary is tree to rotate.
3	**Why an induction motor will never run at its synchronous speed?**BTL 2 If the rotor runs at synchronous speed, then there would be no relative speed between the two; hence no rotor EMF, no rotor current and so no rotor torque to maintain rotation. That is why the rotor runs at a speed, which is always less than syn. speed.
4	**State the advantages of skewing. (Nov/Dec 2011)**BTL 2 ➢ It reduces humming and hence quite running of motor is achieved. ➢ It reduces magnetic locking of the stator and rotor.
5	**State the condition for maximum torque.** BTL 1 $R_2=X_2$
6	**What are the effects of increasing rotor resistance on starting current and starting torque?** BTL 1 ➢ The additional external resistance reduces the rotor current and hence the current drawn from the supply. ➢ It improves the starting torque developed by improving the power factor in high proportion to the decrease in rotor current.
7	**What is slip of an induction motor? (Nov/Dec 2011) & (Nov/Dec 2012) & (Nov/Dec 2013 & 2014)** BTL 1 The slip speed is defined as the ratio of relative speed to synchronous speed is expressed as % slip S=(Ns-N)/Ns*100

8	**What are the advantages of slip-ring IM over cage IM?** BTL 1 ➢ Rotor circuit is accessible for external connection. ➢ By adding external resistance to the rotor circuit, the starting current is reduced with the added advantage of improving starting torque. ➢ Additional speed control methods can be employed with the accessibility in the rotor circuit.
9	**Name the tests to be conducted for predetermining the performance of 3-phase induction machine.**BTL 1 ➢ No load test. ➢ Blocked rotor test.
10	**What is the information obtained from no-load test in a 3-phase I M?** BTL 1 ➢ No –load input current per phase, Io. ➢ No load power factor and hence no-load phase angle. ➢ Iron and mechanical losses together. ➢ Elements of equivalent circuit shunt branch.
11	**What is the information obtained from blocked rotor test in a 3-phase I M?** BTL 1 ➢ Blocked rotor input current per phase at normal voltage. ➢ Blocked rotor power factor and hence phase angle. ➢ Total resistance and leakage reactance per phase of the motor as referred to the stator.
12	**What is circle diagram of an IM?** BTL 2 When an I M operates on constant voltage and constant frequency source, the loci of stator current phasor is found to fall on a circle. This circle diagram is used to predict the performance of the machine at different loading conditions as well as mode of operation.
13	**What are the advantages and disadvantages of circle diagram method of predetermining the performance of 3 –phase IM?** BTL 2 The prediction can be carried out when any of the following information is available. The input line current., the input power factor, the active power input, the reactive power input, The apparent power input, The output power, The slip of operation, The torque developed, The equivalent rotor current per phase, Maximum output power, Maximum torque developed. The only disadvantage is, being a geometrical solution; errors made during measurements will affect the accuracy of the result.
14	**What are the advantages and disadvantages of direct load test for 3 – phase IM?** BTL 2 Advantages ➢ Direct measurement of input and output parameters yield accurate results. ➢ Aside from the usual performance other performances like mechanical vibration, noise etc can be studied. ➢ By operating the motor at full load for a continuous period, the final steady temperature can be measured. Disadvantages ➢ Testing involves large amount of power and the input energy and the entire energy delivered is wasted.
15	**What is an induction generator? (April/May 2012)** BTL 1 An induction generator does not differ in its construction from an induction motor. Whether the induction, machine acts as generator or motor depends solely upon its slip. Below synchronous speed it can operate only as motor, above synchronous speed it operates as

	generator and is now called as induction generator.
16	**What do you mean by slip speed?** BTL 1 The difference between the synchronous speed and the rotor speed N is called as slip speed. The rotor speed will be always less than synchronous speed.
17	**Why an induction motor at no-load operates at very low power factor?** BTL 2 The current drawn by an induction motor running at no load is largely a magnetizing current. So, no-load current lags the applied voltage by a large angle. Therefore, the power factor of a lightly loaded induction motor is very low.
18	**What is cogging of induction motor?** BTL 1 When the number of teeth in stator and rotor are equal, the stator and rotor teeth have a tendency to align themselves exactly to minimum reluctance position. In such case the rotor may refuse to accelerate. This phenomenon is called "magnetic locking, or cogging.
19	**Write the advantages of double squirrel cage induction motor. (Nov/Dec 2012 & 2014)** BTL 1 ➢ Improves the starting torque ➢ Low I^2R loss under running conditions and hence high efficiency.
20	**How the direction of rotation of a three-phase induction motor can be reversed? (April/May 2012)** BTL 2 The direction of rotation of three phase induction motor can be changed by interchanging any two terminal of input supply (R&Y, R&B, etc.,).The direction of the synchronously rotating field reverses and hence the direction of rotor reverses.
21	**How do change in supply voltage and frequency affect the performance of a 3-phase induction motor? (May/June 2014)**BTL 2 (i) This large change in voltage will result in a large change in the flux density thereby seriously disturbing the magnetic conditions of the motor. (ii) If the supply frequency is changed, the value of air gap flux also gets affected. This may result in to saturation leads to the sharp rise in the no load current of the motor.
22	**State the condition formaximum torque under running condition. (Nov/Dec 2015)** BTL 1 $R_2=SX_2$; R_2 = rotor resistance; X_2 = Rotor reactance; s = slip
23	**What are the losses occurring in an IM and on what factors do they depend?** BTL 1 Magnetic losses $W_{i,}$ Electrical losses $W_{cu}$and Mechanical losses W_m. For IM operating in normal condition (with constant voltage and frequency) magnetic and mechanical losses remain constant whereas electrical losses vary in square proportion to the current.
24	**What is meant by synchronous watts?** BTL 1 The torque developed in an induction motor is proportional to rotor input. By defining a new unit of torque (instead of the force at radius unit) we can say that the rotor torque equals rotor input. The new unit is synchronous watts. Synchronous wattage of an induction motor equals the power transferred across the air-gap to the rotor.

25	**How much torque is developed in an induction motor at synchronous speed? (May/June 2015)** BTL 1 The torque developed in an induction motor at synchronous speed is zero. If the rotor runs at synchronous speed, then there would be no relative speed between the two; hence no rotor EMF, no rotor current and so no rotor torque to maintain rotation. That is why the rotor runs at a speed, which is always less than synchronous speed.
26	**State a method by which starting torque of the induction motor can be increased. (May/June 2015)** BTL 1 By adding external resistance to the rotor circuit to improve the starting torque of induction motor.
	PART * B
1	**Explain the construction and working of three phase induction motor. (Nov/Dec 2011), (April/May 2012) & (Nov/Dec 2012) &(Nov/Dec 2013, Nov 2017, May 2018 & 2014) (13 M)** BTL 1 **Answer: Page - 3.1 to 3.3 & 3.9 to 3.10.- J. Gnanavadivel**   Rotor (4 M) Stator: (3 M) ➢ It is made up with number of stamping. ➢ Stator is wound with a 3 phase winding which is fed from a 3 phase supply. ➢ It is wound for a defined number of poles. ➢ Number of poles is determined from the required speed. ➢ Stator windings are supplied with 3 phase ac supply. ➢ They produce alternating flux which revolves with synchronous speed. ➢ The synchronous speed is inversely proportional to number of poles ($N_s = 120f / P$). ➢ This rotating magnetic flux induces current in rotor windings according to Faraday's law of mutual induction. Rotor: (3 M) ➢ It consists of cylindrical laminated core with parallel slots that can carry conductors. ➢ Conductors are heavy copper or aluminum bars which fits in each slot. ➢ They are short circuited by the end rings. ➢ The slots are not exactly made parallel to the axis of the shaft. ➢ But slots are slotted a little skewed because this arrangement reduces magnetic humming noise & can avoid stalling of motor.

Working Principle (3 M)



- Rate of change of magnetic flux linkage through the circuit.
- As the rotor winding in an induction motor are either closed through an external resistance or directly shorted by end ring.
- Cut the stator rotating magnetic field.
- An emf is induced in the rotor copper bar.
- Due to this emf a current flows through the rotor conductor.
- Here the relative speed between the rotating flux and static rotor conductor is the cause of current generation
- Hence as per Lenz's law the rotor will rotate in the same direction.
- Reduce the causethe rotor speed should not reach the synchronous speed produced by the stator.
- If the speeds equals, there would be no such relative speed, so no emf induced in the rotor.
- No current would be flowing, and therefore no torque would be generated.
- Rotor cannot reach the synchronous speed.
- The difference between the stator and rotor speeds is called the slip.

2

Explain torque slip characteristics of induction motor. (Nov/Dec 2014, Nov 2018) (13 M) BTL 2

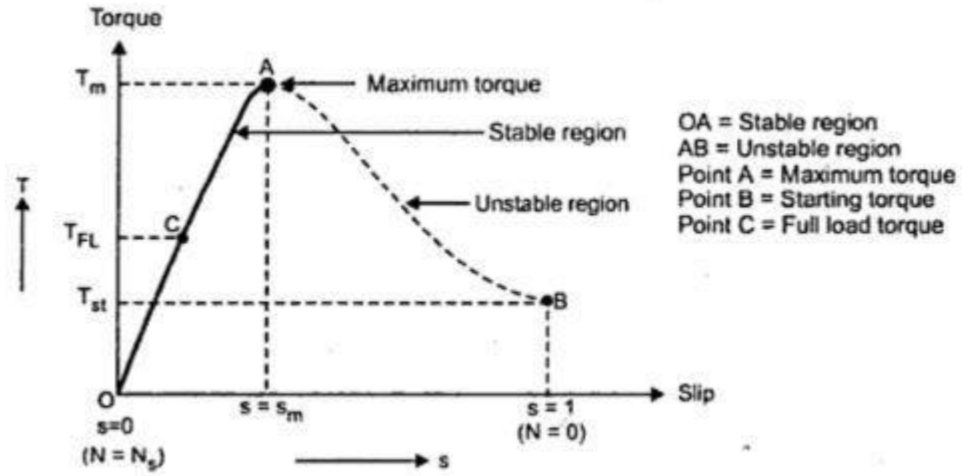
Answer: Page - 3.53 to 3.54 - J. Gnanavadivel

<u>Torque-Slip Characteristics</u>:

- The motor torque under running conditions is given by;
- The following points may be noted carefully:
- At s = 0, T = 0 so that torque-slip curve starts from the origin.
- At normal speed, slip is small so that s X_2 is negligible as compared to R_2.

  $T \alpha s/R_2$

  $T \alpha$ sas R_2 is constant.
- Hence torque slip curve is a straight line from zero slip to a slip that corresponds to full-load.
- As slip increases beyond full-load slip, the torque increases andmaximum at s = R_2/X_2.
- This maximum torque in an induction motor is called pull-out torque.
- Its value is at least twice the full-load value when the motor is operated at rated voltage and frequency.



(4 M)

- Maximum torque, the term $s^2 X_2^2$ increases very rapidly so that R_2^2 may be neglected as compared to $s^2 X_2^2$
- $T \alpha s / s^2 X_2^2$
- α 1/ s ... as X_2 is constant
- Thus the torque is now inversely proportional to slip.
- Hence torque-slip curve is a rectangular hyperbola. (9 M)

3

Derive the torque equation of a three-phase induction motor. (Nov/Dec 2013) &(Nov/Dec 2015, Nov 2017) (8 M) BTL 1

Answer: Page - 3.32 to 3.34 - J. Gnanavadivel

- The torque produced by three phase induction motor depends upon the following three factors:
- Magnitude of rotor current,
- EMF in the rotor part of induction motor,
- Power factorof rotor of the three-phase induction motor.
- Equation of torque as- $T \propto \phi I_2 \cos\theta_2$(4 M)
- Where, T is the torque produced by the induction motor.
- φ is flux responsible for producing induced emf,
- I_2 is rotor current,
- $\cos\theta_2$ is the power factor of rotor circuit.
  - The flux φ produced by the stator is proportional to stator emf E_1. i.e $\varphi \propto E_1$

$$K = \frac{E_2}{E_1}$$

$$or,\ K = \frac{E_2}{\phi}$$

$$or,\ E_2 = \phi$$

- Rotor currentI_2 is defined as the ratio of rotor induced emf under running

$$i.e\ I_2 = \frac{sE_2}{Z_2}$$

- sE_2 to total impedance, Z_2 of rotor side, (4 M)
- $Z_2 = \sqrt{R_2^2 + (sX_2)^2}$ Putting this value in above equation we get,

$$I_2 = \frac{sE_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

- s = slip of induction motor

$$\cos\theta_2 = \frac{R_2}{Z_2} = \frac{R_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

-

$$T \propto E_2 \frac{sE_2}{\sqrt{R_2^2 + (sX_2)^2}} \times \frac{R_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

$$T \propto sE_2^2 \frac{R_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

- Removing proportionality constant we get,

$$T = KsE_2^2 \frac{R_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

$$This\ comstant\ K = \frac{3}{2\pi n_s}$$

- Where, n_s is synchronous speed in r. p. s, $n_s = N_s / 60$. So, finally the equation of torque becomes,

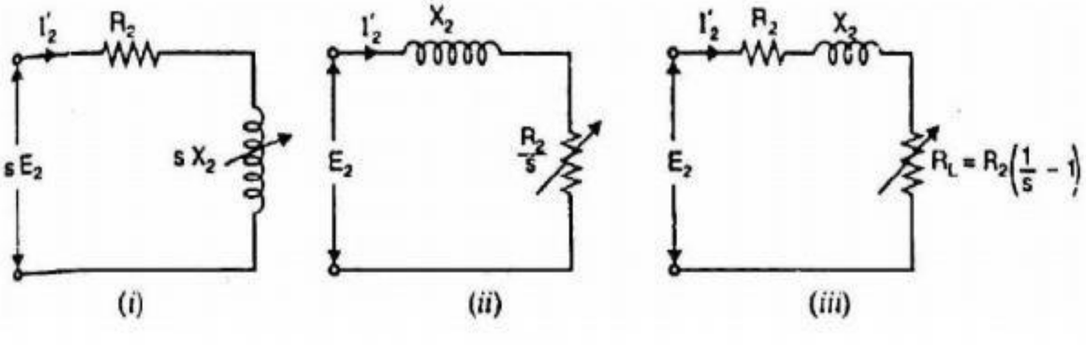
$$T = sE_2^2 \times \frac{R_2}{R_2^2 + (sX_2)^2} \times \frac{3}{2\pi n_s} N - m$$

- Derivation of K in torque equation. (5 M)

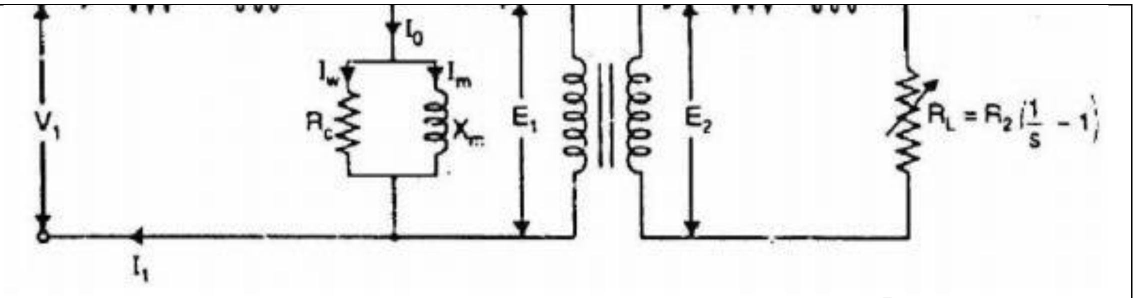
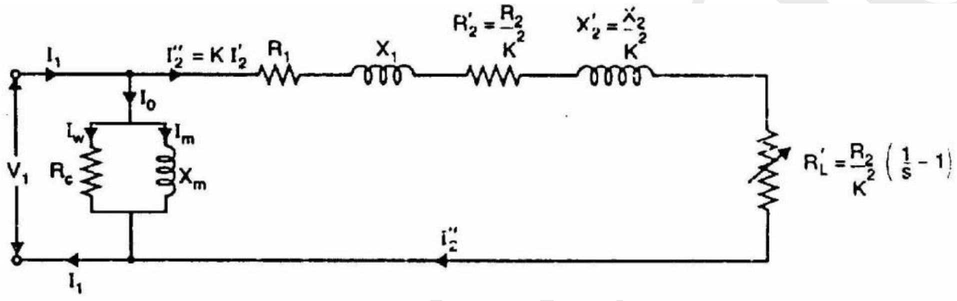
4

Develop an equivalent circuit for three phase induction motor. Nov/Dec 2011)&(Nov/Dec 2012, Nov/Dec 2015, May 2018) (13 M) BTL 6

Answer: Page - 3.84 to 3.89 - J. Gnanavadivel



- (4 M)

	➢  (4 M) ➢  (5 M)
5.	**A 6 pole, 50Hz, 3 phase, induction motor running on full load develops a useful torque of 160Nm. When the rotor emf makes 120 complete cycle per minute. Calculate the shaft power input. If the mechanical torque lost in friction and that for core loss is 10 Nm, compute.** **The copper loss in the rotor windings.** **The input of motor.** **The efficiency. The total stator loss is given to be 800W. (Nov/Dec 2011)&(Nov/Dec 2015) (13 M)** BTL 5 **Answer: Page - 3.83 - J. Gnanavadivel** ➢ Frequency of rotor emf = fr = 120/60 = 2 Hz ➢ Slip = s = fr/f = 2/50 = 0.04 ➢ Ns = 120f/P = 1000 rpm ➢ Motor Speed N= Ns(1 – s) = 1000(1 – 0.04) = 960 rpm (4 M) ➢ Tsh = Pout * 60 / (2 π N) = 16085 W ➢ Pm = Tg * 2πN/60 = 17291 N-m (4 M) ➢ Pcu = 720.45 W ➢ P2 = 18011.4 W ➢ Pin = 18211.4 W ➢ Efficiency = 88.32 % (5 M)
6	**Describe the no load and blocked rotor tests in a three-phase induction motor. (13 M)** BTL 4 **Answer: Page - 3.102 - J. Gnanavadivel** Calculation of No Load Test of Induction Motor: (6 M) ➢ Let the total input power supplied to induction motor be W_0 watts.

- $W_0 = \sqrt{3} V_1 I_0 Cos\Phi_0$
- Where, V_1 = line voltage
- I_0 = No load input current
- Rotational loss = $W_0 - S_1$
- Where, S_1 = stator winding loss = $N_{ph} I^2 R_1$
- N_{ph} = Number phase
- The various losses like windage loss, core loss, and rotational loss are fixed losses
- Stator winding loss = $3I_o^2R_1$
- Where, I_0 = No load input current
- R_1 = Resistance of the motor
- Core loss = $3G_oV^2$

Calculations of Blocked Rotor Test of Induction Motor: (7 M)

- $W_{cu} = W_s - W_c$
- Where, W_c = core loss
- $W_{cu} = 3I^2R_{01}$
- Where, R_{01} = Motor winding of stator and rotor as per phase referred to stator.

$$R_{01} = \frac{W_{cu}}{3I_s^2} \ldots\ldots\ldots\ldots (1)$$

- Now let us consider I_s = short circuit current
- V_s = short circuit voltage
- Z_0 = short circuit impedance as referred to stator

$$Z_{01} = \frac{short\ circuit\ voltage\ per\ phase}{short\ circuit\ current} = \frac{V_s}{I_s} \ldots\ldots\ldots\ldots (2)$$

- Therefore, X_{01} = Motor leakage reactanceper phase referred to stator

$$X_{01} = \sqrt{Z_{01}^2 - R_{01}^2}$$

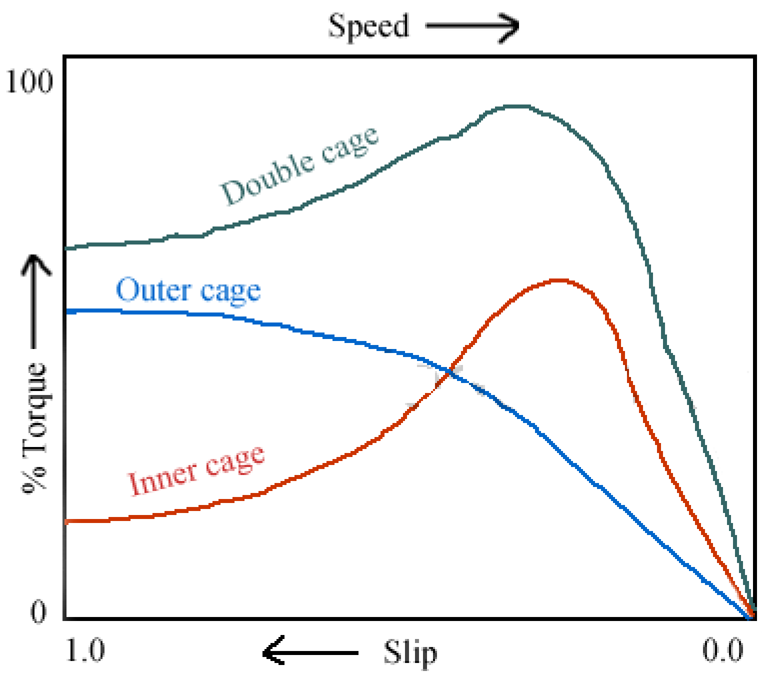
- Stator reactance X_1 and rotor reactance per phase referred to stator X_2 are normally

$$X_1 = X_2 = \frac{X_{01}}{2}$$

assumed equal. Th

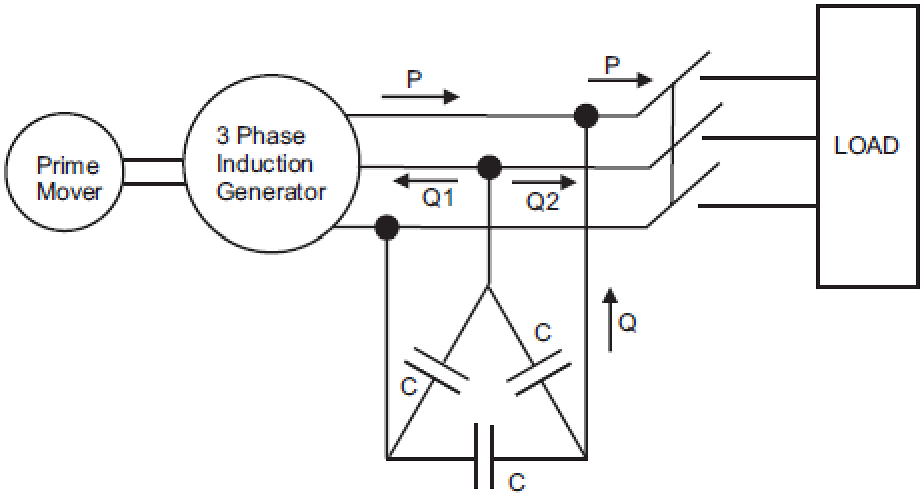
- stator resistance per phase R_1
- rotor resistance per phase referred to stator R_2
- $R_2 = R_{01} - R_1$

7.	**Write brief notes on (i) Double Cage rotor (ii) Induction Generator (13 M) (May 2006, Nov 2017)** BTL 2 **Answer: Page –3.116 & 3.119 - J. Gnanavadivel**



(3 M)

- ➢ At starting of the motor, frequency of induced emf is high because of large slip.
- ➢ Reactance of inner cage will be very high, increasing its total impedance.
- ➢ Hence at starting most of the current flows through outer cage despite its large resistance
- ➢ This will not affect the outer cage because of its low reactance.
- ➢ And because of the large resistance of outer cage starting torque will be large.
- ➢ As speed of the motor increases, slip decreases, and hence the rotor frequency decreases.
- ➢ Reactance of inner cage will be low, and most of the current will flow through the inner cage which is having low resistance.
- ➢ Hence giving a good efficiency.
- ➢ When the double cage motor is running at normal speed,
- ➢ Frequency of the rotor emf is so low that the reactance of both cages is negligible.
- ➢ The two cages being connected in parallel, the combined resistance is lower. (4 M)
- ➢ **Induction Generator:**



(3 M)

- This type of generator is also known as self-excited generator.
- Capacitor bank which is connected across its stator terminals
- The function of the capacitor bank is to provide the lagging reactive power to the induction generator as well as load.
- Total reactive power provided by the capacitor bank is equals to sum of reactive power and load.
- There is generation of small terminal voltage oa across the stator terminal.
- Due the residual magnetism when the rotor of the induction machine runs at the required speed.
- Due to this voltageoa the capacitor current ob is produced.
- The currentbc sends current od which generates the voltage de. (3 M)

PART * C

1. **A 746 KW, 3-phase,50 Hz, 16-pole induction motor has a rotor impedance of (0.02+j0.15) Ω at standstill. Full load torque is obtained at 360 rpm. Calculate (i)The ratio of maximum to full-load torque (ii) The speed at maximum torque and (iii) The rotor resistance to be added to get maximum starting torque. (15 M) (May/June 2014)** BTL 5

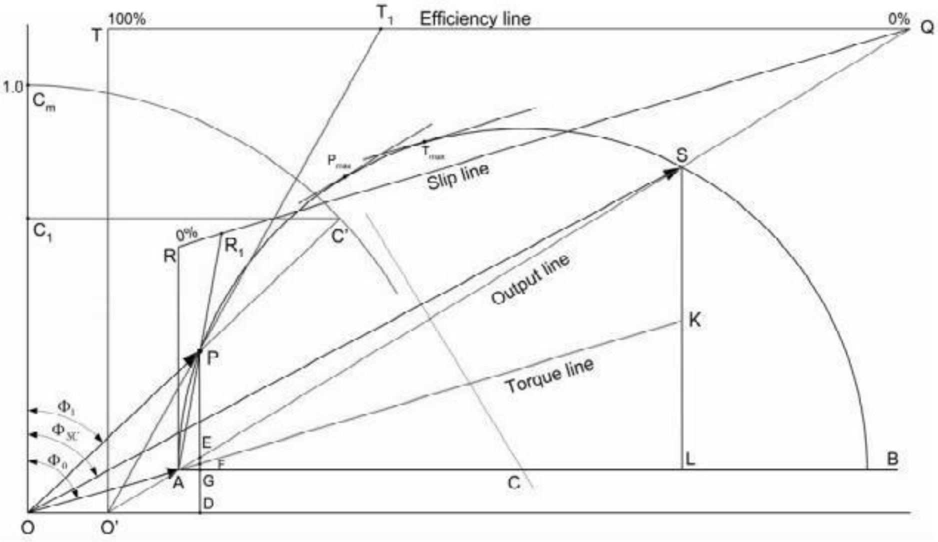
Answer: Page - 3.48 - J. Gnanavadivel

- Ns = 120f/P = 375 rpm
- Sf = (Ns – N)/Ns = 0.04 (4 M)
- a = R2/X2 = 0.133
- $Tf/Tm = 2as_f / (a^2 + s_f^2) = 0.55$
- Tm/Tf = 1.818 (4 M)
- $Sm = R_2/X_2 = 0.02/0.15 = 0.133$
- N = Ns(1-s) = 325 (4 M)
- For maximum torque $R_2 = X_2$. Total resistance = 0.156 ohm
- External resistance required /phase = 0.13 ohm (3 M)

2.

A 29.84 KW,415V,50Hz,3 phase delta connected induction motor gave the following test results:
No load test: 415V, 21A, 1250 W
Blocked rotor test: 100V,45A,2730 W
Stator and rotor ohmic losses at standstill are assumed equal. Draw the induction motor circle diagram and calculate (i)Line current (ii)Power Factor. (15 M)(May/June 2014, Nov 2018)BTL 5

Answer: Page - 3.110 - J. Gnanavadivel



(8 M)

- Cos φ0 = 0.0918
- φ0 = 84.44
- φb = 69.3
- power scale 1 cm = 7120 W
- full load output = 29840 W (4 M)
- Current scale = 4.19 cm
- Phase current = OP = 6 cm = 60 A
- Line current = 104 A
- Power factor = 0.819 (3 M)

3.

The power input to a 3phase induction motor is 60 kW. The stator losses are 1 kW. Find the mechanical power developed and rotor copper loss per phase if the motor is running with a slip or 3 %. (7 M) BTL 5

Answer: Page – 3.73 - J. Gnanavadivel

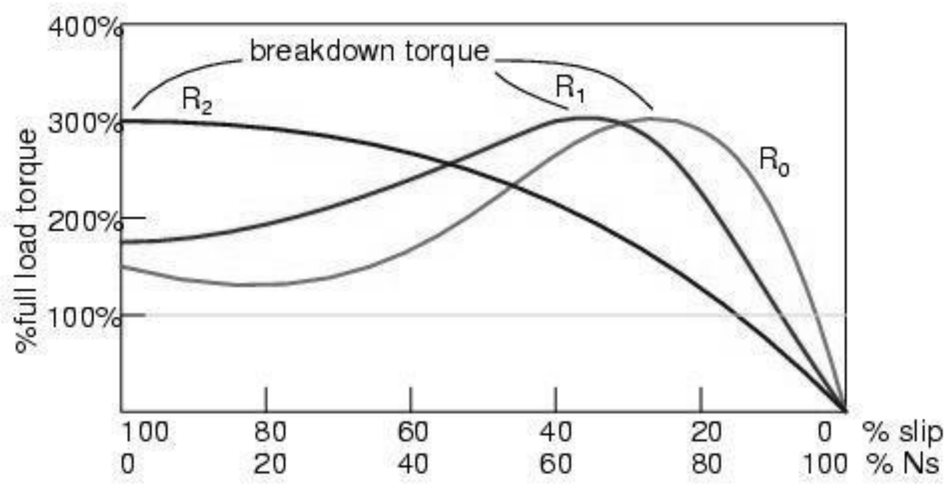
- Input to rotor P2 = 59 kW
- Rotor copper loss Pcu = 1.77 kW(4 M)
- Rotor copper loss per phase = 0.59 kW
- Mechanical power developed = 57.23 kW.(3 M)

4.	**A 3 phase 500 V, 50 Hz induction motor with 6 pole gives an output of 20 kW at 950 rpm with a power factor of 0.8. The mechanical losses are equal to 1 kW. Calculate for this load slip, rotor copper loss, input, if the stator losses are 1.5 kW. (8 M)** BTL 5 A**nswer: Page – 3.73 - J. Gnanavadivel** ➢ Slip = 0.05 ➢ Pm = Pout +Pml = 20 + 1 = 21 kW ➢ P2 = pm/(1-s) = 21.05 kW(4 M) ➢ Pcu = s*P2 = 1.05 kW ➢ Pin = P2 + Stator losses = P2 + Psl = 22.55 kW(4 M)

	UNIT IV - STARTING AND SPEED CONTROL OF THREE PHASE INDUCTION MOTOR
	Need for starting – Types of starters – DOL, Rotor resistance, Autotransformer and Star-delta starters – Speed control – Voltage control, Frequency control and pole changing – Cascaded connection-V/f control – Slip power recovery scheme-Braking of three phase induction motor: Plugging, dynamic braking and regenerative braking.
Q.No	**PART * A**
1	**What is the need of starter for induction motor? (April/May 2012)**BTL 1 The plain induction motor is similar in action to poly phase transformer with a short-circuited rotating secondary. Therefore, if normal supply voltage is applied to the stationary motor, then, as in case of a transformer, a very large initial current about 5-7 times full load current is drawn taken by the stator.
2	**What is the magnitude of starting current & torque for induction motor?(Nov/Dec 2014)**BTL 1 Induction motors, when direct-switched take five to seven times the full load current and develop only 1.5 to 2.5 times their full- load torque.
3	**Name the different types of starters used for induction motor. (Nov/Dec 2013)**BTL 1 ➢ Primary resistor ➢ Autotransformer starter ➢ Star-delta starter ➢ Rotor rheostat
4	**Brief the over –load protection of autotransformer starter.**BTL 1 When the load on the motor is more than the rated value the supply to motor will be cut off.
5	**How the starting current is reduced using rotor resistance starter? (Nov/Dec 2011)**BTL 2 The controlling resistance is in the form of a rheostat, connected in star. The resistance being gradually cut-out of the rotor circuit as the motor gathers speed. Increasing the rotor resistance, not only in the rotor current reduced at starting, but at the same time starting torque is also increased due to improvement in power factor.
6	**Mention the methods of speed control on stator side of induction motor. (Nov/Dec 2011)& (Nov/Dec 2012)**BTL 1 ➢ By changing the applied voltage ➢ By changing the applied frequency ➢ By changing the number of stator poles.
7	**Mention the methods of speed control from rotor side of induction motor. (Nov/Dec 2011)& (Nov/Dec 2012).**BTL 1 ➢ Rotor rheostat control. ➢ By operating two motors in concatenation or cascade. ➢ By injecting an e.m.f in the rotor circuit.

8	**Why speed control is simpler by changing the applied voltage?** BTL 2 ➢ A large change in voltage is required for a relatively small change in speed. ➢ This large change in voltage will result in a large change in the flux density thereby seriously disturbing the magnetic conditions of the motor.
9	**What are the applications of speed control of induction motor by pole changing method?**BTL 1 ➢ Elevator motors ➢ Traction motors ➢ Small motors driving machine tools.
10	**How the speed control is achieved by changing the number of poles?** BTL 2 Synchronous speed of induction motor could also be changed by changing the number of stator poles. This change of number of poles is achieved by having two or more entirely independent stator windings in the same slots.
11	**What are the limitations of rotor rheostat speed control of induction motor?**BTL 2 ➢ With increase in rotor resistance, I^2R losses also increase which decrease the operating efficiency of the motor. In fact, the loss is directly proportional to the reduction in the speed. ➢ Double dependence of speed, not only on R_2 but also on load as well.
12	**What are the advantages of slip power scheme?**BTL 1 Advantages ➢ Easier power control. ➢ Higher efficiency. Disadvantage ➢ Reactive power consumption. ➢ Low power factor at reduced speed.
13	**Mention types of slip power recovery schemes.**BTL 1 ➢ Scherbius system. ➢ Kramer drive.
14	**What is effect of increasing rotor resistance in starting current and torque? (Nov/Dec 2012)** BTL 2 Starting current can be reduced and starting torque can be increased by increasing the rotor resistance of an induction motor.
15	**Why most of the three phase induction motors constructed with delta are connected stator winding? (April/May 2012)** BTL 2 Squirrel cage induction motor started with star to delta starter, therefore stators winding in delta connection.
16	**What is meant by slip power recovery scheme? (Nov/Dec 2013)** BTL 2 Some amount of power is wasted in the rotor circuit,wasted power is recovered by using converter.
17	**What is meant by plugging? (May/June 2014)** BTL 2 The reversal of direction of rotation of motor is the main principle in plugging of motor. In case of an induction motor, it can be quickly stopped by interchanging any two stator leads. Due to this, the direction of rotating magnetic field gets reversed and this produces a torque in reverse direction and the motor tries to rotate in opposite direction.

<table>
<tr><td>18</td><td>While controlling the speed of an induction motor, how is super-synchronous speed achieved?(Nov/Dec 2014) BTL 2
In the super synchronous speed operation, the power flow is from supply to the transformer and the slip power is injected in to the rotor circuit.</td></tr>
<tr><td>19</td><td>What is the relationship between staring torque and full load torque of DOL Starter?BTL 2
$T_{st}/ T_f= (I_{sc}/I_f)^2. s_f$</td></tr>
<tr><td>20</td><td>What are the advantages of autotransformer starter?BTL 1
➢ reduced voltage is applied across the motor terminal.
➢ There is a provision for no-voltage and over-load protection.</td></tr>
<tr><td>21</td><td>How the tandem operations of induction motor start?BTL 2
When the cascaded set is started, the voltage at frequency f is applied to the stator winding of main motor. An induced emf of the same frequency is produced in main motor (rotor) which is supplied to the auxiliary motor. Both the motors develop a forward torque. As the shaft speed rises, the rotor frequency of main motor falls and so does the synchronous speed of auxiliary motor. The set settles down to a stable sped when the shaft speed become equal to the speed of rotating field of Auxiliary motor.</td></tr>
<tr><td>22</td><td>What is the effect of change in supply voltage on starting torque of induction motor? (Nov/Dec 2015) BTL 1
Starting torque of an induction motor will becomes double when slight change in the supply voltage.</td></tr>
<tr><td>23</td><td>State animportant distinguishing factor of induction generator andalternator. (May/June 2015)BTL 1
<table>
<tr><th>Induction Generator</th><th>Alternator</th></tr>
<tr><td>Induction machine is single excited.</td><td>Alternator is doubly excited machine.</td></tr>
<tr><td>Induction Generator, the field is induced in the rotor.</td><td>Alternators use a separate excitation field.</td></tr>
<tr><td>Induction Generator the rotor speed need only be above rated synchronous speed.</td><td>The alternator output frequency is intimately connected to rotor rpm and poles.</td></tr>
</table></td></tr>
<tr><td>24</td><td>Draw the torque speed characteristics of aninduction motor. (May/June 2015)BTL 1</td></tr>
</table>



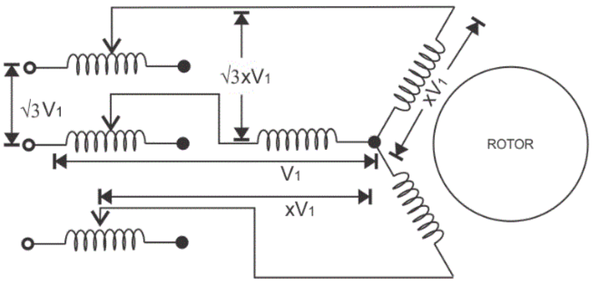
PART * B

1

With neat diagrams explain the working primary resistor starter used for squirrel cage type 3 phase induction motor. (Nov/Dec 2013) (8 M) BTL 1

Answer: Page :4.03 -Gnanavadivel

Using Primary Resistors:



(2 M)

Explanation: (6 M)

- Thus, by adding resistor we can control the supply voltage.
- Only a fraction of the voltage (x) of the supply voltage is applied at the time of starting of the induction motor.
- The value of x is always less than one.
- Due to the drop in the voltage the starting torque also decreases.
- We will derive the expression for the starting torque in terms of the voltage fraction x to show the variation of the starting torque with the value of x.
- As the motor speeds, up the reactor or resistor is cut out from the circuit.
- Finally, the resistors are short circuited when the motor reaches to its operating speed.
- Now let us derive the expression for starting torque in terms of full load torque for the stator resistor starting method.
- We have various quantities that involved in the expression for the starting torque are written below: we define T_s as starting torque

- T_f as full load torque

  I_f as per phase rotor current at full load

  I_s as per phase rotor current at the time of starting

  s_f as full load slip

  s_s as starting slip

  R_2 as rotor resistance

  W_s as synchronous speed of the motor

  Now we can directly write the expression for torque of the induction motor as

$$T = \frac{1}{W_s} \times I^2 \frac{r}{s}$$

- From the help of the above expression we write the ratio of starting torque to full load torque as

$$\frac{T_s}{T_f} = \left(\frac{I_s}{I_f}\right)^2 \times s_f \cdot\cdot\cdot\cdot\cdot\cdot (i)$$

- Here we have assumed that the rotor resistance is constant, and it does not vary with the frequency of the rotor current.
- From the above equation we can have the expression for the starting torque in terms of the full load torque.
- Now at the time of starting the per phase voltage is reduced to xV_1, the per phase starting current is also reduced to xI_s.
- On substituting the value of I_s as xI_s in equation 1. We have

$$\frac{T_s}{T_f} = \left(\frac{xI_s}{I_f}\right)^2 \times s_f$$

$$\frac{T_s}{T_f} = \left(\frac{I_s}{I_f}\right)^2 \times s_f \times x^2$$

- This shows the variation of the starting torque with the value of x.

2

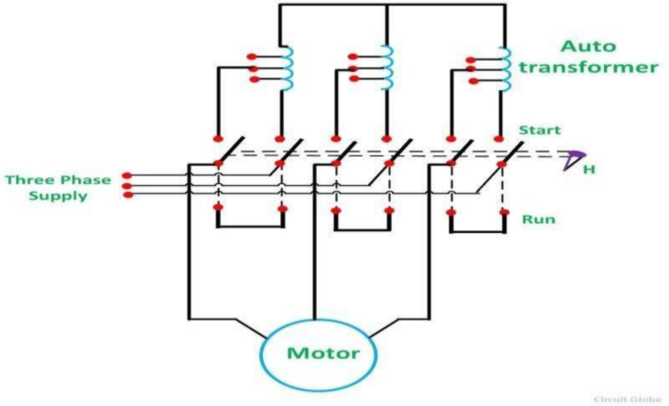
Discuss the various starting methods of induction motors. (April/May 2012, May 2018, Nov 2017) (13 M) BTL 1

Answer: Page -: 4.01 to 4.08 - Gnanavadivel

Auto transformer Starter(6 M)

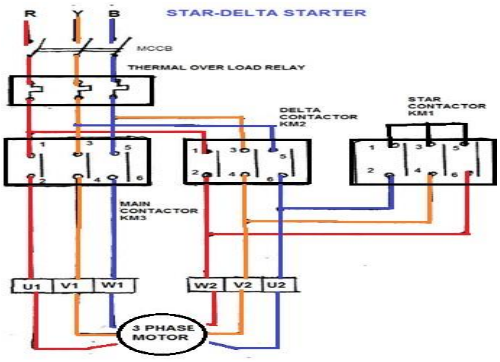
- An Auto Transformer Starter is suitable for both star and delta connected motors.
- Starting current is limited by using a three-phase auto transformer to reduce the initial stator applied voltage.
- It is provided with severaltapings.
- The starter is connected to one tapping to obtain the most suitable starting voltage.
- A double throw switch S is used to connect the auto transformer in the circuit for starting.
- When the **handle H** of the switch S in the **START** position.
- The primary of the auto transformer is connected to the supply line, and the motor is connected to the secondary of the auto transformer.
- When the motor picks up the speed of about 80 percent of its rated value, the handle H is quickly moved to the **RUN** position.

- The handle is held in the **RUN** position by the under- voltage relay.
- If the supply voltage fails or falls below a certain value, the handle is released and returns to the **OFF** position.
- Thermal overload relays provide the overload protection.



Star – Delta Starter:(7 M)

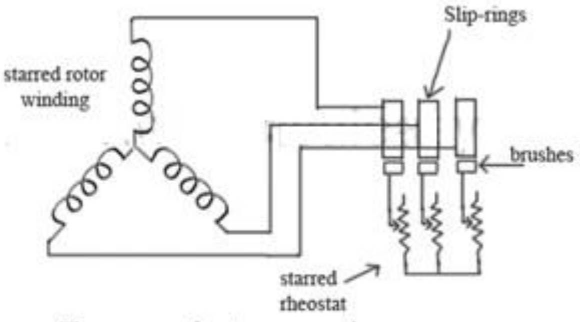
- The main circuit breaker serves as the main power supply switch.
- The main contactor connects the reference source voltage R, Y, B to the primary terminal of the motor U1, V1, W1.
- In operation, Main Contactor (KM3) and the Star Contactor (KM1) are closed initially.
- After a period, the star contactor is opened, and then the delta contactor (KM2) is closed.
- The control of the contactors is by the timer (K1T) built into the starter.
- The Star and Delta are electrically interlocked and preferably mechanically interlocked as well.
- The star contactor serves to initially short the secondary terminal of the motor U2, V2, W2 for the start sequence during the initial run of the motor from standstill.
- This provides one third of DOL current to the motor, thus reducing the high inrush current inherent with large capacity motors at startup.
- Controlling the interchanging star connection and delta connection of an AC induction motor is achieved by means of a star delta or wye delta control circuit.
- The control circuit consists of push button switches, auxiliary contacts and a timer.



3

Describe starter available for 3 phase Slip Ring Induction motor. (8 M) N/D/15,M/J/16|M/J/14,N/D/16 BTL 1

Answer: Page :4.07 - Gnanavadivel



Phase wound rotor connections

(3 M)

Explanation: (5 M)

- Slip-ring motors are started with full line voltage, as external resistance can be easily added in the rotor circuit with the help of slip-rings.
- Introducing resistance in rotor current will decrease the starting current in rotor.
- Also, it improves power factor and the torque is increased.
- The connected rheostat may be hand-operated or automatic.
- Additional resistance in rotor improves the starting torque.
- slip-ring motors can be started on load.
- The external resistance introduced is only for starting purposes and is gradually cut out as the motor gathers the speed.
- These motors are usually started with full line voltage applied across its terminals.
- As these motors have external resistance connected to its rotor circuit.
- The value of starting current is adjusted or kept minimum, by increasing the resistance of the rotor circuit.
- This external resistance can be assumed to be a form of rheostat, connected in star, thus kept at maximum.
- when the motor starts and gradually cut-out as the motor gathers speed.
- This implies that the starting current of the motor is reduced when an external resistance is added in the rotor circuit.
- Thus because of this, the starting torque is increased due to the improvement in power factor.

4

Explain briefly the various speed control schemes of induction motors refer to stator side. (May 2018, Nov 2017) (13 M) BTL 2

Answer: Page:4.09 to 4.19 -Gnanavadivel

The speed control of three phase induction motor from stator side are further classified as :

- V / f control or frequency control.
- Changing the number of stator poles.
- Controlling supply voltage.
- Adding rheostat in the stator circuit.

Speed Control from Stator Side

V / f control or frequency control (4 M)

Whenever three phase supply is given to three phase induction motor rotating magnetic field is produced which rotates at synchronous speed given by

$$N_s = \frac{120f}{P}$$

- In three phase induction motor emf is induced by induction similar to that of transformer which is given by

$$E \ or \ V = 4.44\phi K.T.f \ or \ \phi = \frac{V}{4.44KTf}$$

Where,
K is the winding constant,
T is the number of turns per phase and
f is frequency.

- Now if we change frequency synchronous speed changes.
- But with decrease in frequency flux will increase and this change in value of flux causes saturation of rotor and stator cores.
- Further cause increase in no load current of the motor.
- So,it's important to maintain flux, φ constant and it is only possible if we change voltage.
- If we decrease frequency flux increases but at the same time if we decrease voltage flux will also decease causing no change in flux and hence it remains constant.
- So, here we are keeping the ratio of V/f as constant.
- Hence its name is V/ f method.

Controlling supply voltage:(3 M)

- The torque produced by running three phase induction motor is given by

$$T \propto \frac{sE_2^2R_2}{R_2^2 + (sX_2)^2}$$

- In low slip region $(sX)^2$ is very very small as compared to R_2.
- So, it can be neglected. So torque becomes

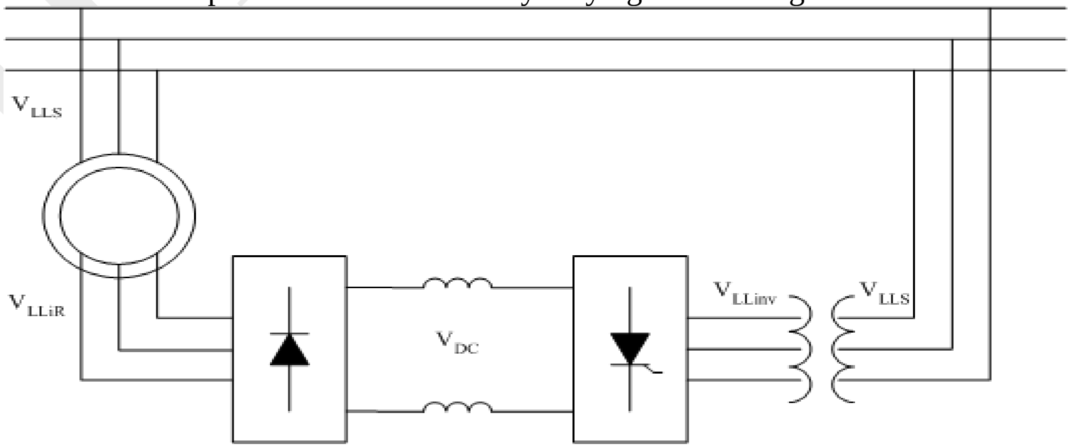
$$T \propto \frac{sE_2^2}{R_2}$$

- Since rotor resistance, R_2 is constant so the equation of torque further reduces to

$$T \ \propto \ sE_2^2$$

- We know that rotor induced emf $E_2 \propto V$. So, $T \propto sV^2$.
- If we decrease supply voltage torque will also decrease.
- But for supplying the same load, the torque must remain the same.
- It is only possible if we increase the slip and if the slip increases the motor will run at reduced speed.
- This method of speed control is rarely used because small change in speed requires large reduction in voltage, and hence the current drawn by motor increases, which cause over heating of induction motor.

Changing the number of stator poles: (3 M)

	➢ The stator is provided by two separate winding. ➢ These two stator windings are electrically isolated from each other and are wound for two different pole numbers. ➢ Supply is given to one winding only and hence speed control is possible. ➢ Disadvantages of this method is that the smooth speed control is not possible. ➢ This method is costlier and less efficient as two different stator winding are required. ➢ This method of speed control can only be applied for squirrel cage motor. **Adding rheostat in the stator circuit:** (3 M) ➢ In this method of speed control of three phase induction motor rheostat is added in the stator circuit due to this voltage gets dropped. ➢ In case of three phase induction motor torque produced is given by $T \propto sV_2^2$. ➢ If we decrease supply voltage torque will also decrease. ➢ But for supplying the same load, the torque must remain the same and it is only possible if we increase the slip and if the slip increase motor will run reduced speed.
5	**Explain in detail the slip power recovery scheme.(Nov/Dec 2011&2012& 2013 & 2014)(May/June 2014) (13 M)** BTL 2 **Answer: Page: 4.20 to 4.24 -Gnanavadivel** **SCHERBIUS SYSTEM**(6M) ➢ The scherbius system is like Kramer system but only difference is that in the Kramer system the feedback is mechanical and in the scherbius system the return power is electrical. ➢ The different types of scherbius system are: • Conventional scherbius drive • Static scherbius drive CONVENTIONAL SCHERBIUS DRIVE: ➢ This method consists of SRIM, rotary converter, DC motor and induction generator. ➢ Here, the rotary converter converts slip power into DC power and the DC power fed to the DC motor. ➢ The Dc motor is coupled with induction generator. ➢ The induction generator converters the mechanical power into the electrical power and returns it to the supply line. ➢ The SRIM speed can be controlled by varying the field regulator of the DC motor. 

STATIC SCHERBIUS DRIVE:

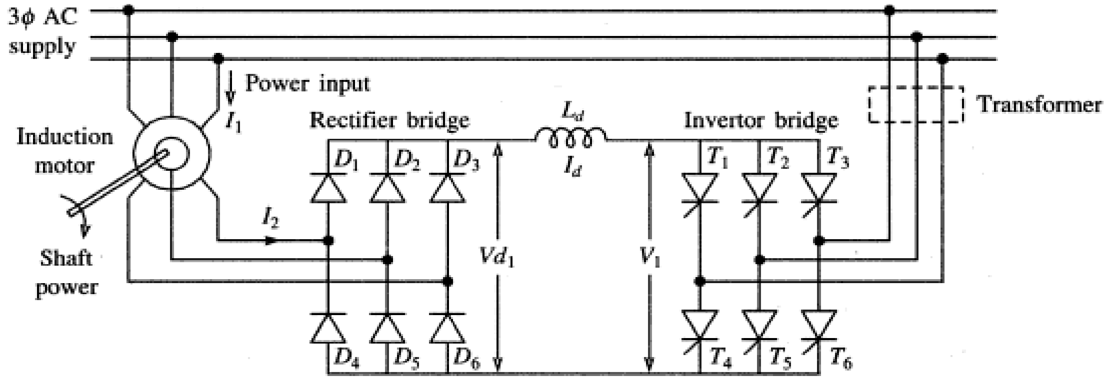
- ➢ For the speed control SRIM both below and the above synchronous speed, static scherbius drive is used.
- ➢ This system can again be classified as
  - DC link static scherbius drive
  - Cycloconverter static scherbius drive

DC LINK STATIC SCHERBIUS DRIVE(7 M)

- ➢ This system consists of SRIM, two numbers of phase-controlled bridges, smoothing inductor and step up transformer.
- ➢ This system used for sub synchronous and super synchronous speed operation.

Sub synchronous speed operation

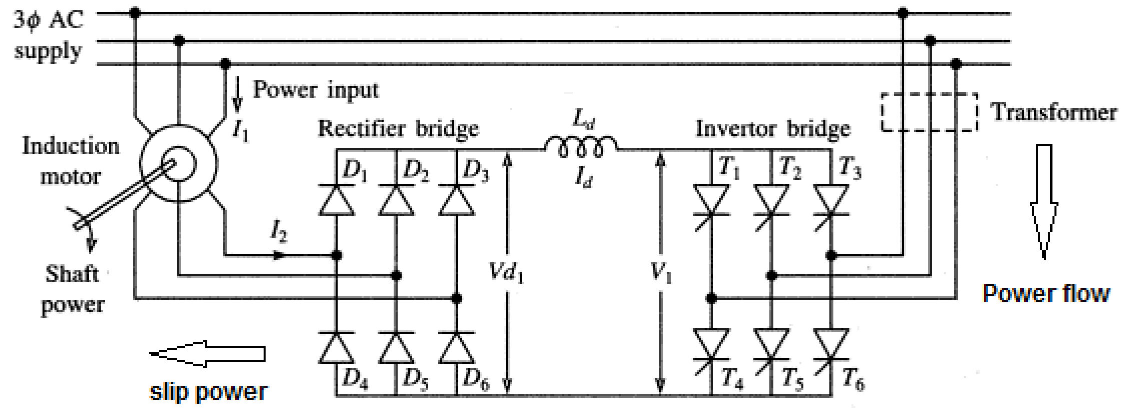
- ➢ In sub synchronous speed control of SRIM, slip power is removed from the rotor circuit and is pumped back into the ac supply.
- ➢ In the scherbius system, when a machine is operated at sub synchronous speed.
- ➢ Phase controlled bridge 1 operates in the rectifier mode and bridge 2 operates in the inverter mode.
- ➢ In other words, bridge 1 has firing angle less than the 900 whereas bridge 2 has firing angle more than 900
- ➢ The slip power flows from rotor circuit to bridge 1, bridge2, transformer and return to the supply.



- ➢ **Slip power→ rectifier (bridge1) → inverter bridge2→transformer→supply**

Super synchronous speed operation

- ➢ In super synchronous speed operation, the additional power is fed into the rotor circuit at slip frequency.
- ➢ In the scherbius system, when the machine is operated at super synchronous speed,
- ➢ Phase controlled bridge 2 should operate in rectifier mode and bridge1 in inverter mode.
- ➢ In other words, the bridge2 has firing angle less than 900 and bridge 1 has firing angle more than 900.
- ➢ The slip power flows from the supply to transformer, bridge2 (rectifier), bridge1 (line commutated inverter) and to the rotor circuit.



- **Supply → transformer →rectifier (bridge2) → Bridge 1 (inverter) →rotor circuit**
- Near synchronous speed, the rotor voltage is low, and forced commutation must be employed in the inverter.
- The replacement of 6 diodes by 6 thyristors increases the converter cost and also necessitate the introduction of slip frequency gating circuit.
- Difficulty is experienced near synchronous speed when slip frequency emfs are insufficient for line or natural commutation.
- Forced commutation methods are necessary for the passage through synchronism.

PART * C

1.

Explain the various techniques of speed control of induction motor from rotor side control. (April/May 2012) (May/June 2014) (15 M) BTL 2

Answer: Page: 4.15 to 4.20 - Gnanavadivel

Adding external resistance on rotor side: (5 M)

- In this method of speed control of three phase induction motor external resistance are added on rotor side.
- The equation of torque for three phase induction motor is

$$T \propto \frac{sE_2^2 R_2}{R_2^2 + (sX_2)^2}$$

- The three-phase induction motor operates in low slip region.
- In low slip region term $(sX)^2$ becomes very very small as compared to R_2.
- So, it can be neglected. and also, E_2 is constant.
- So, the equation of torque after simplification becomes,

$$T \propto \frac{s}{R_2}$$

- Now if we increase rotor resistance, R_2 torque decreases but to supply the same load torque must remain constant.
- So, we increase slip, which will further result in decrease in rotor speed.
- Thus, by adding additional resistance in rotor circuit we can decrease the speed of three phase induction motor.

Advantage

- Addition of external resistance starting torque increases.

Disadvantages:

- The speed above the normal value is not possible.
- Large speed change requires large value of resistance and if such large value of resistance is added in the circuit it will cause large copper loss and hence reduction in efficiency.
- Presence of resistance causes more losses.
- This method cannot be used for squirrel cage induction motor.

Cascade control method: (5 M)

- The two three phase induction motor are connected on common shaft and hence called cascaded motor.
- One motor is the called the main motor and another motor is called the auxiliary motor.
- The three-phase supply is given to the stator of the main motor while the auxiliary motor is derived at a slip frequency from the slip ring of main motor.
- Let N_{S1} be the synchronous speed of main motor.
  N_{S2} be the synchronous speed of auxiliary motor.
  P_1 be the number of poles of the main motor.
  P_2 be the number of poles of the auxiliary motor.
  F is the supply frequency.
  F_1 is the frequency of rotor induced emf of main motor.
  N is the speed of set and it remains same for both the main and auxiliary motor as both the motors are mounted on common shaft.
- S_1 is the slip of main motor.

$$S_1 = \frac{N_{S1} - N}{N_{S1}}$$

$$F_1 = S_1 F$$

- The auxiliary motor is supplied with same frequency as the main motor i.e

$$F_1 = F_2$$

$$N_{S2} = \frac{120F_2}{P_2} = \frac{120F_1}{P_2}$$

$$N_{S2} = \frac{120S_1F}{P_2}$$

- Now put the value of

$$S_1 = \frac{N_{S1} - N}{N_{S1}}$$

$$We\ get,\ N_{S2} = \frac{120F(N_{S1} - N)}{P_2 N_{S1}}$$

- Now at no load, the speed of auxiliary rotor is almost same as its synchronous speed i.e $N = N_{S2}$

$$N = \frac{120F(N_{S1} - N)}{P_2 N_{S1}}$$

- Now rearrange the above equation and find out the value of N, we get,

$$N = \frac{120F}{P_1 - P_2}$$

- This cascaded set of two motors will now run at new speed having number of poles ($P_1 + P_2$).
- In the above method the torque produced by the main and auxiliary motor will act in same direction, resulting in number of poles ($P_1 + P_2$).
- Such type of cascading is called cumulative cascading.
- There is one more type of cascading in which the torque produced by the main motor is in opposite direction to that of auxiliary motor.
- Such type of cascading is called differential cascading; resulting in speed corresponds to number of poles ($P_1 - P_2$).

Injecting slip frequency emf into rotor side: (5 M)

- When the speed control of three phase induction motor is done by adding resistance in rotor circuit,
- Therefore, the efficiency of three phase induction motor is reduced by this method of speed control.
- This slip power loss can be recovered and supplied back in order to improve the overall efficiency.
- This scheme of recovering the power is called slip power recovery scheme.
- This is done by connecting an external source of emf of slip frequency to the rotor circuit.
- The injected emf can either oppose the rotor induced emf or aids the rotor induced emf.
- If it opposes the rotor induced emf, the total rotor resistance increases and hence speed decreases.
- The injected emf aids the main rotor emf the total decreases and hence speed increases.

Therefore by injecting induced emf in rotor circuit the speed can be easily controlled.

2.

A 3ph 440 V distribution circuit is designed to supply not more than 1200A. Assuming that a 3ph squirrel cage induction motor has full-load efficiency of 0.85 and a full-load power factor of 0.85 and that the starting current at rated voltage is 5 times the rated full load current what is the maximum permissible kW rating of the motor if it is to be started using an auto transformer stepping down the voltage to 80%?N/D/14 (15 M) BTL 5

- Maximum possible permissible current that induction motor can take from the distribution circuit is 1200A at the time of starting.
- $I_{st} = 5 * I_{rated}$
- $I_{L(rated)} = \frac{I_{st}}{5} = \frac{1200}{5} = 240A$
- Maximum kW rating= $\sqrt{3} V_l I_l \cos\phi * \eta$
    - $= \sqrt{3} * 400 * 240 * 0.85 * 0.8$
    - = 113.068kW(5 M)
- If it is designed to have sta-delta starter, then star delta starter is equivalent to autotransformer with 57.8% tapping i.e. ratio$(\frac{1}{\sqrt{3}})$

- $I_{st} = X_0^2 * 5 * I_L = (\frac{1}{\sqrt{3}} * 5 * I_L)$
- $I_L = \frac{1200*3}{5} = 720A$
- $(kW)_{max}) = \sqrt{3} * 400 * 720 * 0.8 * 0.85$=339.204kW (5 M)
- For autotransformer starts,$X^2 * 5 * I_L$
- 1200=$(0.8)^2)$* 5* I_L
- $I_L = 375A$
- $(kW)_{max} = \sqrt{3} * 400 * 720 * 0.8 * 0.85$=176.669Kw(5M)

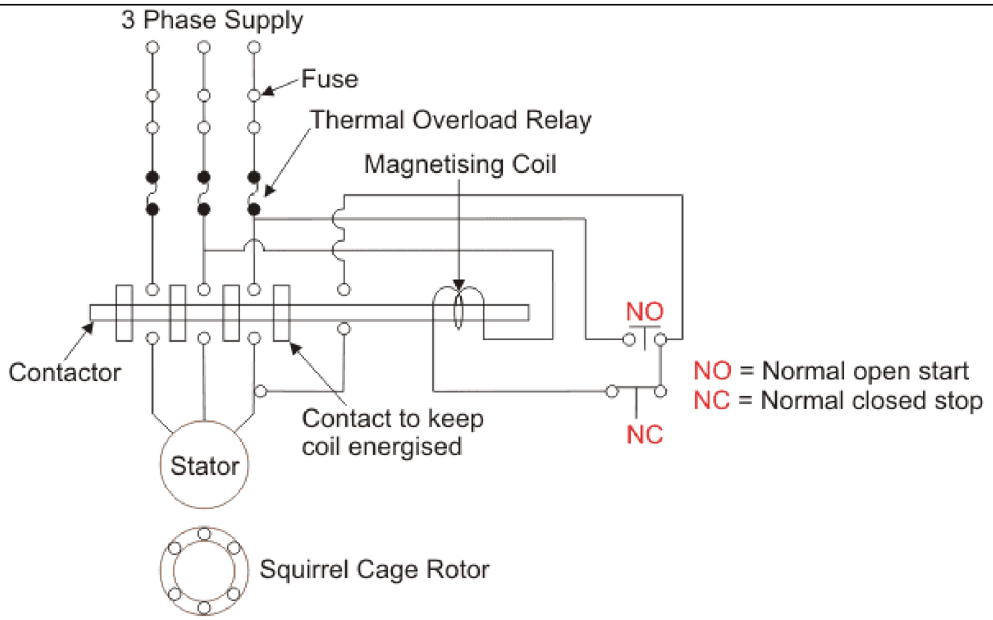
Explain with neat diagram, the construction and working of DOL starter. (15 M) BTL 1

Answer: Page :4.01 -Gnanavadivel

Construction of DOL Starter (5 M)

- It consists of two buttons, GREEN for starting and RED for stopping purpose.
- The DOL starter comprises of an MCCB or circuit breaker, contactor and an overload relay for protection.
- To start the motor, we close the contact by pushing Green Button, and the full line voltage appears to the motor.
- Contactor can be of 3 poles or 4-pole. Below given contactor is of 4-pole type.
- It contains three NO (normally open) contacts that connect the motor to supply lines,
- Fourth contact is "hold on contact" (auxiliary contact) which energizes the contactor coil after the start button is released.
- If any fault occurs, the auxiliary coil gets de-energized.
- Hence the starter disconnects the motor from supply mains.
- Overload Protection When motor draws excessive current to meet the load requirement.
- If load requirement goes beyond the rated limit, termed as Overload.
- Overload protection is a type of security when motor draws over current or excessive current and causes overheating of the equipment.
- Overload is also the type of over current.
- So, overload relays are employed to limit the amount of current drawn.
- Fuse or MCB used in the system protects the over current.

Working of DOL Starter(5 M)



Explanation:(5 M)

- The DOL starter connects the 3-phase main with the motor.
- The control circuit is connected to any two phases and energised from them only.
- When we press the start button, the current flows through contactor coil (Magnetizing Coil) and control circuit also.
- The current energizes the contactor coil and leads to close the contacts.
- 3-phase supply becomes available to the motor.
- If we press the stop button, the current through the contact becomes discontinued.
- Hence supply to the motor will not be available.
- Similar thing will happen when overload relay operates.
- Since the supply of motor breaks, the machine will come to rest.
- The contactor coil (Magnetizing Coil) gets supply even though we release start button because when we release start button.
- It will get supply from the primary contacts as illustrated in the diagram of the Direct Online Starter**.**

	UNIT V SINGLE PHASE INDUCTION MOTORS AND SPECIAL MACHINES
	Constructional details of single phase induction motor – Double field revolving theory and operation – Equivalent circuit – No load and blocked rotor test – Performance analysis – Starting methods of single-phase induction motors – Capacitor-start capacitor run Induction motor- Shaded pole induction motor - Linear induction motor – Repulsion motor - Hysteresis motor - AC series motor- Servo motors- Stepper motors - introduction to magnetic levitation systems.
Q.No	**PART * A**
1	**Name the two windings of a single-phase induction motor. (Nov/Dec 2018)**BTL 1 ➢ Running winding (main winding) ➢ Starting winding (auxiliary winding)
2	**What are the various methods available for making a single-phase motor self-starting? (Nov/Dec 2012)** BTL 1 ➢ By splitting the single phase ➢ By providing shading coil in the poles ➢ Repulsion starts method. ➢ Capacitor starts capacitor run.
3	**Differentiate "Capacitor start" and "Capacitor start capacitor run" induction motors.** BTL 4 In "capacity, start" motor capacitor is connected in series with the starting winding. But it will be disconnected from the supply when the motor picks up its speed. But in capacitor start, capacitor-run motor the above starting winding and capacitor are not disconnected, but always connected in the supply. So it has high starting and running torque.
4	**Why single-phase induction motor has low power factor?** BTL 2 The current through the running winding lags the supply voltage by a very large angle. Therefore, power factor is very low.
5	**Why a capacitor run type motor is considered as superior one?** BTL 2 ➢ It has high starting and running torques. ➢ Current drawn is less because of higher power factor ➢ It can be started with some load.
6	**How can a universal motor rotation be reversed?** BTL 2 ➢ The direction of rotation of the concentrated-pole (or salient-pole) type universal motor may be reversed by reversing the flow of current through either the armature or field windings. ➢ The direction of rotation of the distributed field compensating type universal motor may be reversed by interchanging either the armature or field leads and shifting the brushes against the direction in which the motor win rotates.
7	**What is the function of centrifugal switch in a single phase - induction motor? (April/May 2012)** BTL 1 Its function is to automatically disconnect the starting winding from the supply when the motor has reached 70 to 80 percent of its full speed is reached.
8	**Why a single-phase induction motor is not self-starting?** BTL 2

	When the motor is fed from a single-phase supply, its stator winding produces an alternating or pulsating flux, which develops no torque. That is why a single-phase motor is not self-starting.
9	**Why should a motor be named as universal motor?** BTL 2 The available supply in the universe is both A.C and D.C. So the rotor, which works on both A.C and D.C, is called universal motor.
10	**What is the use of shading ring in a shaded pole motor?** BTL 1 The shading coil causes the flux in the shaded portion to lag the flux in UN shaded portion of pole. This gives in effect a rotation of flux across the pole (ace and under the influence of this moving flux a starting torque is developed.
11	**Stare the advantages of using capacitor start motor over a resistance split phase motor. (April/May 2012)** BTL1 ➢ The starting current of capacitor start motor is less than resistance split phase motor ➢ Starting torque of the capacitor motor is twice that of resistance start motor.
12	**How will you change the direction of a split phase induction motor? (Nov/Dec 2014)** BTL 2 By changing the direction of current either in the starting winding or in the running winding the direction of rotation can be changed.
13	**State double revolving field theory. (Nov/Dec 2013)** BTL 1 Double revolving theory, formulated by Ferrari, states that a single pulsating magnetic field ϕ_m as its maximum value can be resolved into two rotating magnetic fields of $\phi_m / 2$ as their magnitude rotating in opposite direction as synchronous speed proportional to the frequency of the pulsating field.
14	**What type of motor is used for ceiling fan? (Nov/Dec 2011) (May/June 2014)** BTL 2 Singe phase induction motor.
15	**State the application of shaded pole motor. (Nov/Dec 2011)** BTL 1 ➢ Low power household application because the motors have low starting torque and efficiency ratings ➢ Hair dryers, humidifiers and timing devices.
16	**What is meant by single phasing? (Nov/Dec 2012)** BTL 1 Induction motor can operate in single phase supply is called as single phasing.
17	**What is the principle of reluctance motor? (Nov/Dec 2014)** BTL 1 A reluctance torque is the torque produced in a motor in which the reluctance of the airgap is a function of angular position of the rotor, with respect to stator coils. A motor which develops torque only due to the difference in reluctance in two axes is known as reluctance motor.
18	**What could be the reasons if a split-phase motor runs too slow?** BTL 1 Any one of the following factors could be responsible. ➢ Short-circuited or open winding in field circuit. ➢ Over load. ➢ Grounded starting and running winding. ➢ Wrong supply voltage and frequency.
19	**What is the main basic difference between the principle of operation of a 3-phase and single -phase induction motors?** BTL 1

<table>
<tr><td></td><td>When three-phase supply is given to 3-phase induction motor, a rotating magnetic field is produced and the rotor-starts rotating. But when single-phase supply is given to single-phase motor only a pulsating flux is produced. So motor is not self-starting. Therefore, to make it self-starting split-phase arrangement is made by providing an auxiliary winding.</td></tr>
<tr><td>20</td><td>What is a universal motor? BTL 1
A universal motor is defined as a motor, which may be, operated either on direct current or single-phase A.C supply, at approximately, the same speed and output.</td></tr>
<tr><td>21</td><td>State some applications of universal motor. BTL 1
Used for sewing machines, table fans, vacuum cleaners, hair driers, blowers and kitchen appliances etc.</td></tr>
<tr><td>22</td><td>What are the inherent characteristics of plain 1-phase Induction motor? BTL 1
A plain 1-phase Induction motor is not used in practice due to the following inherent characteristics
➢ A plain 1-phase Induction motor does not have any starting torque.
➢ However, if the rotor is initially given a starting torque, by some means, the motor can pick up its speed in a direction at which the initial torque is given and deliver the required output.</td></tr>
<tr><td>23</td><td>Give the names of three different types of single-phase induction motor. BTL 1
➢ Split-phase motor
➢ Shaded pole motor
➢ Single phase series motor
➢ Repulsion motor
➢ Reluctance motor</td></tr>
<tr><td>24</td><td>How can a universal motor rotation be reversed? BTL 2
➢ The direction of rotation of the concentrated-pole (or salient-pole) type universal motor may be reversed by reversing the flow of current through either the armature or field windings.
➢ The direction of rotation of the distributed field compensating type universal motor may be reversed by interchanging either the armature or field leads and shifting the brushes against the direction in which the motor win rotates.</td></tr>
<tr><td>25</td><td>How can the direction of a capacitor run motor be reversed? (Nov/Dec 2015) BTL 2
The direction of rotation of capacitor run motor can be reversed by reversing the connection of any one of the winding.</td></tr>
<tr><td>26</td><td>Distinguish the terms rotating and pulsating magnetic fields. (May/June 2015) BTL 4
<table>
<tr><td>Rotating magnetic field</td><td>Pulsating magnetic field</td></tr>
<tr><td>Three phase induction motor produce rotating magnetic field.</td><td>Single phase induction motor produce pulsating magnetic field.</td></tr>
<tr><td>Field strength is high</td><td>Field strength is low</td></tr>
<tr><td>Resultant flux will be 1.5 times the maximum flux at starting.</td><td>Resultant flux will be zero at starting.</td></tr>
</table></td></tr>
<tr><td>27</td><td>State the limitations of shaded pole motors. (May/June 2015) BTL 1
➢ Low power factor.
➢ The starting torque is very poor.
➢ The efficiency is very low as, the copper losses are high due to presence of copper</td></tr>
</table>

band.

PART * B

1

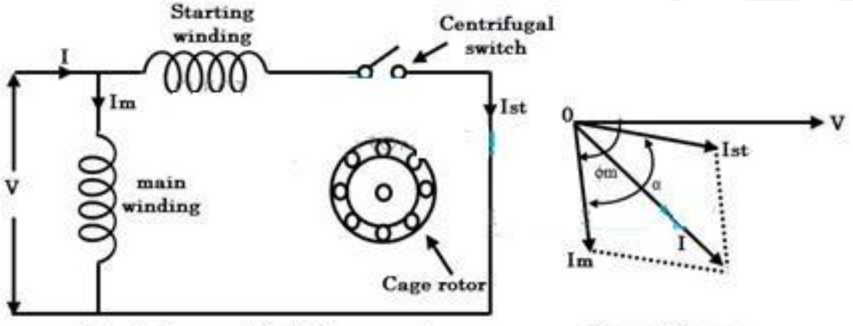
Give the classification of single phase motors. Explain any two types of single phase induction motors. (13M) (Nov/Dec 2013, May 2018)BTL 1

Answer: Page:5.07 to 4.15 – J. Gnanavadivel

- Split phase induction motor
- Capacitor start induction motor
- Capacitor start capacitor run induction motor
- Shaded pole induction motor (2 M)

The single-phase induction motor is classified according to the starting methods,

Resistance start (split phase) induction motor (5 M)



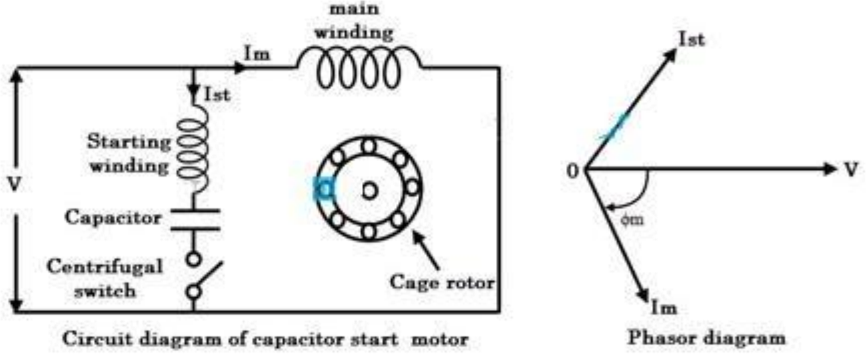
Circuit diagram of split phase motor Phasor diagram

- The essential parts of the split phase motor include main winding, auxiliary winding and a centrifugal switch.
- The auxiliary or starting winding carries a series resistance such that its impedance becomes highly resistive in nature.
- It is not wound identical to the main winding but contains fewer turns of much smaller diameter as compared to main winding.
- This will reduce the amount of start current lags the voltage.
- The main winding is inductive in nature in such that current lags the voltage by some angle.
- This winding is designed for the operation of 75 % of synchronous speed and above.
- These two windings are connected in parallel across the supply.
- Due to the inductive nature, current through main winding lags the supply voltage by a large angle.
- Current through starting winding is almost in phase with voltage due to resistive nature.
- Hence there exists a phase difference between these currents and thereby phase difference between the fluxes produced by these currents.
- The resultant of these two fluxes produce rotating magnetic field and hence the starting torque.
- The centrifugal switch is connected in series with the starting winding.
- When the motor reaches 75 to 80 percent of synchronous speed, the centrifugal switch is opened mechanically and thereby auxiliary winding is out of the circuit.
- Therefore, the motor runs only with main winding.

- Split phase motors give poor starting torque due to small phase difference between main and auxiliary currents.
- Also, the power factor of these motors is poor.
- These are mainly used for easily started loads such as blowers, fans, washing machines, grinders, etc.

Capacitor Start Induction Motor(6 M)

- This motor is similar to the split phase motor.
- Capacitor is connected in series to auxiliary winding.
- This is a modified version of split phase motor.
- Since the capacitor draws a leading current, the use of a capacitor increases the phase angle between the two currents (main and auxiliary) and hence the starting torque.
- Here the capacitor is of dry-type electrolytic one which is designed only for alternating current use.
- Due to the inexpensive type of capacitors, these motors become more popular in wide applications.
- These capacitors are designed for definite duty cycle, but not for continuous use.
- The schematic diagram of capacitor start motor is shown in figure below.



Circuit diagram of capacitor start motor

Phasor diagram

- The operation of this motor is similar to the split phase motor where the starting torque is provided by additional winding.
- Once the speed is picked up, the additional winding along with capacitor is removed from the circuit with the help of centrifugal switch.
- But, the difference is that the torque produced by this motor is higher than split phase motor due to the use of capacitor.
- Due to the presence of a capacitor, the current through auxiliary winding will leads the applied voltage by some angle which is more than that of split case type.
- Thus, the phase difference between main and auxiliary currents is increased and thereby starting torque.
- The performance of this motor is identical to the split phase motor when it runs near full load RPM.
- Due to the capacitor, the inrush currents are reduced in this motor.
- These motors have very high starting torque up to 300% full load torque.
- However, the power factor is low at rated load and rated speed.
- Owing to the high starting torque, these motors are used in domestic as well as industrial applications such as water pumps, grinders, lathe machines, compressors, drilling machines, etc.

2

Explain the double field revolving theory for operation of single phase induction motor. (13M) (April/May 2012) & (Nov/Dec 2012) (May/June 2014) (Nov/Dec 2014)(Nov/Dec 2015, Nov 2017)BTL 6

Answer: Page: 5.03 to 5.06 - J. Gnanavadivel

Double field revolving theory: (6 M)

- According to this theory, any alternating quantity can be resolved into two rotating components.
- Which rotate in opposite directions and each having magnitude as half of the maximum magnitude of the alternating quantity.
- In case of single phase induction motors, the stator winding produces an alternating magnetic field having maximum magnitude of Φ_{1m}.
- According to double revolving field theory, consider the two components of the stator flux.
- Each having magnitude half of maximum magnitude of stator flux i.e. ($\Phi_{1m}/2$).
- Both these components are rotating in opposite directions at the synchronous speed N_s which is dependent on frequency and stator poles.
- Let Φ_f is forward component rotating in anticlockwise direction.
- $\Phi_b$is the backward component rotating in clockwise direction.
- The resultant of these two components at any instant gives the instantaneous value of the stator flux at the instant.
- So resultant of these two is the original stator flux.

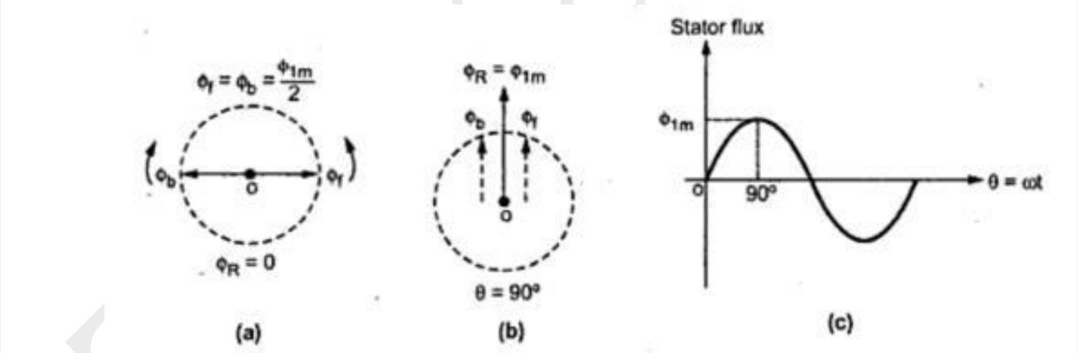


Fig. 1 Stator flux and its two components(2 M)

- The Fig. 1 shows the stator flux and its two components Φ_f andΦ_b.
- At start both the components are shown opposite to each other in the Fig.1(a).
- Thus, the resultant $\Phi_R = 0$. This is nothing but the instantaneous value of the stator flux at start.
- After 90° , as shown in the Fig. 1(b), the two components are rotated in such a way that both are pointing in the same direction.
- Hence the resultant Φ_R is the algebraic sum of the magnitudes of the two components. So $\Phi_R = (\Phi_{1m}/2) + (\Phi_{1m}/2) = \Phi_{1m}$.
- This is nothing but the instantaneous value of the stator flux at $\theta = 90^o$ as shown in the Fig 1(c).
- Thus, continuous rotation of the two components gives the original alternating stator flux.
- Both the components are rotating and hence get cut by the motor conductors.
- Due to cutting of flux, e.m.f. gets induced in rotor which circulates rotor current.

- The rotor current produces rotor flux.
- This flux interacts with forward component Φ_f to produce a torque in one particular direction say anticlockwise direction.
- While rotor flux interacts with backward component Φ_b to produce a torque in the clockwise direction.
- So if anticlockwise torque is positive then clockwise torque is negative.
- At start this two torque are equal in magnitude but opposite in direction.
- Each torque tries to rotate the rotor in its own direction.
- Thus, net torque experienced by the rotor is zero at start.
- And hence the single-phase induction motors are not self-starting.

Torque speed characteristics **(**5 M)

- The two oppositely directed torques and the resultant torque can be shown effectively with the help of torque-speed characteristics.
- It is shown in the Fig.2.

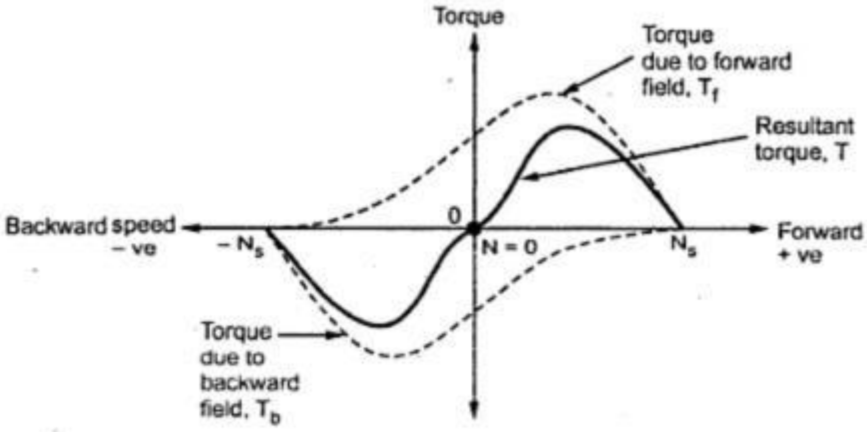


Fig. 2 Torque-speed characteristic

- At start N = 0 and at that point resultant torque is zero.
- So single phase motors are not self-starting.
- However, if the rotor is given an initial rotation in any direction.
- Resultant average torque increases in the direction in which rotor initially rotated.
- And motor starts rotating in that direction.
- But in practice it is not possible to give initial torque to rotor.
- Externally hence some modifications are done in the construction of single phase induction motors to make them self-start.

3

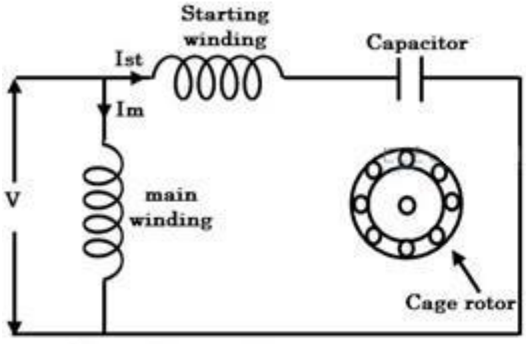
Explain the principle and operation of capacitor run induction motor and capacitor-start capacitor run induction motor. (May 2018) (13 M) BTL 2

Answer: Page: 5.10 - J. Gnanavadivel

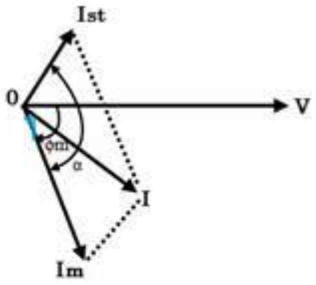
Permanent Capacitor Induction Motor(6 M)

- This motor is also called as a capacitor run motor.
- Low capacitor is connected in series with the starting winding and is not removed from the circuit even in running condition.
- Due to this arrangement, centrifugal switch is not required.

- Here the capacitor can run continuously.
- The low value capacitor produces more leading phase shift bur less total starting current as shown in phasor diagram.
- Hence, the starting torque produced by these motors will be considerably lower than that of capacitor start motor.
- The schematic circuit of this motor is shown in figure below.



Circuit diagram of capacitor run motor

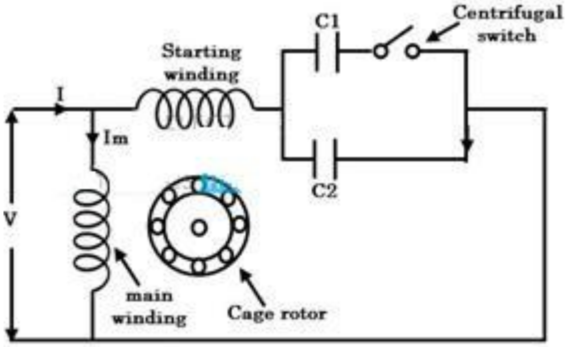


Phasor diagram

- In this, the auxiliary winding and capacitor remains in circuit permanently and produce an approximate two-phase operation at rated load point.
- This will result better power factor and efficiency.
- However, the starting torque is much lower in these motors, typically about 80 percent of full load torque.
- Due to the continuous duty of auxiliary winding and capacitor, the rating of these components should withstand running conditions and hence permanent capacitor motor is more than equivalent split phase or capacitor start motors.
- These motors are used in exhaust and intake fans, unit heaters, blowers, etc.

Capacitor Start and Capacitor Run Induction Motor(7 M)

- These motors are also called as two-value capacitor motors.
- It combines the advantages of capacitor start type and permanent capacitor type induction motors.
- This motor consists of two capacitors of different value of capacitance for starting and running.
- A high value capacitor is used for starting conditions while a low value is used for running conditions.
- It is to be noted that this motor uses same winding arrangement as capacitor-start motor during start-up and permanent capacitor motor during running conditions.
- The schematic arrangement of this motor is shown in figure below.



Circuit diagram of capacitor start capacitor run motor

- At starting, both starting and running capacitors are connected in series with the auxiliary winding.
- Thus, the motor starting torque is more compared with other types of motors.
- Once the motor reaches some speed, the centrifugal switch disconnects the starting capacitor and leaves the running capacitor in series with auxiliary winding.
- Thus, both running and auxiliary windings remain during running condition, thereby improved power factor and efficiency of the motor.
- These are the most commonly used single phase motors due to high starting torque and better power factor.
- These are used in compressors, refrigerators, air conditioners, conveyors, ceiling fans, air circulators, etc.

4

Explain the working principle of single phase induction motor. Mention its four applications. (13 M) BTL 2

Answer: Page: 5.02 - J. Gnanavadivel

Stator:

- As its name indicates stator is a stationary part of induction motor.
- Single phase AC supply is given to the stator of single phase induction motor.

Rotor:

- The rotor is a rotating part of an induction motor.
- The rotor connects the mechanical load through the shaft.
- The rotor in the single-phase induction motor is of squirrel cage rotor type.
- The **construction of single phase induction motor** is almost similar to the squirrel cage three-phase induction motor.
- But in case of a single phase induction motor, the stator has two windings instead of one three-phase winding in three phase induction motor.

Working Principle of Single Phase Induction Motor

- When we apply a single-phase AC supply to the stator winding of single phase induction motor.
- The alternating current starts flowing through the stator or main winding.
- This alternating current produces an alternating flux called main flux.
- This main flux also links with the rotor conductors and hence cut the rotor conductors.
- According to the Faraday's law of electromagnetic induction, emf gets induced in the rotor.

- As the rotor circuit is closed one so, the current starts flowing in the rotor.
- This current is called the rotor current.
- This rotor current produces its flux called rotor flux.
- Since this flux is produced due to the induction principle so, the motor working on this principle got its name as an induction motor.
- Now there are two fluxes one is main flux, and another is called rotor flux.
- These two fluxes produce the desired torque which is required by the motor to rotate. (5 M)

Why Single-Phase Induction Motor is not Self Starting? (3 M)

- According to double field revolving theory, we can resolve any alternating quantity into two components.
- Each component has a magnitude equal to the half of the maximum magnitude of the alternating quantity, and both these components rotate in the opposite direction to each other.
- For example - a flux, φ can be resolved into two components.

$$\frac{\phi_m}{2}\ and\ -\frac{\phi_m}{2}$$

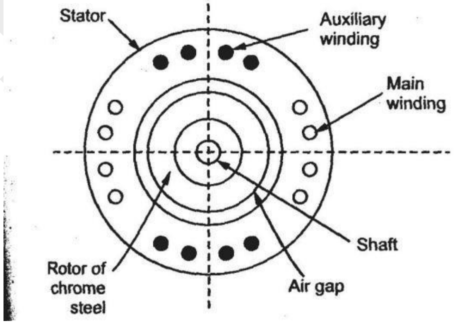
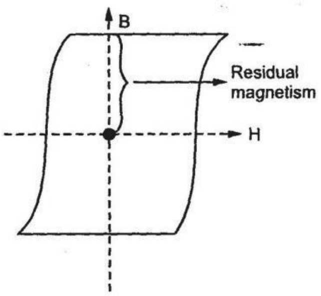
- Each of these components rotates in the opposite direction i. e if one $\varphi_m/2$ is rotating in clockwise direction then the other $\varphi_m / 2$ rotates in anticlockwise direction.
- When we apply a single-phase AC supply to the stator winding of single phase induction motor.
- it produces its flux of magnitude, φ_m.
- According to the double field revolving theory, this alternating flux, φ_m is divided into two components of magnitude $\varphi_m/2$.
- Each of these components will rotate in the opposite direction, with the synchronous speed, N_s.
- Let us call these two components of flux as forwarding component of flux, φ_f and the backward component of flux, φ_b.
- The resultant of these two components of flux at any instant of time gives the value of instantaneous stator flux at that particular instant.

$$i.e. \phi_r = \frac{\phi_m}{2} + \frac{\phi_m}{2}\ or\ \phi_r = \phi_f + \phi_b$$

- Now at starting condition, both the forward and backward components of flux are exactly opposite to each other.
- Also, both of these components of flux are equal in magnitude.
- So, they cancel each other and hence the net torque experienced by the rotor at the starting condition is zero.
- So, the **single-phase induction motors** are not self-starting motors.

Methods for Making Single Phase Induction as Self Starting Motor (3 M)

- We require two alternating flux, having some phase difference angle between them.
- When these two fluxes interact with each other, they will produce a resultant flux.
- This resultant flux is rotating in nature and rotates in space in one particular direction only.
- Once the motor starts running, we can remove the additional flux.
- The motor will continue to run under the influence of the main flux only.

	➢ Depending upon the methods for making asynchronous motor as Self Starting Motor. Four **types of single phase induction motor**namely, (2 M) ➢ Split phase induction motor, ➢ Capacitor start inductor motor, ➢ Capacitor start capacitor run induction motor, ➢ Shaded pole induction motor. ➢ Permanent split capacitor motor or single value capacitor motor.
5	**Write the principle and working of hysteresis motor and AC series motor. Explain briefly.(13 M) (Nov/Dec 2011)& (Nov/Dec 2012, Nov 2017) (May/June 2014, May 2018) (Nov/Dec 2014)**BTL 2 **Answer: Page:5.46 to 5.49 - J. Gnanavadivel** **Constructional features of Hysteresis Motor:**(7 M) It consists of ➢ Stator ➢ Single phase stator winding ➢ Rotor ➢ Shaft ➢ Shading coil **Stator:** ➢ Stator of hysteresis motor is designed in a particular manner to produce synchronous revolving field from single phase supply. ➢ Stator carries two windings, o main winding o auxiliary winding. ➢ In another type of design of hysteresis motor, the stator holds the poles of shaded type. **Rotor:** ➢ Rotor of hysteresis motor is made of magnetic material that has high hysteresis loss property. ➢ Example of this type of materials is chrome, cobalt steel or alnico or alloy. ➢ Hysteresis loss becomes high due to large area of hysteresis loop.   **OPERATION** ➢ Starting behavior of a hysteresis motor is like a single phase induction motor and running behavior is same as a synchronous motor.

- Step by step its behavior can be realized in the working principle that is given below.
- When stator is energized with single phase AC supply, rotating magnetic field is produced in stator.
- To maintain the rotating magnetic field the main and auxiliary windings must be supplied continuously at start as well as in running conditions.
- At the starting, by induction phenomenon, secondary voltage is induced in the rotor by stator rotating magnetic field.
- Hence eddy current is generated to flow in the rotor and it develops rotor.
- Thus, eddy current torque is developed along with the hysteresis torque in the rotor.
- Hysteresis torque in the rotor develops as the rotor magnetic material is with high hysteresis loss property and high retentivity.
- The rotor goes under the slip frequency before going to the steady state running condition.
- So, it can be said that when the rotor starts to rotate with the help of these eddy current torque due to induction phenomenon, it behalves like a single-phase induction motor.

APPLICATIONS

- Sound producing equipment
- Sound recording instruments
- High quality record players
- Timing devices
- Electric clocks
- Tele-printers.

AC series motors(6 M)

- It is also known as the modified DC series motor as their construction is very similar to that of the DC series motor.
- An AC supply will produce an unidirectional torque because the direction of both the currents (i.e. armature current and field current) reverses at the same time.
- Due to presence of alternating current, eddy currents are induced in the yoke and field cores which results in excessive heating of the yoke and field cores.
- Due to the high inductance of the field and the armature circuit, the power factor would become very low.
- There is sparking at the brushes of the DC series motor.
- So, considering above points we can say that we don’t have good performance of DC series motor on the application of AC supply.
- Now to reduce the eddy currents there is need to laminate the yoke and field core.
- Power factor is directly related to reactance of the field and armature circuit.
- We can reduce the field winding reactance by reducing the number of turns in the field winding.
- On reducing the number of turns, field mmf will decrease and due to this the air gap flux decrease.
- The overall result of this is that there is an increase in the speed of the motor but decrease in the motor torque which is not desired.

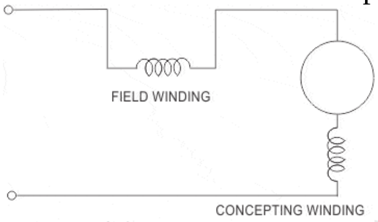
TYPES

- Conductively compensated type of motors.

- Inductively compensated type of motors.

Conductively Compensated Type of Motors

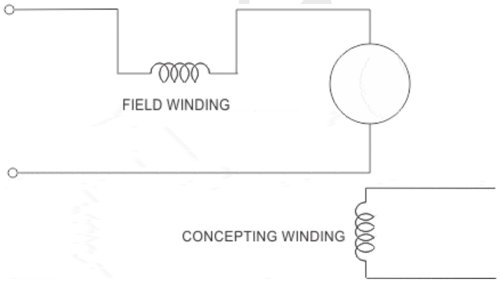
- Given below is the circuit diagram of the conductively compensated type of motors.
- In this type of motor, the compensating winding is connected in series with the armature circuit.
- The winding is put in the stator slots. The axis of the compensating winding is 90^o (electrical) with main field axis.



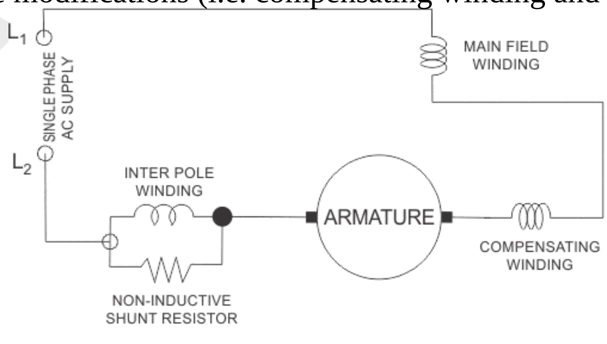
(a)

Inductively Compensated Type of Motors

- Given below is the circuit diagram of the inductively compensated type of motors.
- In this type of motor, the compensating winding has no interconnection with the armature circuit of the motor.
- In this case, a transformer action will take place as the armature winding will act as primary winding of the transformer.
- Compensation winding will act as a secondary winding.
- The current in the compensating winding will be in phase opposition to the current in the armature winding.



- Given below is the complete schematic diagram of the single-phase**AC series motor** with all the modifications (i.e. compensating winding and inter pole).



AC Series Motor with Interpoles and compensating Windings

6

Explain the principle of operation and applications of repulsion motor. (8M) (April/May 2012)BTL 2

Answer: Page:5.44 to 5.47 - J. Gnanavadivel

Repulsion Motor:

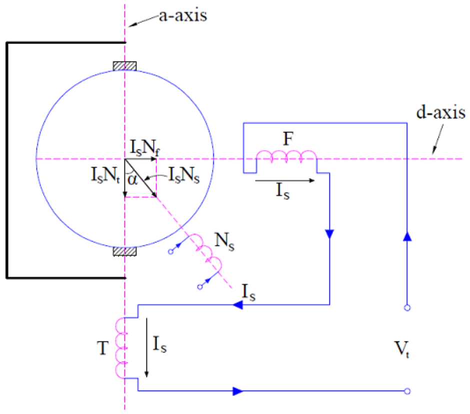
- It is a special kind of single phase AC motor which works due to the repulsion of similar poles.
- The stator of this motor is supplied with 1 phase AC supply and rotor circuit is shorted through carbon brush.

Construction of Repulsion Motor:(3 M)

- The main components of repulsion motor are stator, rotor and commutator brush assembly.
- The stator carries a single phase exciting winding similar to the main winding of single phase induction motor.
- The rotor has distributed DC winding connected to the commutator at one end just like in DC motor.
- The carbon brushes are short circuited on themselves.
- Stator winding have single phase AC winding which produces the working mmf in the air gap.
- The brushes on rotor are shown to be shorted.
- As the rotor circuit is shorted, the rotor receives power from stator by transformer action.

Working principle of Repulsion Motor:(5 M)

- The basic principle behind the working of repulsion motor is that “similar poles repel each other.”
- This means two North poles will repel each other.
- Similarly, two South poles will repel each other.
- When the stator winding of repulsion motor is supplied with single phase AC, it produces a magnetic flux along the direct axis.
- This magnetic flux when link with the rotor winding, creates an emf.
- Due to this emf, a rotor current is produced.
- This rotor current in turn produces a magnetic flux which is directed along the brush axis due to commutator assembly.
- Due to the interaction of stator and rotor produced fluxes, an electromagnetic torque is produced.
- In the above figure, the angle α between the stator produced field and brush axis is 90°.
- This means, the brush axis is in quadrature with the direct.
- Under this condition, there will not be any mutual induction between the stator and rotor windings.
- Therefore, no emf and hence no rotor current is produced. Thus, no electromagnetic torque is developed.
- This means that motor will not run when $\alpha = 90°$.
- As the stator produced flux is unaffected by the zero rotor mmf, this condition is similar to the open circuit transformer.
- This is the reason, the brush position of $\alpha = 90°$ is called open-circuit, no-load, high impedance or neutral position.



PART * C

1

Explain the no-load test and blocked rotor test for obtaining the equivalent circuit parameters of a single-phase induction motor.(15M) (Nov/Dec 2014, Nov 2017)BTL 3

Answer: Page: 5.18 to 5.21- J. Gnanavadivel

EQUIVALENT CIRCUIT OF SINGLE PHASE INDUCTION MOTOR

Without core loss(7 M)

- Let the stator impedance be Z Ω

$Z = R_1 + j X_1$

R_1 = Stator resistance

X_1 = Stator reactance

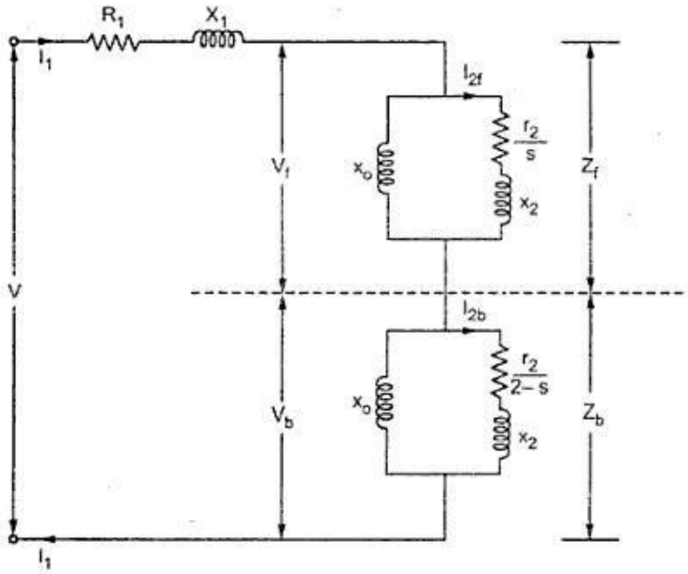
X_2 = rotor reactance referred to stator

R_2 = rotor resistance referred to stator

- Hence the impedance of each rotor is $r_2 + j x_2$ where

$x_2 = X_2/2$

- The resistance of forward field rotor is r_2/s while the resistance of backward field rotor is $r_2/(2 - s)$.
- The r_2 value is half of the actual rotor resistance referred to stator.
- As the core loss is neglected, R_o is not existing in the equivalent circuit.
- The x_o is half of the actual magnetizing reactance of the motor.
- So the equivalent circuit referred to stator is shown in the Fig.1.



- Now the impedance of the forward field rotor is Z_f which is parallel combination of $(0 + j\,x_o)$ and $(r_2/s) + j\,x_2$

$$\therefore \qquad Z_b = \frac{j x_o\left[\left(\frac{r_2}{2-s}\right)+j x_2\right]}{\frac{r_2}{2-s}+j(x_o+x_2)}$$

- While the impedance of the backward field rotor is Z_b which is parallel combination of $(0 + j\,x_o)$ and $(r_2 / 2\text{-}s) + j\,x_2$

$$\therefore \qquad Z_b = \frac{j x_o\left[\left(\frac{r_2}{2-s}\right)+j x_2\right]}{\frac{r_2}{2-s}+j(x_o+x_2)}$$

- Under standstill condition, s = 1 and 2 - s = 1 hence $Z_f = Z_b$ and hence $V_f = V_b$.
- But in the running condition, V_f becomes almost 90 to 95% of the applied voltage.

$\therefore$ $Z_{eq} = Z_1 + Z_f + Z_b$ = Equivalent impedance

and $I_{2b} = /((r_2/2\text{-}s) + j\,x_2)$

P_f = Power input to forward field rotor

$= (I_{2f})^2\,(r_2/s)$ watts

P_b = Power input to backward field rotor

$= (I_{2b})^2\,(r_2/2\text{-}s)$ watts

$P_m = (1 - s)$\{ Net power input\}

$= (1 - s)\,(P_f - P_b)$ watts

$P_{out} = P_m$ - mechanical loss - core loss

∴ T_f = forward torque = $P_f/(2\pi N/60)$ N-m

and Tb = backward torque = $P_b/(2\pi N/60)$ N-m

T = net torque = $T_f - T_b$

while T_{sh} = shaft torque = $P_{out}/(2\pi N/60)$ N-m

%η = (net output / net input) x 100

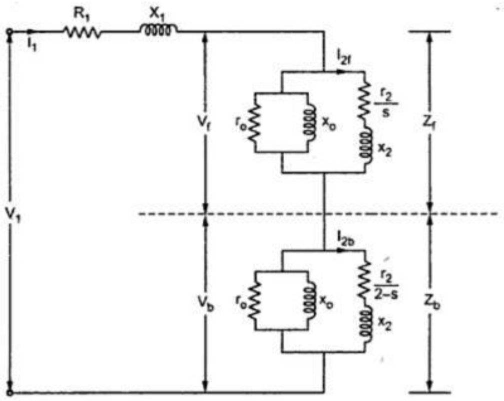
With core loss(8 M)

- If the core loss is to be considered then it is necessary to connect a resistance in parallel with, in an exciting branch of each rotor is half the value of actual core loss resistance.
- Thus, the equivalent circuit with core loss can be shown as in the Fig. 2.

- Let Z_{of} = Equivalent impedance of exciting branch in forward rotor $= r_o \| (j\, x_o)$

and Z_{ob} = Equivalent impedance of exciting branch in backward rotor $= r_o \| (j\, x_o)$

∴ $Z_f = Z_{of} \| (r_2/s + j\, x_2)$



2

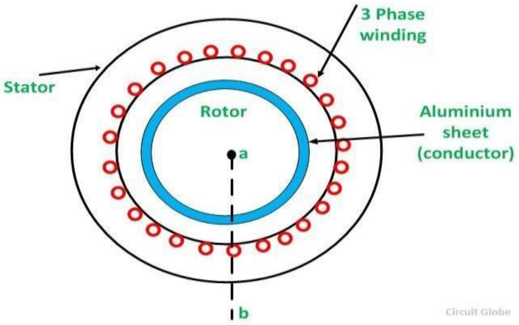
Explain the operating principle of Linear Induction Motor with neat diagram. (Nov/Dec 2015)(Nov/Dec 2015) (15 M) BTL 2

Answer: Refer Notes

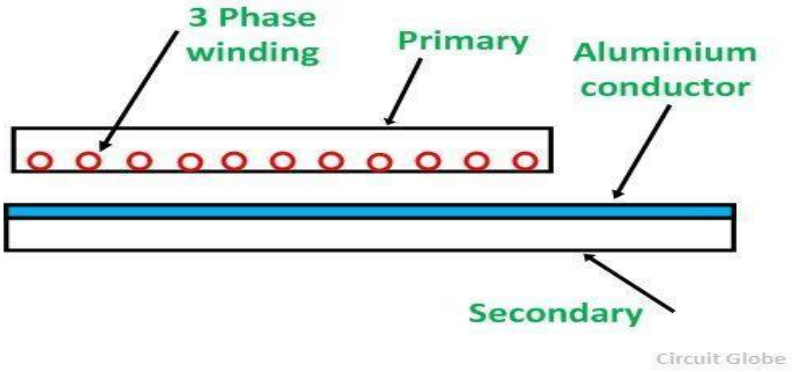
- A **Linear Induction Motor** is an advanced version of rotary induction motor.
- It gives a linear translational motion instead of the rotational motion.
- The stator is cut axially and spread out flat.
- In this type of motor, the stator and rotor are called primary and secondary

respectively.

- ➢ The secondary of the linear induction motor consists of a flat aluminium conductor with a ferromagnetic core.
- ➢ The polyphase rotator induction motor is shown below. (5 M)

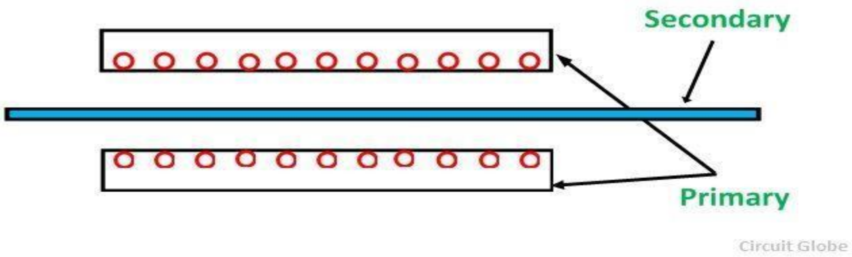


- ➢ If the stator is cut along the line ab and spread out flat the figure formed is



(8 M)

- ➢ If a three-phase supply is connected to the stator of an induction motor, a rotating flux is produced.
- ➢ This flux rotates at a synchronous speed in the air gap.
- ➢ Similarly, if the primary of the linear induction motor is connected to the three-phase supply.
- ➢ A flux is produced which travel across the length of the primary.
- ➢ A current is generated in the conductor which is made of the aluminum material.
- ➢ The current, which is induced in the linear induction motor interacts with the travelling flux produces a linear force.
- ➢ If secondary of the linear induction motor is fixed and the primary is free to move, the force will move the primary in the direction of the travelling wave.
- ➢ The double sided linear induction motor (DLIM) is shown in the figure below.



- The Double sided linear induction motor has primary on both the sides of the secondary.
- The linear synchronous speed of the travelling wave is given by the equation shown below.

$$v_s = 2f\,(\text{pole pitch})\,\frac{m}{s} \ldots\ldots..(1)$$

Where f is the supply frequency in hertz.

- In the rotary induction motor, the speed of the secondary in the linear induction motor is less than the synchronous speed v_s and is given as

$$v_r = v_s\,(1 - s) \ldots\ldots..(2)$$

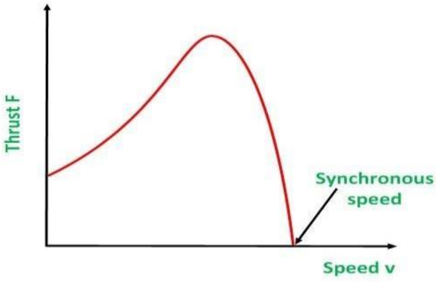
- Where s is the slip of the linear induction motor and is given as

$$s = \frac{v_s - v_r}{v_s} \quad \text{pu} \quad \ldots\ldots\ldots.(3)$$

- The linear force is given by the equation shown below.

$$F = \frac{\text{air gap power}}{\text{linear synchronous velocity } (v_s)}$$

- The thrust velocity curve of the linear induction motor is similar to that of the speed torque curve of the rotary induction motor.
- It is shown in the figure below.



Applications of the Linear Induction Motor (2 M)

- The main application of the LIM is in transportation and in electric traction system.
- Primary is mounted on the vehicle and the secondary is laid on the track.
- It is used in the cranes
- Pumping of liquid metals
- Actuators for the movement of doors
- Used in High voltage circuit breakers and also in accelerators.

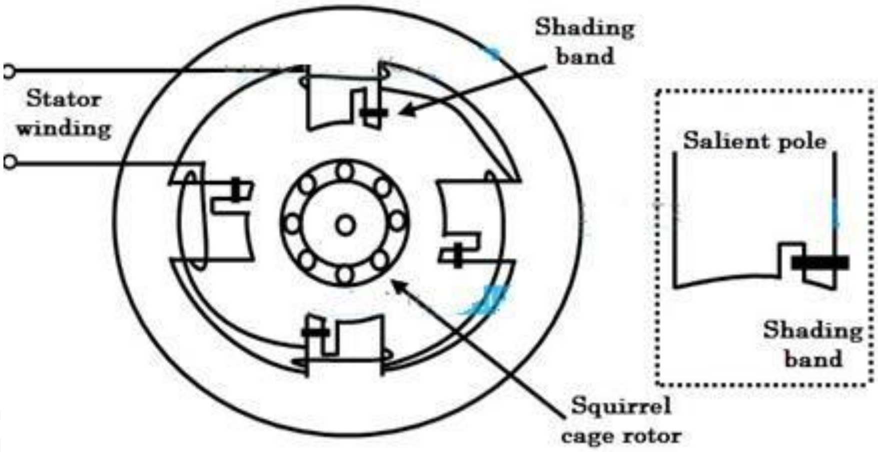
3

Explain shaded pole induction motor with neat diagram. (Nov 2017, Nov 2018) (15 M) BTL 2

Answer: Page: 5.13 - J. Gnanavadivel

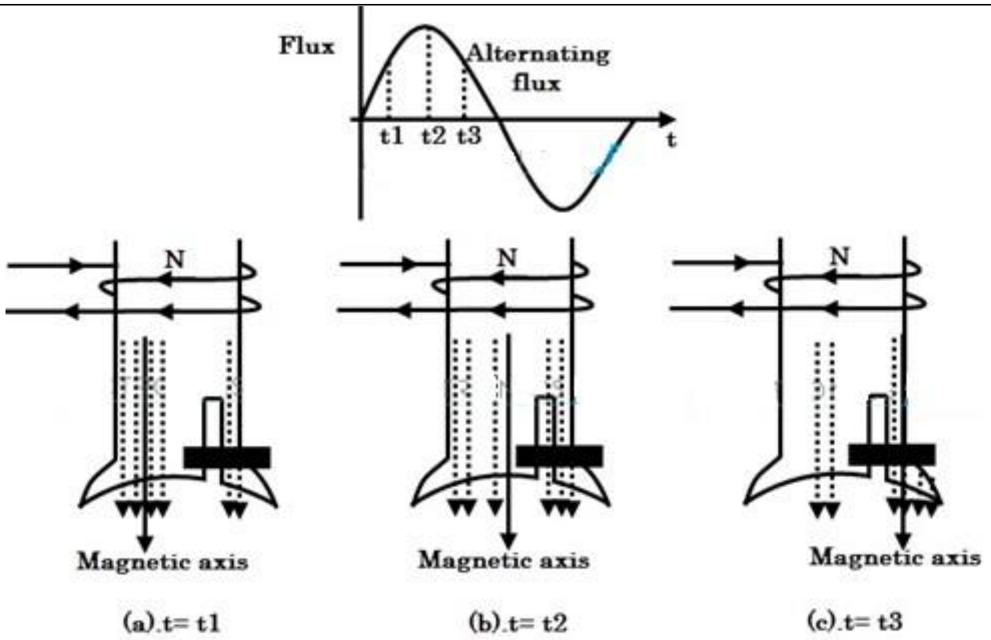
Shaded Pole Induction Motor

- This motor uses entirely different technique to start the motor as compared with other motors so far we have discussed now.
- This motor doesn't use any auxiliary winding or even it doesn't have a rotating field, but a field that sweeps across the pole faces is enough to drive the motor.
- So, the field moves from one side of the pole to another side of the pole.
- Although these motors are of small ratings, inefficient and have low starting torque.
- These are used in a variety of applications due to its outstanding features like ruggedness, low initial cost, small size and simple construction.
- A shaded pole motor consists of a stator having salient poles (or projected poles), and a rotor of squirrel cage type.
- In this, stator is constructed in a special way to produce moving magnetic field.
- Stator poles are excited with its own exciting coils by taking the supply from a single-phase supply.
- A 4-pole shaded pole motor construction is given in below figure. (5 M)



4-Pole Shaded pole motor construction

- Each salient pole is divided into two parts; shaded and un-shaded.
- A shading portion is a slot cut across the laminations at about one third distance from one edge, and around this a heavy copper ring is placed.
- This part where shading coil is placed is generally termed as shaded part of the pole and remaining portion is called as un-shaded part as shown in figure.
- When an alternating supply is given to the stator coils, an alternating flux will be produced.
- The distribution of flux in the pole face area is influenced by the presence of copper shading band.
- Let us consider the three instants, t1, t2, and t3 of alternating flux for an half cycle of the flux as shown in figure.



(5 M)

- At instant t= t1, the rate of change of flux (rising) is very high.
- Due to this flux, an emf is induced in the copper shading band and as the copper shading band is shorted, current circulates through it.
- This causes current to create its own field.According to Lenz's law, the current through copper shading band opposes the cause.
- Therefore, the flux produced by shading ring opposes the main flux.
- So, there is weakening of flux in the shaded part while crowding of flux in un-shaded part.
- So, the axis of overall flux shifts to non-shaded part of the pole as shown in the figure.
- At instant t=t2, the rate of rise of flux is almost zero, and hence very little emf is induced in the shaded band.
- It results negligible shaded ring flux and hence there is no much effect on distribution of main flux.
- Therefore, the distribution of flux is uniform, and the overall flux axis lies at the center of the pole as shown in figure.
- At instant t=t3, the rate of change of flux (decreasing) is very high and induces emf in copper shading band.
- The flux produced by the shading ring is now opposes the cause according to Lennz's law.
- Here, the cause is decreasing flux, and opposing means its direction is same as that of main flux.
- Hence, this flux strengthens the main flux.
- So there will be crowding of flux in the shaded part compared to the non-shaded part.
- Due to this overall flux axis shifts to the middle of shaded part.
- This sequence will repeat for negative cycle too and consequently it produces moving magnetic field for every cycle from non-shaded part of the pole to shaded

part of the pole.

- Due to this field, motor produces the starting torque. This starting torque is low about 40 to 50 percent of full load torque.
- Therefore, these motors are used in low starting torque applications such as fans, toy motors, blowers, hair dryers, photocopy machines, film projectors, advertising displays, etc. (5 M)

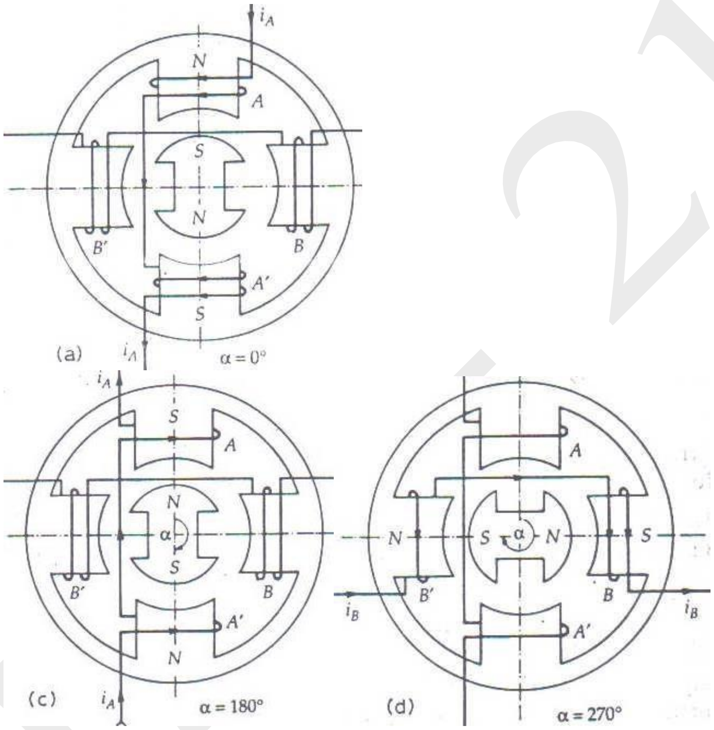
4.

Explain the construction and working of stepper motor. (Nov 2018, Nov 2017) (15 M) BTL1

Permanent Magnet (PM) Stepper Motor: (10 M)

- Permanent-magnet (PM) stepper motor has a stator construction like that of the single-stack variable reluctance motor.
- The rotor is cylindrical and consists of permanent-magnet poles made of high retentivity steel.

Diagram: (5 M)



- The direction of rotation depends on polarity of phase current.
- Clockwise - A+, B+, A-, B-, A+.
- Anticlockwise - A+, B-, A-, B+, A+.
- The PM stepper motors produces more toque per ampere stator current than VR motor.

EE8402 TRANSMISSION AND DISTRIBUTION L T P C

OBJECTIVES:

- To study the structure of electric power system and to develop expressions for the computation of transmission line parameters.
- To obtain the equivalent circuits for the transmission lines based on distance and to determine voltage regulation and efficiency.
- To understand the mechanical design of transmission lines and to analyze the voltage distribution in insulator strings to improve the efficiency.
- To study the types, construction of cabilitys and methods to improve the efficiency.
- To study about distribution systems.

UNIT I TRANSMISSION LINE PARAMETERS 9

Structure of Power System - Parameters of single and three phase transmission lines with single and double circuits -Resistance, inductance and capacitance of solid, stranded and bundled conductors, Symmetrical and unsymmetrical spacing and transposition - application of self and mutual GMD; skin and proximity effects -Typical configurations, conductor types and electrical parameters of EHV lines.

UNIT II MODELLING AND PERFORMANCE OF TRANSMISSION LINES 9

Performance of Transmission lines - short line, medium line and long line - equivalent circuits, phasor diagram, attenuation constant, phase constant, surge impedance - transmission efficiency and voltage regulation, real and reactive power flow in lines - Power Circle diagrams - Formation of Corona – Critical Voltages – Effect on Line Performance.

UNIT III MECHANICAL DESIGN OF LINES 9

Mechanical design of OH lines – Line Supports –Types of towers – Stress and Sag Calculation – Effects of Wind and Ice loading. Insulators: Types, voltage distribution in insulator string, improvement of string efficiency, testing of insulators.

UNIT IV UNDER GROUND CABILITYS 9

Underground cabilitys - Types of cabilitys – Construction of single core and 3 core Cabilitys - Insulation Resistance – Potential Gradient - Capacitance of Single-core and 3 core cabilitys
- Grading of cabilitys - Power factor and heating of cabilitys– DC cabilitys.

UNIT V DISTRIBUTION SYSTEMS 9

Distribution Systems – General Aspects – Kelvin’s Law – AC and DC distributions - Techniques of Voltage Control and Power factor improvement – Distribution Loss –Types of Substations -Methods of Grounding – Trends in Transmission and Distribution: EHVAC, HVDC and FACTS (Qualitative treatment only).

OUTCOMES:

- To understand the importance and the functioning of transmission line parameters.
- To understand the concepts of Lines and Insulators.
- To acquire knowledge on the performance of Transmission lines.
- To understand the importance of distribution of the electric power in power system.
- To acquire knowledge on Underground Cabilitys
- To become familiar with the function of different components used in Transmission and Distribution levels of power system and modelling of these components.

TEXT BOOKS:

1. D.P.Kothari, I.J. Nagarath, ‘Power System Engineering’, Mc Graw-Hill Publishing Company limited, New Delhi, Second Edition, 2008.
2. C.L.Wadhwa, ‘Electrical Power Systems’, New Academic Science Ltd, 2009.
3. S.N. Singh, ‘Electric Power Generation, Transmission and Distribution’, Prentice Hall of India Pvt. Ltd, New Delhi, Second Edition, 2011.

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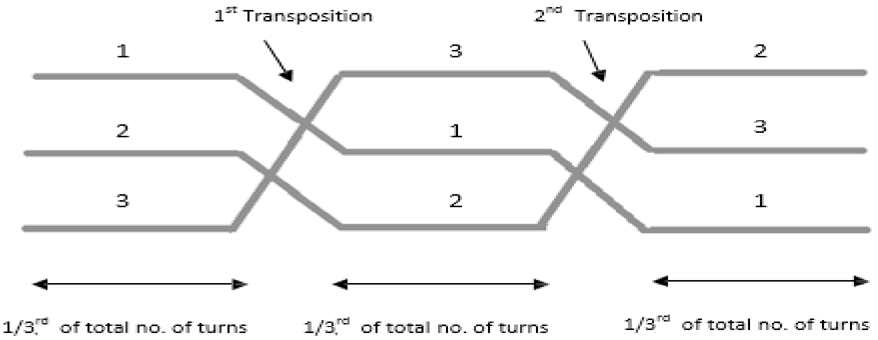
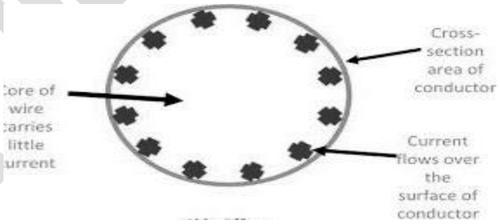
1. B.R.Gupta, ‘Power System Analysis and Design’ S. Chand, New Delhi, Fifth Edition, 2008.
2. Luces M.Fualken berry, Walter Coffer, ‘Electrical Power Distribution and Transmission’, Pearson Education, 2007.
3. Arun Ingole, "power transmission and distribution" Pearson Education, 2017
4. J.Brian, Hardy and Colin R.Bayliss ‘Transmission and Distribution in Electrical Engineering’, Newnes; Fourth Edition, 2012.
5. G.Ramamurthy, “Handbook of Electrical power Distribution,” Universities Press, 2013.

	Subject Code: EE8402 **Year/Semester: II/04** **Subject Name: Transmission & Distribution** **Subject Handler: Mr.S.Baskaran** **UNIT I – TRANSMISSION LINE PARAMETERS**
	Structure of Power System - Parameters of single and three phase transmission lines with single and double circuits -Resistance, inductance and capacitance of solid, stranded and bundled conductors, Symmetrical and unsymmetrical spacing and transposition - application of self and mutual GMD; skin and proximity effects -Typical configurations, conductor types and electrical parameters of EHV lines.
	PART*A
1	**What is meant by proximity effect? (R2008-M/J 2014), (R2017-A/M 2019), (R2008-M/J 2014), (R2013-A/M 2018) BTL1** The alternating magnetic flux in a conductor caused by the current flowing in neighbouring conductor gives rise to circulating currents which cause an apparent increase in the resistance of a conductor. This phenomenon is called proximity effect.
2	**State the limitations of high transmission voltages. (R2008-A/M 2015) BTL1** The limitations of high transmission voltage are: Cost of transformer, switchgear and other terminal apparatus are very high. With the increase in the voltage of transmission, the insulation required between the conductors and the earthed tower increases. This increase the cost of line support ➢ With increase in the voltage of transmission, more clearance is required between conductors and ground. Hence higher towers are required
3	**List out the advantages of high voltage A.C transmission. (R2008-N/D 2011) BTL1** High power transferability of AC lines. Line losses decrease with increase of transmission voltage and improvement of power factor for same power transfer. Bulk power transfer from large group of generating stations upto main transmission network.
4	**Why is electrical power preferably to be transmitted at a high voltage? (R2013-A/M 2015)** **Why is power transmitted at high voltage? (R2013-N/D 2015) BTL1** The power that has to be transmitted through transmission lines is very large and if this power is transmitted at 11KV (or 33KV) the line current and the power loss would be very large. Therefore this voltage is stepped up to a higher vale by step up transformers located in sub stations
5	**What are the advantages of high voltage power transmission? (R2013-M/J 2016) BTL2** 1. Lesser conductor material required. 2. Transmission line efficiency is increased. 3. Percentage line drop decreases, this leads to better voltage regulation.

6	**6. What is meant by transposition in overhead transmission line? (R2008-A/M 2015), (R2013-M/J 2016) R2017-N/D 2018)N/D 2019** **What is transposition? Why are transmission line transposed? (R2013-N/D2017)** **What is the need of transposition? (R2008-N/D 2011) BTL1** Transmission lines are conductors, that carry electric power from generating plants to the substations that deliver power to customers. At a generating plant, electric power is “stepped up” to several thousand volts by a transformer and delivered to the transmission line. The transposition is defined as interchanging of position of the line conductors at regular intervals along the line so that each conductor occupies the original position of every other conductor over at equal distance. Such an exchange of positions is known as transposition. 
7	**What is skin effect? On what factors does it depend? (R2008-A/M 2015), (R2008-M/J 2014), (R2013-N/D 2016), (R2008-N/D 2010), (R2008-N/D2012)** **State skin effect in transmission lines. Mention its effect on the resistance of the line. (R2013-A/M 2017) BTL1 N/D 2017** The non-uniform distribution of electric current over the surface or skin of the conductor carrying a.c is called the skin effect. In other words, the concentration of charge is more near the surface as compared to the core of the conductor. The ohmic resistance of the conductor is increased due to the concentration of current on the surface of the conductor.  Factors affecting skin effect 1. Frequency – Skin effect increases with the increase in frequency. 2. Diameter – It increases with the increase in diameter of the conductor. 3. The shape of the conductor – Skin effect is more in the solid conductor and less in the stranded conductor because the surface area of the solid conductor is more. 4. Type of material – Skin effect increase with the increase in the permeability of the material (Permeability is the ability of material to support the formation of the magnetic field).
8	**7. Write the expression for a capacitance of a 1phase Transmission line. (R2008-N/D2012) BTL1** Capacitance of a Single Phase Two Wire Line**:**

	$C_{AB} = \frac{\pi \varepsilon_0}{\log_e \frac{d}{r}}$ F / m **Capacitance to Neutral:** Capacitance to neutral, $C_N = C_{AN} = C_{BN} = 2C_{AB}$ $C_N = \frac{2 \pi \varepsilon_0}{\log_e \frac{d}{r}}$ F / m
9	**A three phase transmission line has its conductors at the corners of an equilateral triangle with side 3m. The diameter of each conductor is 1.63cm. Find the inductance per km per phase of the line. (R2013- A/M 2015), (R2008 – N/D 2013) BTL2** L = 10^{-7}(0.5 + 2lnD/r)H/m. D=3m, diameter = 1.63cm; r=0.815cm=0.00815 m, L= 12.3167 ×10^{-7}H/m L= 12.3167 ×10^{-4}H/km, L= 1.23167 mH/km
10	**What are the components of a power system? (R2008-M/J 2014) BTL2** The components of a power system are: Generating station, Step up transformer, Step down transformer, Transmission line, Switching station, Primary distribution line, Secondary distribution line, Feeder, Distributor and Service mains.
11	**How inductance and capacitance of a transmission line are affected are affected by the spacing between the conductors? (R2008-M/J 2016) BTL1** For a single phase line the conductor inductance is L = 2 * 10^{-7} ln (D/r) H/m Here D is the distance between the centers of conductors. The capacitance between the conductors is C = $2\pi\varepsilon_O$/ ln (D/r) F/m. Both inductance and capacitance depends upon the spacing between the conductors D and hence they get affected.
12	**What are composite conductors? (R2008-M/J 2016) BTL2** The standard conductors which are normally used for transmission lines operating at high voltages are known as "composite conductors", They are so called as they consist of two or more elements or strands electrically in parallel.
13	**What are the advantages of using bundled conductors? (R2013-N/D 2016), (R2008-N/D 2010), (R2008-N/D2014) BTL2** Advantages of Bundled Conductors: 1. Bundling of conductors leads to reduction in line inductance.

	2. For decrease in inductance of line, the capacitance of the line increases, the net SIL of the line also increases automatically, and hence the power transfer capability too. Hence using bundled conductors is an effective way of increasing SIL, i.e. Surge Impedance Loading. 3. The most important advantage of bundled conductors is its ability to reduce Corona. 4. Reduction in formation of corona leads to less power loss in corona and hence improved transmission efficiency of the line. 5. Reduction in communication line interference due to reduction in corona. 6. The ampacity i.e. the current carrying capacity of bundled conductors is much increased in comparison to single large conductor owing to reduced skin effect. 7. As the bundled conductors have more effective surface area exposed to air, it has better and efficient cooling and hence better performance compared to a single conductor..
15	**Why the concept of self GMD is not applicable for capacitance calculation? (R2013-N/D2017) BTL1** Self GMD of a conductor depends upon the size and shape of the conductor and is independent of the spacing between the conductors so it is not applicable for capacitance calculation.
16	**Distinguish between self and mutual GMD. (R2013-N/D 2015) BTL1**
17	**Mention the advantages of transposition of conductors. (R2013-N/D 2015)BTL1** When **conductors** are not **transposed** at regular intervals, the inductance and capacitance of the **conductors** will not be equal. When **conductors** such as telephone lines are run in parallel to transmission lines, there is a possibility of high voltages induced in the telephone lines.This can result in acoustic shock or noise. Transposition greatly reduces this undesired phenomenon.
18	**Mention the transmission voltages that are followed in Tamil Nadu. (R2013-A/M 2017) BTL1** The Tamil Nadu Transmission Corporation Limited (TANTRANSCO) is an electric power transmission system operator owned by Government of Tamil Nadu. It was established in November 2010, as a result of restructuring the Tamil Nadu Electricity Board. It is a subsidiary of TNEB Limited. The TANTRANSCO maintains all the substations in Tamil Nadu apart from the Power Grid Corporation of India Limited (PGCIL). 400/230 kV substations, 230/110 kV substations, 110 kV substations, 33 Kv substations.
19	**8. Why EHV lines are constructed using bundle conductors? BTL1** i.To reduce corona loss, ii. To minimize interference, iii. To reduce circuit inductance ,iv.To decrease voltage drop, v. To increase stability margin

Table for question 16:

GMD	GMR
It is also called as mutual GMD	It is also called as self GMD
Geometrical mean of the distance from one end to other	Geometrical mean of distance between all pair of element
It is depend upon spacing	Independent of spacing
Independent on size and shape	Depend on size and shape

20

9. Write the advantages of A.C transmission. BTL1

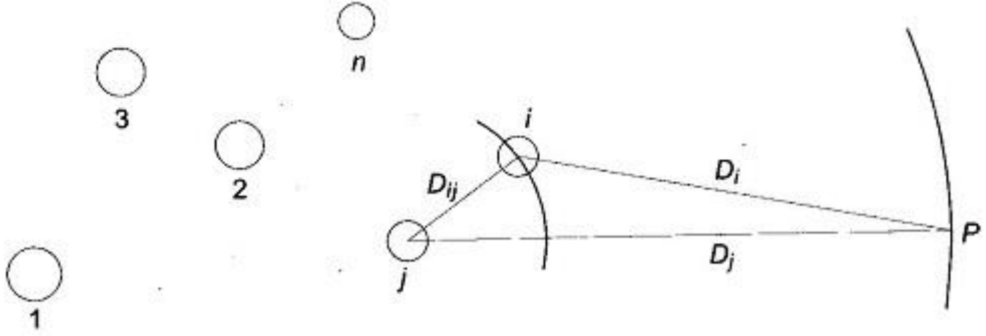
The advantages of A.C transmission are:

1. It can be generate power at very high voltages.
2. The maintenance of A.C. substation is easy and cheaper.
3. A.C. voltage can be stepped up or stepped down with the help of transformer.
4. Construction is simple.
5. Fault can be detected very easily.
6. There is no converter device required.

PART –B

1. (i)Derive an expression for the flux linkages of one conductor in a group of n-conductors carrying currents whose sum is zero. Hence derive an expression for inductance of composite conductors of a single phase consisting of m-strands in one conductor and n-strands in the other conductor. **(R2008-N/D2014) BTL3**

Flux Linkages of one Conductor in a Group – As shown in Fig. , consider a group of *n* parallel round conductors carrying phasor currents I_1, 1_2,…, I_n whose sum equals zero. Distances of these conductors from a remote point *P* are indicated as D_1, D_2,…, D_n. Let us obtain an expression for the total flux linkages of the ith conductor of the group considering flux up to the point *P* only.



$$\lambda_{ii} = 2 \times 10^{-7} I_i \ln \frac{D_i}{r'_i} \text{ Wb-T/m}$$

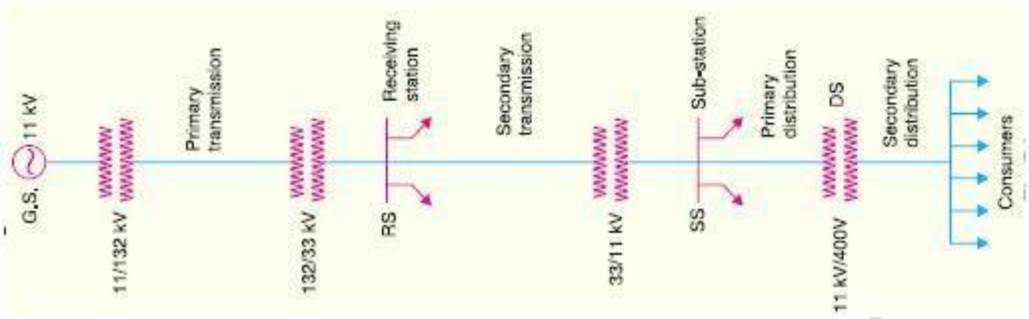
$$\lambda_{ij} = 2 \times 10^{-7} I_j \ln \frac{D_j}{D_{ij}} \text{ Wb-T/m}$$

$$\lambda_i = \lambda_{i1} + \lambda_{i2} + \dots + \lambda_{ii} + \dots + \lambda_{in}$$

$$= 2 \times 10^{-7} \left(I_1 \ln \frac{D_1}{D_{i1}} + I_2 \ln \frac{D_2}{D_{i2}} + \dots + I_i \ln \frac{D_i}{r'_i} + \dots + I_n \ln \frac{D_n}{D_{in}} \right)$$

	In order to account for total flux linkages of conductor *i*, let the point *P* now recede to infinity. The terms such as In D_1/D_n etc. approach In 1 = 0. Also for the sake of symmetry, denoting r'_i as D_{ii}, we have $\lambda_i = 2 \times 10^{-7} \left(I_1 \ln \frac{1}{D_{i1}} + I_2 \ln \frac{1}{D_{i2}} + I_2 \ln \frac{1}{D_{ii}} + \ldots + I_n \ln \frac{1}{D_{in}} \right)$ Wb-T/m
2.	A 220kV,50Hz, 200km long transposed three phase line has its conductors on the corners of triangle with sides 6m, 6m and 10m.The conductor radius is 1.81cm. Find the capacitance per phase per km of the line. (8) **(R2013-N/D2017) BTL3** Equilateral spacing d1=6m, d2=6m d3=a0m. Radius of conductor= r= 1.81 cm Capacitance of each conductor to neutral = 2πεo/log d/r F/m
3.	Derive the expression for inductance of a three phase line with unsymmetrical Spacing. **(R2008-N/D 2010), (R2013-N/D2017) R2017 N/D 2018BTL3** It is rather difficult to maintain symmetrical spacing as shown in Fig. while constructing a transmission line. With asymmetrical spacing between the phases, the voltage drop due to line inductance will be unbalanced even when the line currents are balanced. Consider the three-phase asymmetrically spaced line shown in Fig. 1in which the radius of each conductor is assumed to be *r* . The distances between the phases are denoted by D_{ab}, $D_{bc}$and D_{ca}. We then get the following flux linkages for the three phases. $\lambda_a = 2\times10^{-7}\left(I_a \ln \frac{1}{r'} + I_b \ln \frac{1}{D_{ab}} + I_c \ln \frac{1}{D_{ca}} \right)$ $\lambda_c = 2\times10^{-7}\left(I_c \ln \frac{1}{r'} + I_a \ln \frac{1}{D_{ca}} + I_b \ln \frac{1}{D_{bc}} \right)$ $\lambda_b = 2\times10^{-7}\left(I_b \ln \frac{1}{r'} + I_a \ln \frac{1}{D_{ab}} + I_c \ln \frac{1}{D_{bc}} \right)$

	It can be seen that the inductances contain imaginary terms. The imaginary terms will vanish only when D_{ab}= D_{bc}= D_{ca}.
4.	Draw and explain the structure of typical electrical power system with various voltage levels BTL2 R2017 A/M 2019 **Answer:** ***1. Generating station:*** **i)** Generating station represents the generating station, where electric power is produced by 3 phase alternator operating in parallel. **ii)** The usual generation voltage is 11kV. The power generated at this voltage is stepped upto 132 kV, 220kV, 400 kV. As the transmission of electric power at high voltages have so many advantages, viz; saving of conducting material, high transmission efficiency and less sine loss. ***1. Primary Transmission:*** i) The electric power at high voltage (say 132 kV) is transmitted by 3 phase, 3 wire overhead system to the outskirts of the city. This form the primary transmission ***2. Secondary Transmission:*** **i)** The primary transmission line terminates at the receiving station, which usually lies at the outsides of the city at the receiving station, the voltage is reduced is reduced to 33 kV by 3 phase, 3 wire over head system to various sub stations located at the strategic points in the city. This forms secondary transmission. ***3. Primary Distribution :*** **i)** The secondary transmission line terminates at the sub station where voltage is reduced from 33 kV to 11 kV 3 phase 3 wire. **ii)** The 11 kV line runs along the important roadsides of the city. This forms the primary Distribution. ***4. Secondary Distribution:*** **i)** The electric power from primary distribution line is delivered to distribution sub stations. **ii)** These sub stations are located near the consumer localities and step down the voltage to 400 V and between any phase and neutral is 230V. **iii)** The 3 phase residential lighting load is connected between any one phase and neutral whereas 3 phase 400V motor loads are connected across 3 phase lines directly.



5

4. Compare EHVAC and HVDC transmission system.

BTL2(ND16) Comparison of HVDC and EHVAC Transmission

The relative merits of the two modes of transmission which need to be considered by a system is based on the following factors:

1. Economics of transmission
2. Technical performance
3. Reliability

1. Economics of transmission

(i) Investment cost

(ii) Operational cost

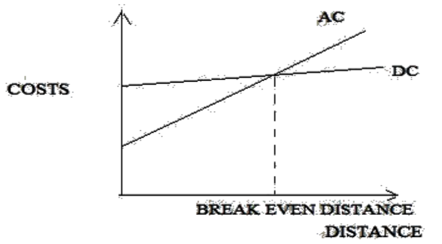
Investment Cost

It includes cost of right of way, transmission towers, conductors, insulators and terminal equipment.

Operational Cost

Mainly includes the cost of losses.

- The characteristics of insulators vary with the type of voltage applied.
- DC line can carry power with two conductors whereas AC needs three conductors.
- For a given power level, DC line requires less Right of Way, simpler and cheaper towers and reduced conductor and insulator costs.
- Power losses are also reduced in DC as there are only two conductors.
- Absence of skin effect with DC is also beneficial in reducing power losses.
- Corona effects tend to be less significant on DC conductors than for AC
- AC tends to be more economical for less than breakeven distance and costlier for

	longer distances • Breakeven distances can vary from 500 to 800km in overhead lines depending on the per unit line costs 

	PART*C

1. Derive from first principles the capacitance per km to neutral of three phase overhead transmission line with overhead transmission line with unsymmetrical spacing of conductors assuming transportation **BTL3**

(i) Starting from fundamental derivation of flux linkages with conductor per phase, derive an expression for the inductance per phase for a 3 phase overhead transmission system when conductors are symmetrically placed. (10) **(R2008-A/M 2015) BTL3**

(ii)A 3 phase 80 km long transmission line has its conductors of 1.0 cm diameter spaced at the corners of the equilateral triangle of 100 cm side. Find the inductance per phase of the system. (6) **(R2008-A/M 2015)**

1. (i) Explain about skin and proximity effects. **(R2008 – N/D 2013)**

(ii)If the double circuit 3 phase line shown has conductors of diameter 2.5 cm and distance of separation (D) is 2 m in the hexagonal spacing arrangement, calculate the phase to neutral capacitance in µF per 100 km of the line. (10) **(R2008-A/M 2015) BTL3**

A single phase line consists of two parallel conductors which form a rectangular loop of one turn. When an alternating current flows through such a loop, a changing magnetic flux is set up. The changing flux links the loop and hence the loop (or single phase line) possesses inductance. It may appear that inductance of a single phase line is negligible because it consists of a loop of one turn and the flux path is through air of high reluctance. But as the X

- sectional area of the loop is very large, even for a small flux density, the total flux linking the loop is quite large and hence the line has appreciable inductance.

The conductors are spaced several metres and the length of the line is several kilometres. Therefore, the loop has a large X-sectional area.

Consider a single phase overhead line consisting of two parallel conductors *A* and *B* spaced
d metres apart as shown in Fig. Conductors *A* and *B* carry the same amount of current

(*i.e.* $I_A = I_B$), but in the opposite direction because one forms the return circuit of the other.

☐ $I_A + I_B = 0$

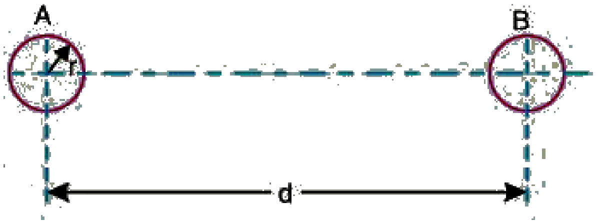


Fig.2.6

Flux linkages with conductor *A* due to its own current

$$= \frac{\mu_0 \, I_A}{2\pi}\left(\frac{1}{4} + \int_r^{\infty} \frac{dx}{x}\right) \quad ...(i)$$

Flux linkages with conductor *A* due to current I_B

$$= \frac{\mu_0 \, I_B}{2\pi}\int_d^{\infty} \frac{dx}{x} \quad ...(ii)$$

In order to find the inductance of conductor *A* (or conductor *B*), we shall have to consider the flux linkages with it. There will be flux linkages with conductor *A* due to its own current

I_A and also due to the mutual inductance effect of current I_B in the conductor *B.*

Total flux linkages with conductor A is

$$\psi_A = \text{exp. } (i) + \text{exp } (ii)$$

$$= \frac{\mu_0 I_A}{2\pi}\left(\frac{1}{4} + \int_r^{\infty}\frac{dx}{x}\right) + \frac{\mu_0 I_B}{2\pi}\int_d^{\infty}\frac{dx}{x}$$

$$= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} + \int_r^{\infty}\frac{dx}{x}\right)I_A + I_B\int_d^{\infty}\frac{dx}{x}\right]$$

$$= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} + \log_e \infty - \log_e r\right)I_A + \left(\log_e \infty -\right.\right.$$

$$= \frac{\mu_0}{2\pi}\left[\left(\frac{I_A}{4} + \log_e \infty\,(I_A + I_B) - I_A \log_e r - I\right.\right.$$

$$= \frac{\mu_0}{2\pi}\left[\frac{I_A}{4} - I_A \log_e r - I_B \log_e d\right] \quad (\because I_A$$

Now, $I_A + I_B = 0$ or $-I_B = I_A$

$\therefore$ $-I_B \log_e d = I_A \log_e d$

$\therefore$ $\psi_A = \frac{\mu_0}{2\pi}\left[\frac{I_A}{4} + I_A \log_e d - I_A \log_e r\right]$ wb

$$= \frac{\mu_0}{2\pi}\left[\frac{I_A}{4} + I_A \log_e \frac{d}{r}\right]$$

$$= \frac{\mu_0 I_A}{2\pi}\left[\frac{1}{4} + \log_e \frac{d}{r}\right] \text{ wb-turns/m}$$

Inductance of conductor $A, L_A = \frac{\psi_A}{I_A}$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4} + \log_e \frac{d}{r}\right] \text{H / m} = \frac{4\pi \times 10^{-7}}{2\pi}\left[\frac{1}{4} + \text{l}\right.$$

$\therefore$ $L_A = 10^{-7}\left[\frac{1}{2} + 2\log_e \frac{d}{r}\right] \text{H / m}$

Loop inductance $= 2\,L_A$ H/m $= 10^{-7}\left[1 + 4\log_e \frac{d}{r}\right] \text{H / m}$

$\therefore$ Loop inductance $= 10^{-7}\left[1 + 4\log_e \frac{d}{r}\right] \text{H / m}$

Derive the expression for inductance of 3 – phase transmission line. (ND10, MJ13, ND15)

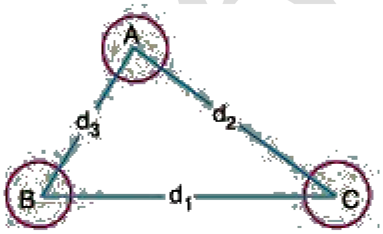
Inductance of a 3-Phase Overhead Line *BTL3*

Fig.2.7 shows the three conductors *A*, *B* and *C* of a 3-phase line carrying currents I_A, I_B and I_C

respectively. Let d_1, d_2 and d_3 be the spacings between the conductors as shown. Let us

further assume that the loads are balanced *i.e.* $I_A + I_B + I_C = 0$. Consider the flux linkages with conductor *A*. There will be flux linkages with conductor *A* due to its own current

and also due to the mutual inductance effects of I_B and I_C.



UNIT II -
MODELLING AND PERFORMANCE OF TRANSMISSION LINES

Performance of Transmission lines - short line, medium line and long line - equivalent circuits, phasor diagram, attenuation constant, phase constant, surge impedance - transmission efficiency and voltage regulation, real and reactive power flow in lines - Power Circle diagrams - Formation of Corona – Critical Voltages – Effect on Line Performance.

PART*A

1. **Define transmission efficiency. (R2013-N/D 2015) BTL1**

The ratio of power obtained at the receiving end to the power at sending end is called transmission efficiency of the line.

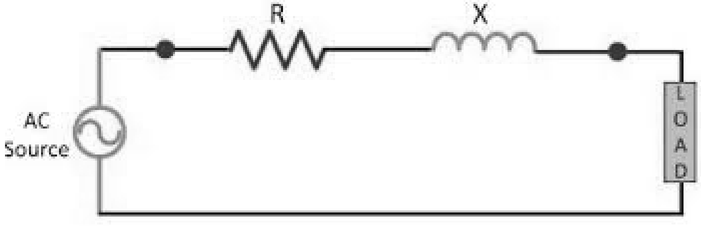
2. **Define voltage regulation of a transmission line. (R2008-M/J 2014)**

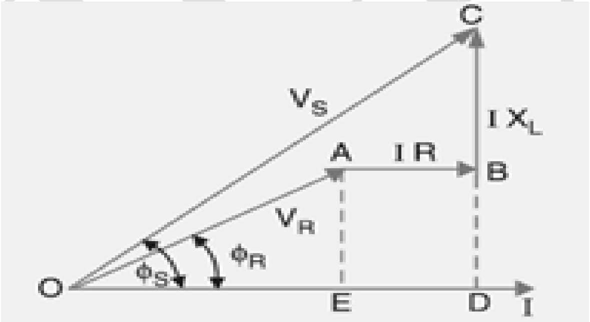
Define voltage regulation in connection with transmission lines. (R2008-N/D2012), (R2008 – N/D 2013) BTL1 R2017 A/M 2019

It is defined as the change in receiving end voltage expressed in percentage of full load voltage when load is from NL to FL keeping sending end voltage and frequency as constant.

%regulation = $\frac{Vro-Vr}{Vr}$x100 or %regulation = (Vs – Vr)/Vr × 100

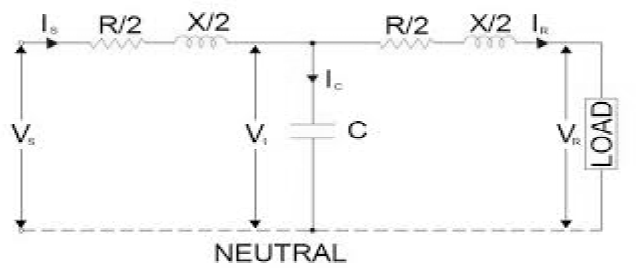
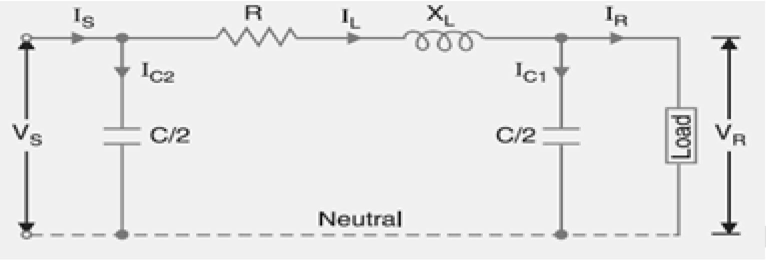
3. **Draw the equivalent circuit and phasor diagram for short transmission line. (R2008-M/J 2016)BTL1**





4. **Draw the normal T and π model of medium transmission line with its parameter filled. (R2008-A/M 2015) BTL1**

Nominal T

	 **Nominal π** 
5.	**What is the difference between nominal T and nominal π methods? (R2008-M/J 2014) BTL1** In nominal T method, the total capacitance of each conductor is concentrated at the centre of the line and half the line impedance is lumped on its either side. In nominal πmethod, one half of the total capacitance of each conductor is lumped at both the ends.
6.	**Mention the range of surge impedance value for a overhead transmission line and a underground cable? (R2008-M/J 2016) BTL1** **What is the range of surge impedance in case of underground cables? (R2008-N/D2012)** An impedance which renders the line as infinite line is known as surge impedance. It has a value of about 400 ohms and phase angle varying from 0 to –15 degree for overhead lines and around 40 - 50ohms for underground cables.
7.	**Write the formula for finding surge impedance of transmission line. (R2013-N/D 2015) BTL1** In the power system network the characteristic impedance is sometimes referred as surge impedance. It is defined as $\sqrt{(Z/Y)}$ or $\sqrt{(Zoc.Zsc)}$ Where, Z = series impedance of line, Y = Shunt admittance of line. where Zoc and Zsc are impedances measured at sending end with the receiving end open circuited and short circuited.
8.	**What is meant by surge impedance? (R2008-A/M 2015) BTL1** An impedance which renders the line as infinite line is known as surge impedance.

9. **Distinguish between attenuation and phase constant. (R2008-N/D 2011) BTL1**

S.NO	ATTENUATION CONSTANT.	PHASE CONSTANT.
1	The real part of propagation constant	The imaginary part of propagation constant
2	It is denoted by α	It is denoted by β
3	It is the change in the magnitude per unit length of the line	It is the change in the phase per unit length of the line
4	It is expressed in nepers per unit length	It is expressed in radians per unit length

10. **What is surge impedance loading? (R2013-A/M 2018) BTL1**

In electric power transmission, the characteristic impedance of a transmission line is expressed in terms of the surge impedance loading (SIL), or natural loading, being the power loading at which reactive power is neither produced nor absorbed: The surge impedance loading of a line is the power delivered by a line to a purely resistive load equal to its surge impedance. The line is assumed to have no resistance.

$$Surge\ impedance\ loading\ = \frac{VLL^2}{Zo}$$

11. **What is Ferranti effect? (R2016- A/M 2015), (R2013-N/D2017), (R2013-M/J 2016), (R2008-N/D 2010), (R2013-A/M 2017), (R2013-A/M 2018), (R2008-N/D 2011), (R2008 – N/D 2013) BTL1**

At no load condition in transmission line the voltage at receiving and is more than that sending end because of the effect of the line capacitance. In electrical engineering, the Ferranti effect is an increase in voltage occurring at the receiving end of a long transmission line, above the voltage at the sending end. This occurs when the line is energized, but there is a very light load or the load is disconnected. The capacitive line charging current produces a voltage drop across the line inductance that is in-phase with the sending end voltages considering the line resistance as negligible. Therefore both line inductance and capacitance are responsible for this phenomenon.

Under no load or light loadconditions, $V_R > V_S$

12. **How are transmission line classified? (R2013-N/D2017) BTL1**

Short transmission line - length is about 50 km and the line voltage is less than 20kv

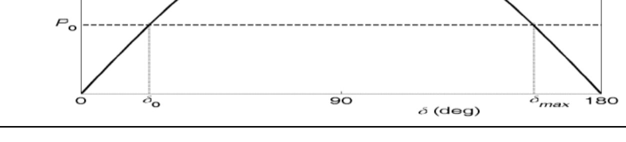
Medium transmission line - length is about 50 to 150 km and the line voltage is 20kv to 100kv

Long transmission line - length is about 150 km and the line voltage is Above 100kv

13. **State the condition of maximum power delivered and draw the power angle diagram. (R2013-N/D 2016) BTL1**

The sending and receiving end voltages be given by

,$V_S = V_1\angle\delta, \quad V_R = V_2\angle 0°$, $P_{max} = V_1V_2/X$ is the maximum power that can be transmitted over the transmission line.



14.	**What is corona? (R2013-M/J 2016) BTL1** It can be noticed that near the overhead lines there exists a hissing noise and sometimes a faint violet glow. The effect due to which such phenomenon exists surrounding the overhead lines is called corona effect
15.	**Mention the significance of surge impedance loading. (R2013-M/J 2016), (R2013-A/M 2017) BTL1** It is used in the prediction of maximum loading capacity of transmission lines. The theoretical significance of the surge impedance is that if a purely resistive load, equal to o the end of a transmission line with no resistance, a voltage surge introduced to the sending end of the line would be absorbed completely at the receiving end.
16.	**What are the methods adopted to reduce corona loss? (R2013-A/M 2018) BTL1** Increasing the conductor size Increasing the conductor spacing Using hollow and bundled conductors
17.	**Define Critical disruptive voltage. (R2008-N/D2014), (R2008-N/D 2011)** **What is meant by disruptive critical voltage? (R2008 – N/D 2013) BTL1** It is defined as the voltage at which complete disruption of dielectric occurs. This voltage corresponds to the gradient at the surface equal to breakdown strength of air. It is the minimum disruptive voltage at which corona occurs. $V_c=g_o\delta m_o r \ln(D/r)$ KV/phase where, g_o - potential gradient at the surface of conductor (volts/cm) δ - air density correction factor, m_o - irregularity factor r - radius of conductor (cm), D - spacing between conductor (cm)
18.	**What is meant by 'natural loading' of transmission lines? (R2008-N/D2014) BTL1** The natural or surge impedance loading or SIL of a transmission line is the MW loading of a transmission line at which a natural reactive power balance occurs. It is the maximum power transmitted when a lossless line operating at its nominal voltage, is terminated with a resistance equal to surge impedance of the line.
19.	**Why the control of reactive power is essential for maintaining a desired voltage profile? (R2008-N/D2014) BTL1** **1.** To produce substantially flat voltage profile, **2.** To improve the system stability, **3.** To increase the power transfer capacity.

20.	**Define visual corona. BTL1** **Visual critical voltage** It is the minimum phase-neutral voltage at which corona glow appears all along the line conductors. It has been seen that in case of parallel conductors, the corona glow does not begin at the disruptive voltage Vcbut at a higher voltage Vv, called visual critical voltage. The phase-neutral effective value of visual critical voltage is given by the following empirical formula:
	PART * B
1.	*Explain corona formation, factors affecting corona and methods to reduce the corona (ND12, MJ15) BTL2 AM 2018* **Corona** When an alternating potential difference is applied across two conductors whose spacing is large as compared to their diameters, there is no apparent change in the condition of atmospheric air sur- rounding the wires if the applied voltage is low. when the applied voltage exceeds a certain value, called critical disruptive voltage, the conductors are surrounded by a faint violet glow called corona. The phenomenon of corona is accompanied by a hissing sound, production of ozone, power loss and radio interference. The higher the voltage is raised, the larger and higher the luminous envelope becomes, and greater are the sound, the power loss and the radio noise. If the applied voltage is increased to breakdown value, a flash-over will occur between the conductors due to the breakdown of air insulation. The phenomenon of violet glow, hissing noise and production of ozone gas in an overhead transmission line is known as **corona.** If the conductors are polished and smooth, the corona glow will be uniform throughout the length of the conductors, otherwise the rough points will appear brighter. With d.c. voltage, there is difference in the appearance of the two wires. The positive wire has uniform glow about it, while the negative conductor has spotty glow. *(i) Corona formation* Some ionisation is always present in air due to cosmic rays, ultraviolet radiations and radioactivity. Therefore, under normal conditions, the air around the conductors contains some ionised particles (*i.e.*, free electrons and +ve ions) and neutral molecules. When p.d. is applied between the conductors, potential gradient is set up in the air which will have maximum value at the conductor surfaces. Under the influence of potential gradient, the existing free electrons acquire greater velocities. The greater the applied voltage, the greater the potential gradient and more is the velocity of free

2. *Explain the following i) Critical disruptive voltage ii) visual critical voltage iii) power* ‘ **loss due to corona iv) Advantages and disadvantages of corona (MJ15, ND16, MJ17) BTL2**

(i) Critical disruptive voltage. It is the minimum phase-neutral voltage at which corona occurs.

Consider two conductors of radii r cm and spaced d cm apart. If V is the phase-neutral potential, then potential gradient at the conductor surface is given by:

3 **Derive the expression for voltage regulation and transmission efficiency of short transmission line. (MJ13) BTL3 A/M 2019**

Performance of single phase Short Transmission Lines:

- The effects of line capacitance are neglected for a short transmission line.
- Therefore, while studying the performance of such a line, only resistance and inductance of the line are taken into account.
- The equivalent circuit of a single phase short transmission line is shown in Fig.3.1 (i).
- Here the total resistance and inductance are shoen as concentrared or lumped instead of being distributed. The circuit is a simple ac series circuit.

Let I = load current

R = loop resistance *i.e.*, resistance of both conductors

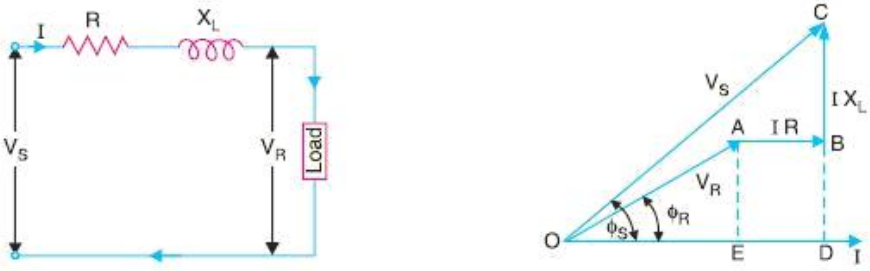
X_L = loop reactance

V_R = receiving end voltage

$\cos \phi_R$ = receiving end power factor (lagging)

V_S = sending end voltage

$\cos \phi_S$ = sending end power factor



(*i*) (*ii*)

The *phas .1 (*ii*). From the right angled traingle *ODC*, we get,

* **Phasor diagram.** Current I is taken as the reference phasor. OA represents the receiving end

voltage VR leading I by □R. AB represents the drop IR in phase with I. BC represents the inductive drop IXL and leads I by 90 O. OC represents the sending end voltage V and leads I by □ .

$$
\begin{aligned}
& & (OC)^2 &= (OD)^2 + (DC)^2 \\
&\text{or} & V_S^2 &= (OE + ED)^2 + (DB + BC)^2 \\
& & &= (V_R \cos \phi_R + IR)^2 + (V_R \sin \phi_R + IX_L)^2 \\
&\therefore & V_S &= \sqrt{(V_R \cos \phi_R + IR)^2 + (V_R \sin \phi_R + IX_L)^2}
\end{aligned}
$$

$$(i) \quad \text{\%age Voltage regulation} = \frac{V_S - V_R}{V_R} \times 100$$

$$(ii) \quad \text{Sending end } p.f., \cos \phi_S = \frac{OD}{OC} = \frac{V_R \cos \phi_R + IR}{V_S}$$

$$
\begin{aligned}
(iii) \quad \text{Power delivered} &= V_R I_R \cos \phi_R \\
\text{Line losses} &= I^2 R \\
\text{Power sent out} &= V_R I_R \cos \phi_R + I^2 R \\
\text{\%age Transmission efficiency} &= \frac{\text{Power delivered}}{\text{Power sent out}} \times 100 \\
&= \frac{V_R I_R \cos \phi_R}{V_R I_R \cos \phi_R + I^2 R} \times 100
\end{aligned}
$$

PART*C

1 Deduce an expression for the sending end and receiving end power of a line in terms of voltages and ABCD constant. **(R2013-N/D2017) BTL3**

ii)A 220kV,50Hz, 200km long transposed three phase line has its conductors on the corners of triangle with sides 6m, 6m and 10m.The conductor radius is 1.81cm. Find the capacitance per phase per km of the line.(8) **(R2013-N/D2017) BTL3**

Explain the formation of corona, critical voltages, corona loss, advantages, disadvantages and methods to reduce the effect of corona.

. A 3ϕ, 50Hz, transmission 30km long has a total series impedance of (40+j125) Ω and shunt admittance of 10-3 mho. The load is 50MW at 220kV with 0.8pf lag. Find the sending end voltage, current, power factor, efficiency and regulation using nominal π-method.(16) **(R2013-N/D2017)**

Derive the expression for the real and reactive power flow through transmission lines. (16) **(R2013-N/D2017)**

(ii) A three phase transmission line having a series impedance (20+j30)Ω delivers 7MW at 33kV and 0.8 lagging power factor. Find the sending and voltage, regulation and power angle. Neglect shunt capacitance.(6) **(R2013-N/D2017) BTL3**

	UNIT III – MECHANICAL DESIGN OF LINES
	Mechanical design of OH lines – Line Supports –Types of towers – Stress and Sag Calculation – Effects of Wind and Ice loading. Insulators: Types, voltage distribution in insulator string, improvement of string efficiency, testing of insulators
	PART*A
1.	**What are the factors on which conductor spacing and ground clearance depend? (R2008-N/D2014) BTL1** Nominal system Voltage, Maximum Voltage, Size of the conductor, Sag and Tension, Diameter and shape of conductor.
2.	**What is a shackle insulator? (R2008-M/J 2014) BTL1** When the low voltage transmission line meets a dead end or a corner or a sharp curve it is subjected to a greater tension. The insulators, which are used to relieve the low voltage line of excessive tension, are called shackle insulators.
3.	**1. What are the advantages of string insulators? (R2008-N/D 2011) BTL1** Cheaper than pin type insulators for voltage greater than 33 KV Number of disc can be inserted depending upon the voltage that flows. Failure in any one unit will not affect the entire string. Replacement can be done easily.More flexibility. Conductor runs below the cross arm, so line conductors are less affected by lightening. Arrangements act as lightening arrestors.
4.	**4. What is the purpose of insulator? (R2016- A/M 2015) BTL1** (a) The insulators provide necessary insulation between line conductors and supports andthus prevent any leakage current from conductors to earth
5.	**5. Define safety factor of insulator. Why it is desired to have this value be high? (R2008-A/M 2015) BTL1** The ratio of puncture strength to flash over voltage is called as safety factor. It is desirable to have high value of safety factor so that a flash-over takes place before the insulator gets punctured. For pin type insulators, the value of safety factor is about 10.

6.	**What is meant by tower spotting? (R2013-N/D 2015) BTL1** After tower designs are finalised the spotting chart or structure limitator charts are prepared. It is a precise job as it has an implication on overall cost
7.	**What is a sag template? (R2008-M/J 2014), (R2013-N/D 2015), (R2013-A/M 2018) BTL1** A Sag Template is a very important tool with the help of which the position of towers on the Profile is decided so that they conform to the limitations of vertical and wind loads on any particular tower, and minimum clearances, as per I.E. Rules, required to be maintained between the line conductor to ground, telephone lines, buildings, streets, navigable canals, power lines, or any other object coming under or near the line.
8.	**Define string efficiency. (R2008-M/J 2016), (R2013-N/D 2015), (R2008-N/D 2010) N/D 2018 BTL1** The ratio of voltage across the whole string to the product of number of discs and the voltage across the disc nearest to the conductor is known as string efficiency. $\%\text{ string efficiency} = \dfrac{\text{Voltage across string}}{\mathbf{n \times Voltage\ across\ disc\ nearest\ to\ the\ conductor}} \times 100$
9.	**What are the methods of improving string efficiency in line insulators? (R2013-N/D 2016)** (i) By using longer cross arms (ii) By grading the insulators (iii) By using a guard ring
10.	**What are the desirable properties of insulator? (R2013-N/D2017) BTL1** (i)High mechanical strength. (ii) High electrical resistance (iii) High relative permittivity (iv) High ratio of puncture strength (v) The insulator material should be non porou
11.	**Give the significance of a stringing chart. (R2013-N/D2017) BTL1** For finding the sag in the conductor In the design of insulator string In the design of tower To find the distance between the towers
12.	**What are the factors affecting sag in a transmission line? (R2013-N/D 2016), (R2008-N/D 2010), (R2008-M/J 2016)N/D 2019** **Enlist any two factors that affect sag in the transmission line. (R2013-A/M 2017)** **Give any two factors that affect sag in an overhead line. (R2008-N/D2012) BTL1** The two factors that affect the sag in transmission line arethe length of span , the working tensile stress which depends on the wind and the ice load. Tension and sag of a conductor is always compensated with respect to the design.

14.	**What are the tests performed on the insulators? (R2013-M/J 2016) BTL1** Mechanical tests, Electrical insulation tests, Environmental tests, Temporary cycle tests and corona and radio interference tests According to the British Standard, the electrical insulator must undergothe following tests . Flashover tests of insulator . Performance tests . Routine tests
15.	**Specify the different types of insulators. (R2013-A/M 2017) BTL1** Pin type insulators, (ii) Suspension insulators (iii) Strain insulators (iv) Shackle insulators (v) Stay insulators ➢
16.	**State the advantages of suspension type insulators. (R2013-A/M 2018) BTL2** Each unit of disc is designed for a low voltage, say 11 kV. Hence, depending upon the working voltage, desired number of discs can be connected in series to form an insulator string suitable for particular voltage. If any of the discs in insulator string is damaged, it can be replaced easily. Replacement of the whole string is not required. In case of increased demand on the line, the line voltage can be increased and the additional insulation required for the raised voltage can be easily provided by adding the desired number of discs in the insulator strings. As the line conductors are suspended by suspension strings, they run below the earthed cross-arms of the towers. This arrangement provides partial protection from lightning.
17.	**Define sag. (R2013-M/J 2016), (R2008 – N/D 2013) BTL1** Thedifferenceinlevelbetweenthepointsof supportsandthelowestpointofthe conductoris called as sag.
18.	**Why are insulators used in overhead lines? (R2008-N/D2014) BTL1** Insulators are used to support the conductors and withstand both the normal operating voltage and surges due to switching and lightning. It also provide necessary insulation between line conductors, tower and thus prevent any leakage from conductors to earth
19.	**Mention the Benefits of Transmission Line Surge Arresters.** BTL1 Lowers initial cost of new or transmission line upgrades by making construction more compact and transmitting more energy in the same right of way. ➢ Reduces the height of transmission lines by eliminating shield wire. ➢ Improves outage statistics by eliminating back flashover from the tower ground lead to the phase conductor.
20.	**How does grading ring improve string efficiency? (R2008 – N/D 2013) BTL1** This method uniforms the potential distribution across each units in insulator strings. Thereby string efficiency improves.

	PART*B
1.	An overhead line has a span of 160m of stranded copper conductor between level supports. The sag is 3.96 m at —5.50 C with 9.53 mm thick in ice coating and wind pressure of 40 Kgf/m2 of projected area. Calculate the temperature at which the sag will remain the same under conditions of no ice and no wind. The particulars of the conductor are as follows: Size of conductor 7/3.45 mm, Area of cross section 64.5 mm2 weight of conductor 0.594 Kgf/m, Modulus of elasticity 12700 Kgf/mm2, CoeficientQf linear expansion 1.7 x 10-510 C, Assume 1 ms of ice to weight 913.5 Kgf. **(R2008-M/J 2014) BTL3** A transmission line has a span of 275m between level supports. The conductor has an effective diameter of 1.96cm and weighs 0.865kg/m.If the conductor has ice coating of radial thickness 1.27 cm and is subjected to a wind pressure of 3.9gm/sq.cm of projected area.The ultimate strength of the conductor is 8060 kg.Calculate the sag if the factor safety is 2 and weight of 1 c.c of ice is 0.91gm**. (R2013-M/J 2016), (R2008-N/D2014) BTL3** Each line of a 3 phase system is suspended by a string of 3 identical insulators of self capacitance C farad. The shunt capacitance of connecting metal work of each insulator is 0.2 C to earth and 0.1 C to line. Calculate the string efficiency of the system, if a guard ring increases the capacitance to the line of metal work of the lowest insulator to 0.3C. **(R2008-N/D2014) BTL3** What are the various properties of insulators? Draw with neat sketches and explanation of pin and suspension type insulators. Compare their merits and demerits. **(R2008-M/J 2014),** R2008-N/D 2010), **(R2013-N/D2017),** (R2016- A/M 2015), **(R2008-N/D2014)N/D 2019** An insulator string consists of three units each having a safe working voltage of 15 Kv. The ratio of self capacitance to shunt capacitance is 6:1. Determine the line voltage and string efficiency. **(R2013-N/D2017)** Prove that a transmission line conductor between two supports at equal heights takes the form of a catenary. **(R2013-N/D2017)** What is a sag template?Explain how this is useful for location of towers and stringing of power conductors. **(R2013-N/D2017)**

2	***Describe the various methods to improve string efficiency. (ND12, ND15, MJ16)*** ***Methods of Improving String Efficiency*** *BTL3* • It has been seen above that potential distribution in a string of suspension insulators is not uniform. The maximum voltage appears across the insulator nearest to the line conductor and decreases progressively as the cross arm is approached. • If the insulation of the highest stressed insulator breaks down or flash over takes place, the breakdown of other units will take place in succession. • This necessitates equalizing the potential across the various units of the string *i.e.* to improve the string efficiency. The various methods for this purpose are: • The value of string efficiency depends upon the value of K i.e., ratio of shunt capacitance to mutual capacitance. The lesser the value of K, the greater is the string efficiency and more uniform is the voltage distribution. • The value of K can be decreased by reducing the shunt capacitance. In order to reduce shunt capacitance, the distance of conductor from tower must be increased i.e., longer cross-arms should be used.
3	**1. Explain with neat sketch, the different types of insulators.(ND10, MJ14, ND14, MJ15, ND16) BTL2** **Types of Insulator** There are mainly three types of insulator likewise 1. Pin Insulator 2. Suspension Insulator 3. Stray Insulator ***In addition to that there are other two types of electrical insulator available mainly for low voltage application, i.e stay insulator and shackle i***

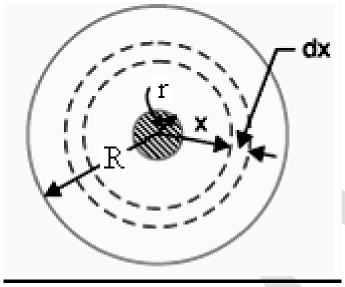
	PART*C
1.	A string of eight suspension insulators is to be graded to obtain uniform distribution of voltage across the string.If the capacitance of the top unit is 10 times the capacitance to ground of each unit,determine the capacitance of the remaining seven units.(10) **(R2013-N/D 2015),** (R2008-M/J 2016) **A/M 2018 BTL3** A transmission line conductor at a river crossing from towers at heights of 50m and 80m above water level. The horizontal distance between between the towers is 300m. If the tension in the conductor is 2000kg, find the clearance between the conductor and water level point midway between the towers. Weight of conductor per metre = 0.84. Assume that the conductor takes the shape of a parabola. (R2008-M/J 2016) **A/M 2018 BTL3** A string of eight suspension insulators is to be graded to obtain uniform distribution of voltage across the string.If the capacitance of the top unit is 10 times the capacitance to ground of each unit,determine the capacitance of the remaining seven units.(10) **(R2013-N/D 2015),** (R2008-M/J 2016)

	UNIT IV – UNDER GROUND CABILITYS
	Underground cabilitys - Types of cabilitys – Construction of single core and 3 core Cabilitys - Insulation Resistance – Potential Gradient - Capacitance of Single-core and 3 core cabilitys Grading of cabilitys - Power factor and heating of cabilitys– DC cabilitys.
S.No.	**PART*A**
1	**1. What is belted cable? (R2013-N/D2017) BTL1** The conductors (usually three) are bunched together and then bounded with an insulating paper ‘belt’. In such cables, each conductor is insulated using paper impregnated with a suitable dielectric. The gaps between the conductors and the insulating paper belt are filled with a fibrous dielectric material such as Jute or Hessian. This provides flexibility as well as a circular shape. As we discussed earlier (in Construction of Cables), the jute layer is then covered by a metallic sheath and armouring for protection. One particular speciality of this cable is that its shape may not be perfectly circular. It is kept non-circular to use the available space more effectively
2	**State the limitations of solid type cables. How are these overcome in pressure cables? (R2008-A/M 2015) BTL1** Limitations of solid type cables. All the cables of above construction are referred to as solid type cables because solid insulation is used and no gas or oil circulates in the cable sheath. The voltage limit for solid type cables is 66 kV due to the following reasons : a As a solid cable carries the load, its conductor temperature increases and the cable com-

	pound insulating compound over paper) expands. This action stretches the lead sheath which may be damaged. b.When the load on the cable decreases, the conductor cools and a partial vacuum is formed within the cable sheath. If the pinholes are present in the lead sheath, moist air may be drawn into the cable. The moisture reduces the dielectric strength of insulation and may eventually cause the break-down of the cable. C .In practice, voids are always present in the insulation of a cable. Modern techniques of manufacturing have resulted in void free cables. However, under operating conditions, the voids are formed as a result of the differential expansion and contraction of the sheath and impregnated com-pound. The breakdown strength of voids is considerably less than that of the insulation. If the voidis small enough, the electrostatic stress across it may cause its breakdown. The voids nearest to the conductor are the first to break down, the chemical and thermal effects of ionisation causing perma-nent damage to the paper insulation. 3.Pressure cables For voltaFor voltages beyond 66 kV, solid type cables are unreliable because thereis a danger of breakdown of insulation due to the presence of voids. When the operating voltages are greater than 66 kV, pressure cables are used. In such cables, voids are eliminated by increasing the pressure of compound and for this reason they are called pressure cables.
3	**What is the main purpose of armouring? (R2016- A/M 2015) BTL1** Over the bedding, armouring is provided which consists of one or two layers of galvanized steel wire or steel tape. Its purpose is to protect the cable from mechanical injury while laying it and during the course of handling
4.	**What is meant by dielectric stress in a cable? (R2008-M/J 2014) BTL1** Under Operating Conditions, the insulation of a cable is subjected to electrostatic force known as dielectric stress. It is the tensile force experienced by cable insulation. For a single core cable, $V= (q/(2\pi\varepsilon))\ln R/r$ Stress $E = q/(2\pi\varepsilon x)$ $E= (V/x \ln (R/r))$ Maximum stress in dielectric occurs at minimum value of radius ($x = r$)
5	**What are the modern practices adopted to avoid grading of cables? (R2008-M/J 2016) BTL1** Grading is only useful for very high voltage cables for which the ratio D/d is large.The modern trend is to avoid grading as far as possible and employ oil-filled or gas-pressure cables.
6.	**Mention any four insulating materials used for underground cables. (R2013- N/D 2016) BTL1** ➢ The principal insulating materials used in cables are rubber, vulcanized Indian rubber, impregnated paper, varnished cambric and polyvinyl chloride
7	**A single core cable, 1.7 km long , has a conductor radius of 13mm and an insulation thickness of 5.8mm. The dielectric has a relative permittivity of 2.8. Find the capacitance per metre length of cable. (R2013-N/D 2015)**

	Length of cable = 1.7 km=1700 m
8	**Give the relation for insulation resistance of a cable. (R2008 – N/D 2013) BTL1** $R = \frac{\rho}{2\pi l}\ \ln\ \frac{R}{r}$ohms
9	**Define grading of cables? (R2008-N/D2012)A/M 2018 N/D 2019 BTL1** The process of achieving uniform electrostatic stress in the dielectric of cables is known as **grading of cables.** The electrostatic stress in a single core cable has a maximum value (g_{max}) at the conductor surface and goes on decreasing as we move towards the sheath. The maximum voltage that can be safely applied to a cable depends upon g_{max} i.e., electrostatic stress at the conductor surface. For safe working of a cable having homogeneous dielectric, the strength of dielectric must be more than g_{max}. If a dielectric of high strength is used for a cable, it is useful only near the conductor where stress is maximum. But as we move away from the conductor, the electrostatic stress decreases, so the dielectric will be unnecessarily overstrong. In order to overcome disadvantages, it is necessary to have a uniform stress distribution in cables. This can be achieved by distributing the stress in such a way that its value is increased in the outer layers of dielectric. This is known as grading of cables.
10	**What are the methods of grading of cables? (R2008-N/D 2011)** **What are the two different methods of grading of cables? (R2013-A/M 2017) BTL1** (i)Capacitance grading (ii)Intersheath grading
11	**What are the main requirements of the insulating materials used for cables? (R2013-A/M 2018) BTL1** 1. High insulation resistance to avoid leakage current 2. High dielectric strength to avoid electrical breakdown of cable 3. Good mechanical properties (tenacity and elasticity). Good tenacity is required in the materials to withstand the mechanical handling of the cables 4. Immune to attacks by acids and alkalies, over a range of temperature of about -18°C to 94°C 5. Non hydroscopic because the dielectric strength of any material goes very much down with the moisture content. In case of insulator is hydoscopic, it must be enclosed in a water tight covering like lead sheath etc 6. Non inflammable 7. Low coefficient of thermal expansion 8. Low permittivity 9. Capable of withstanding high rupturing voltage

12	**What is the necessity of grading of an underground cable? (R2008-N/D 2010)** Grading of the underground cable is done to achieve uniform electrostatic stress in the dielectric of cable
13	**Classify the cables used for three phase service. (R2013-M/J 2016 BTL1** 1.Belted cables - upto 11 kV 2. Screened cables - from 22 kV to 66 kV (i)H – Type cables (ii)S-L Type cables 3. Pressure cables - beyond 66 kV. (i)Oil filled cables (ii) Gas pressure cables.
14	**What are the factors to be considered while selecting a cable for a particular service? (R2008-N/D2014) BTL1** **1.** Materials, **2.** Working Voltage, **3.** Load Current, **4.** Short circuit current, **5.** Load factor, **6.** Frequency, **7.** Acceptable Voltage Drop, Economics
15	**What are the advantages of gas pressure cables? BTL1** (i)Maintenance cost is small (ii) The nitrogen in the steel tube helps in quenching any fire or flame (iii) No reservoirs or tanks required (iv) The power factor is improved
16	**Write down the various parts of cables. BTL1** **(i)**Core, (ii) Insulation, (iii) Metallic sheath, (iv) Bedding, (v) Armouring, (vi) Serving
17	**Name any four insulating material used for making underground cable. BTL1** The principal insulating materials used in cables are rubber, vulcanized Indian rubber, paper, varnished cambric and polyvinyl chloride
18	**What are the types of cables?** Low tension cable (ii) High tension cable (iii) belted cable (iv) super tension cable (v) extra tension cable
19	**A 1 km long single core cable has a core diameter of 2.5cm, insulation thickness of 1.25 cm and resistivity of the insulation is $\mathbf{4.5 \times 10^4}$ ohms-cm. calculate the insulation resistance/km** $R = \frac{\rho}{2\pi l}\ln\frac{D}{d}$ $t = \frac{D-d}{2}$

	$$t = \frac{D-d}{2}$$ $$D = 5\ cm$$ $$R = \frac{4.5\ \times 10^4}{2\pi \times 100000} \ln \frac{5}{2.5} D = 5\ cm$$ R = 496 Mohm
20	**Show that the insulation resistance of cable is inversely proportional to its length. BTL1**  Derivation: Let, r be the radius of the conductor R be the radius of metallic sheath x be the radius of annulus l be the length of cable ρ be the resistivity of insulation Insulation resistance $dR_{ins} = \frac{\rho\,dx}{2\pi x}$ ohms/m Insulation resistance per meter length is, Rins $= \int_r^R \frac{\rho\,dx}{2\pi x} = \frac{\rho}{2\pi}\int_r^R \frac{dx}{x}$ $= \frac{\rho}{2\pi}$ [ln R – ln r] $= \frac{\rho}{2\pi} \ln \frac{R}{r}$ ohms / m If the cable has length of l meters, then R = $\frac{\rho}{2\pi l}$ ln $\frac{R}{r}$ ohms
21	**What is the function of sheath in a cables? BTL1** The sheath does not allow the moisture to enter and protects the cable from all external influences like chemical or electrochemical attack fire etc

22	**What is meant by serving of a cable? BTL1** A layer of fibrous material permitted with waterproof compound applied to the exterior of the cable is called serving of a cable.
23	**What is mean by capacitance grading?** The grading done by using the layers of dielectrics having different permittivity between the core and the sheath is called capacitance grading
24	**What are the disadvantages of oil filled cables?** 3. The initial cost is very high 4. The long length is not possible 5. The laying of cable is difficult 6. Maintenance of cable is difficult
25	**10. What are the advantages of separate lead sheath cables?** 1. Due to individual lead sheath core to core fault possibility gets minimized 2. The electrical stress are radial in nature 3. Bedding of cable is easy 4. Increases the current carrying capacity

	PART*B
1.	***Explain the Ferranti effect with relevant phasor diagram. (MJ15)A/M 2019*** **BTL2** **Ferranti Effect:** **A long transmission line draws a substantial quantity of charging current. If such a line is open circuited or very lightly loaded at the receiving end, the voltage at receiving end may become greater than voltage at sending end. This is known as Ferranti Effect and is due to the voltage drop across the line inductance (due to charging current) being in phase with the sending end voltages.** **Therefore both capacitance and inductance is responsible to produce this phenomenon The capacitance (and charging current) is negligible in short line but significant in medium line and appreciable in long line. Therefore this phenomenon occurs in medium and long lines. Represent line by equivalent π model.** .
2.	***. Derive the expression for voltage distribution in insulator string and string efficiency. (ND13)*** *N/D 2019 BTL2* **Potential Distribution over Suspension Insulator String** - A string of suspension insulators consists of a number of porcelain discs connected in series through metallic links. Fig.4.11(i) shows 3-disc string of suspension insulators. - The porcelain portion of each disc is in between two metal links. Therefore, each disc forms a capacitor C as shown in Fig.(ii) This is known as mutual capacitance

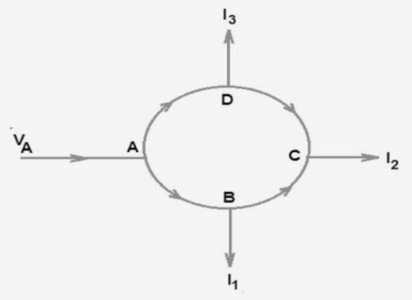
	or self- capacitance. • If there were mutual capacitance alone, then charging current would have been the same through all the discs and consequently voltage across each unit would have been the same i.e., V/3 as shown in fig4.11.(ii) • However, in actual practice, capacitance also exists between metal fitting of each disc and tower or earth. This is known as shunt capacitance C1. • Due to shunt capacitance, charging current is not the same through all the discs of the string Therefore, voltage across each disc will be different. • Obviously, the disc nearest to the line conductor will have the maximum* voltage. Thus referring to Fig V3 will be much more than V2 or V1.
3	***escribe the various methods to improve string efficiency. (ND12, ND15, MJ16)*** ***ethods of Improving String Efficiency*** *BTL2* • It has been seen above that potential distribution in a string of suspension insulators is not uniform. The maximum voltage appears across the insulator nearest to the line conductor and decreases progressively as the cross arm is approached. • If the insulation of the highest stressed insulator breaks down or flash over takes place, the breakdown of other units will take place in succession. • This necessitates equalizing the potential across the various units of the string *i.e.* to improve the string efficiency. The various methods for this purpose are: • The value of string efficiency depends upon the value of K i.e., ratio of shunt capacitance to mutual capacitance. The lesser the value of K, the greater is the string efficiency and more uniform is the voltage distribution. • The value of K can be decreased by reducing the shunt capacitance. In order to reduce shunt capacitance, the distance of conductor from tower must be increased i.e., longer cross-arms should be used. **.**

3.	**Explain the devices for controlling harmonic distortion. (13 M)**BTL2 **Answer: Page: 4.90 - C.Ravichandran** **Series Reactors: (1 M)** Connected in series upstream of a non-linear load **Zigzag Transformers: (1 M)** To control zero-sequence harmonic components **Specially connected Transformers: (1 M)** Inhibits propagation of third-order harmonic currents and their multiples **Using 6-pulse Diode Rectifier: (2 M)** Consists of 6 uncontrollable rectifiers or diodes and an inductor, which together with a DC capacitor forms a low-pass filter for smoothing the DC current. **Using 12-pulse or 24-pulse Diode Rectifier**: **(1 M)** Formed by connecting two 6-pulse rectifiers in parallel to feed a common DC-bus **Using Phase Controlled Thyristor Rectifier: (1 M)** Accomplished by replacing the diodes in a 6-pulse rectifier with thyristors **Using IGBT Bridge**: **(2 M)** Control the Dc voltage level and displacement power factor regardless of the power flow direction **Using a Larger DC or AC Inductor: (1 M)** Connected in its AC input or DC bus **Harmonic Filters: (3 M)** Active and Passive Filters
	PART*C
1.	With neat diagrams, explain the constructional features of various types of cables. (ND12, **Cable for 3-Phase BTL2** • The underground cables are generally required to deliver 3-phase power. For the purpose, either three-core cable or three single core cables may be used. • For voltages upto 66 kV, 3-core cable (i.e., multi-core construction) is preferred due to economic reasons. • However, for voltages beyond 66 kV, 3-core-cables become too large and unwieldy and, therefore, single-core cables are used. • The following types of cables are generally used for 3-phase service : 1. Belted cables — upto 11 kV 2. Screened cables — from 22 kV to 66 kV Pressure cables — beyond 66 Kv

	1. (ii) A single core cable has a conductor diameter of 1 cm and internal sheath diameter of 1.8 cm . If impregnated paper of relative permittivity 4 is used as the insulation , calculate the capacitance for 1km length of the cable. **(R2013-A/M 2018) BTL3** **2.** i)Describe the general construction of an underground cable with a neat sketch. **(R2008-N/D2012) BTL2** 3. **4.** (ii) State the classification of cables and discuss their general construction. **(R2008-N/D2012)** **5.** 19. Describe an experiment to determine the capacitance of a belted cable**(R2008 – N/D 2013)** 6. **7.** (ii)A 33 kV single core cable has a conductor diameter of 1 cm and a sheath of inside diameter 4cm . Find the maximum and minimum stress in the insulation. **(R2008 – N/D 2013) BTL3** 8. 18. Derive an expression for the insulation resistance, capacitance and the electrostatic stre of a single core cable. **(R2008-N/D2014) BTL3**

UNIT V – DISTRIBUTION SYSTEMS	
Distribution Systems – General Aspects – Kelvin's Law – AC and DC distributions - Techniques of Voltage Control and Power factor improvement – Distribution Loss –Types of Substations -Methods of Grounding – Trends in Transmission and Distribution: EHVAC, HVDC and FACTS (Qualitative treatment only).	
PART*A	
Q.No.	**Questions**
1	**What are the major equipments of a substation? (R2008-M/J 2014), (R2013- N/D2017), (R2008-N/D 2010) BTL1** Transformer, circuit breakers, isolators, CT/PT, Bus bar, Earthing switch, shunt capacitors, station batteryand Charging Equipment
2	**List the types of substations. (R2008-N/D2012)A/M 2019 BTL1** Transformer Substations, Switching Substations Industrial Substations, Indoor Substations Outdoor Substations, Underground Substations Pole-mounted Substations
3	**Distinguish between a feeder and a distributor? (R2016- A/M 2015 BTL1)** **Define feeder and distributor. (R2013-N/D 2016)** **What is meant by feeder? (R2013-N/D 2015), (R2008-N/D2012)** **Define the term feeders and service mains. (R2008-N/D 2011)** Distribution feeders: The stepped-down voltage from the substation is carried to distribution transformers via feeder conductors. Generally, no tappings are taken from the feeders so that the

	current remains same throughout. The main consideration in designing of a feeder conductor is its current carrying capacity. **Distributors**: Output from a distribution transformer is carried by distributor conductor. Tappings are taken from a distributor conductor for power supply to the end consumers. The current through a distributor is not constant as tappings are taken at various places throughout its length. So, voltage drop along the length is the main consideration while designing a distributor conductor. **Service mains**: It is a small cable which connects the distributor conductor at the nearest pole to the consumer's end.
4	**Enumerate the various methods of neutral grounding. (R2008-M/J 2014) BTL1** solid grounding, resistance grounding reactance grounding, resonant grounding
5	**Why HVDC line does not require any reactive power compensation? (R2008-M/J 2016) BTL1** HVDC lines do not require any reactive power compensation because of following reason 1. There is no charging current in HVDC line. 2. HVDC lines operates on unity power factor
6	**State the applications of HVDC transmission. (R2013-N/D 2016) BTL1** Long distance bulk power transmission Underground or under water cables Asynchronous interconnection of AC system operating at different frequencies or where independent control of system is desired Control and stabilization of power flows in AC ties in an integrated power system.
7	**What is the need for earthing? (R2013-N/D 2016), (R2008 – N/D 2013)A/M 208 BTL1** 1. To ensure no part other than live part have potential 2. To allow sufficient current to flow safely 3. To limit over voltages between neutral and earth 4. To suppress he dangerous potential gradient
8	**What are the various methods of earthing in substations? (R2008-N/D 2011) BTL1**Solid grounding Resistance grounding Reactance grounding Resonant grounding

9	**State the disadvantages of HVDC transmission. (R2008-N/D 2010) BTL1** The dc voltages cannot be stepped up for transmission of power at high voltages. The dc switches and circuit breakers have their own limitations. Power transmission with HVDC is not economical if the length of transmission line is less than 500km Considerable reactive power is required by converter station. Maintenance of insulator is more.
10	**What are the advantages of ring main distributor? (R2008-M/J 2016) BTL1** In ring power is supplied from both ends as compared to radial • In case of a fault in the radial circuit the entire system goes off unlike in ring where by incase one end gets a fault the other end still keeps on supplying power • Compared to the radial system, the voltage drop is less along the distribution line • More subscribers can be installed to the system than the radial system • Less voltage fluctuations can be seen at client's terminals. Voltage fluctuations in high loaded areas can be reduced using a tie line
11	**What is ring main system? (R2013-A/M 2017), (R2008-N/D2012) BTL1** A ring distributor is a distributor which is arranged to form a closed circuit and which is fed at one or more than one points. If the ring distributor is fed at one point then, for the purpose of calculation, it is equivalent to a straight distributor fed at both ends with equal voltages.  Ring distributor
12	**What is the importance of voltage control? (R2016- A/M 2015) BTL1** The importance of voltage control is firstly, the power network is very extensive and there is a considerable **voltage** drop in transmission and distribution systems. Secondly, the various circuits of the power system have dissimilar load characteristics
13	**Mention the various methods of voltage control in transmission lines. (R2013-N/D 2016) A/M 2019 BTL1** 1. Excitation control and voltage regulators at the generating stations: 2. Use of tap changing transformers at sending end and receiving end of the transmission lines 3. Switching in shunt reactors during low loads or while energizing long EHV lines 4. Switching in shunt capacitors during high loads or low power factor loads

14	**. What are the classifications of substation according to service? (R2016- A/M 2015) BTL1** Based on Service a Substation can be classified by two way, Static Types (AC to AC) Converting Types (AC to DC) According to service, substations are classified as, 1. Transformer substations 2. Switching substations 3. Power factor correction substations 4. Frequency changer substations 5. Converting substations 6. Industrial substations
15	**What are the objectives of FACTS? (R2013-N/D2017), (R2013-M/J 2016) BTL1** Flexible AC Transmission System incorporates power electronics based controllers to enhance the controllability and increase power transfer capability. The two main objectives of FACTS are: (i)To increase the power transfer capability of transmission systems and (ii)To keep power flow over designated routes
16	**What are the advantages of FACT controllers? (R2013-A/M 2018) BTL1** Increase the power transfer capability of transmission networks. Provides direct control of power flow over designated transmission routes. Increases the loading capability of lines to their thermal capabilities Increases the reliability of transmission network. Compensates the power loss due to reactive power of transmission system.
17	**What are the advantages of an Interconnected system? (R2013-A/M 2018) BTL1** **Reduced Plant Reserved Capacity** **Increased Effective Capacity of Power System** **Increased Reliability of Supply** **Economical Operation** Use of Older Plants: Exchange of Peak Loads: Reduced Capital Costs: Savings in Operating Cost

18 **What is the function of isolators? (R2008 – N/D 2013) BTL1**

It is used to disconnect a part of the system for general maintenance and repairs

19 **State Kelvin’s law for size of transmission conductor. (R2008-N/D2014) BTL1**

The annual expenditure on the variable part of the transmission system should be equal to the annual cost of energy wasted in the conductor used in that system.

20 **What is the purpose of terminal and through sub-stations in the power system? (R2008-2014)**

A terminal sub-station is one in which the line supplying to the substation terminates or ends. It may be located at the end of the main line or it may be situated at a point away from main line route.

A through sub-station is one in which the incoming line passes ‘through’ at the same voltage. A tapping is generally taken from the line to feed to the transformer to reduce the voltage to the desired level

21 **How does a.c distribution differ from d.c distribution? (R2008-N/D2014) BTL1**

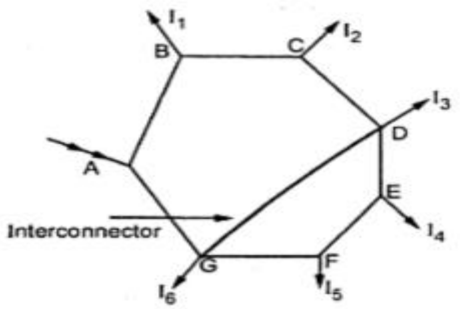
AC distribution	DC distribution
It is possible to construct large high speed AC generators of capacities upto 500MW.	DC generators cannot be built of ratings higher than 5MW because of commutation problem
AC voltage can be efficiently and conveniently raised or lowered for economic transmission and distribution of electric power respectively.	DC power has to be generated at low voltages as there is no economical method of raising the DC voltage.
In AC systems, voltage drop are due to combined effects of resistances, inductances and capacitances.	In DC systems, voltage drop is due to resistances alone.

22 **. Give reason why transmission lines are three phase 3 wire circuits while distribution lines are three phase 4 wire circuits. (R2008 – N/D 2013), (R2008-N/D 2010)**

Transmission lines 3 phase 3 wire circuits while distribution lines are 3 phase 4 wire circuits because transmission line consists of three conductors which represents the phases R, Y, and B whereas distribution line requires neutral in addition with three phases to supply the 1 phase loads of domestic and commercial consumers.

23 **. What is the purpose of inter-connector in a dc ring main distributor? (R2008- A/M 2015)**

What is interconnected system? (R2013-N/D2017) BTL1

	 The ring main system is used to supply a large area sometimes and hence voltage drop across the various sections may become large in such case. Hence to compensate for such excessive voltage drops, the distant points of ring distributor are joined together by a conductor. This is called an interconnector.
24	**What is gas insulated substation? (R2013-A/M 2018) BTL1** A **gas insulated substation** (**GIS**) is a high voltage **substation** in which the major structures are contained in a sealed environment with sulfur hexafluoride **gas** as the **insulating** medium
25	**State the advantages and disadvantages of having two circuit breakers in duplicate bus-bar system. (R2008-A/M 2015)** Duplicate bus bar system consists of two bus-bars, a “main” bus-bar and a “spare” bus-bar. Each bus-bar has the capacity to take up the entire sub-station load. The incoming and outgoing lines can be connected to either bus-bar with the help of a bus-bar coupler which consists of a circuit breaker and isolators. Ordinarily, the incoming and outgoing lines remain connected to the main bus-bar. However, in case of repair of main bus-bar or fault occuring on it, the continuity of supply to the circuit can be maintained by transferring it to the spare bus-bar. For voltages exceeding 33kV, duplicate bus-bar system is frequently used

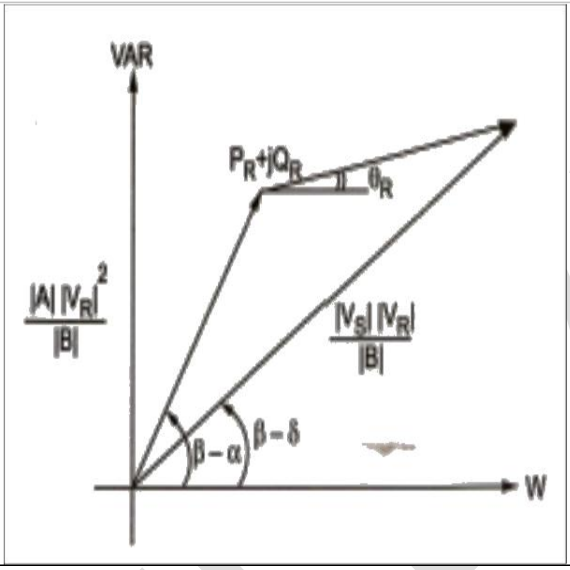
	PART*B
1.	**Describe the concept and procedure to draw the power circle diagram. (ND15) AM 2019***BTL2***POWER CIRCLE DIAGRAM** • By taking either VS, VR, IS or IR as a reference these characteristics can be plotted. These characteristics are nothing but representing circles. Hence such diagrams are called circle diagram. • A circle diagram is drawn with real power P on X-axis and Q on Y axis on complex plane. The circle diagram can be drawn at the sending end as well as at the receiving end. • These diagrams are helpful for determination of active power P, reactive power Q, power angle 8, power factor for given load conditions, voltage conditions and impedance Z of the line.

$$S_R = P_R + jQ_R$$

$$= \frac{|V_S|\ |V_R|}{|B|} \angle\beta-\delta - \frac{|A|\ |V_R|^2}{|B|} \angle\beta-\alpha$$

$$P_R = \frac{|V_S|\ |V_R|}{|B|} \cos(\beta-\delta) - \frac{|A|\ |V_R|^2}{|B|} \cos(\beta-\alpha)$$

$$Q_R = \frac{|V_S|\ |V_R|}{|B|} \sin(\beta-\delta) - \frac{|A|\ |V_R|^2}{|B|} \sin(\beta-\alpha)$$



The real component of $(P_R + jQ_R)$ is,

$P_R = |V_R|\ |I_R| \cos\theta_R$

where θ_R is p.f. at the receiving end

The imaginary component of $(P_R + jQ_R)$ is,

$Q_R = |V_R|\ |I_R| \sin\theta_R$

2 **Describe the different methods of voltage control.**

BTL1 **2(MJ17) Methods of Voltage Control**

There are several methods of voltage control. In each method, the system voltage is changed in accordance with the load to obtain a fairly constant voltage at the consumer's end of the system. The following are the methods of voltage control in an *a.c. power system:

(i) By excitation control
(ii) By using tap changing transformers
(iii) Auto-transformer tap changing
(iv) Booster transformers
(v) Induction regulators
(vi) By synchronous condenser

3	***Explain the different types of FACTS controllers. (MJ16,*** ***ND14) Types of FACTS Controllers*** *BTL2* 1. Series controller 2. Shunt controller 3. Combined series - series controllers 4. Combined series – shunt controller

	PART*C
1.	***Explain i) Radial System ii) Ring main system iii) Interconnected system(ND10,ND13)A/M 2019*** *BTL2* **(i) Radial System.** In this system, separate feeders radiate from a single substation and feed the distributors at one end only. Fig. 1.43 (*i*) shows a single line diagram of a radial system for d.c. distribution where a feeder *OC* supplies a distributor *AB* at point *A* . Obviously, the distributor is fed at one end only *i.e.*, point *A* is this case. Fig. 1.43 (*ii*) shows a single line diagram of radial system for a.c. distribution. The radial system is employed only when power is generated at low voltage and the substation is located at the centre of the load. ***(ii) Ring main system.*** In this system, the primaries of distribution transformers form a loop. The loop circuit starts from the substation bus-bars, makes a loop through the area to be served, and returns to the substation. Fig.1.44.shows the single line diagram of ring main system for a.c. distribution where substation supplies to the closed feeder LMNOPQRS. The distributors are tapped from different points *M*, *O* and *Q* of the feeder through distribu- tion transformers.

2.	***2. Derive the expression for Volume of copper conductor material required for DC and AC Distributors.(MJ13, ND14)*** *BTL2*

Comparison of Conductor Material in Overhead system:

In comparing the relative amounts of conductor material necessary for different systems of transmission, similar conditions will be assumed in each case *viz.*,

(i) Same power (*P watts*) transmitted by each system.

(ii) the distance (*l metres*) over which power is transmitted remains the same.

(iii) the line losses (*W watts*) are the same in each case.

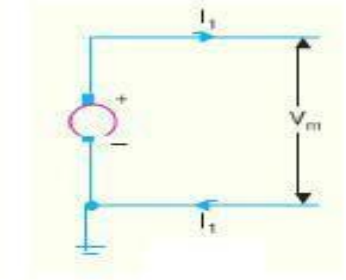
(iv) the maximum voltage between any conductor and earth (V_m) is the same in each case.

1. Two-wire d.c. system with one conductor earthed

In the 2-wire d.c. system, one is the outgoing or positive wire and the other is the return or negative wire as shown in Fig.1.2. The load is connected between the two wires.

Max. voltage between conductors =

V_mPower to be transmitted = P



□ Load current, $I_1 = P/V_m$

If R_1 is the resistance of each line conductor, then,

R_1 = □ l/a_1

where a_1 is the area of X-section of the conductor

$$\text{Line losses,} \quad W = 2I_1^2 R_1 = 2\left(\frac{P}{V_m}\right)^2 \rho \frac{l}{a_1}$$

$$\therefore \quad \text{Area of X-section, } a_1 = \frac{2P^2 \rho l}{W V_m^2}$$

Volume of conductor material required

$$= 2a_1 l = 2\left(\frac{2P^2\rho l}{W V_m^2}\right) l = \frac{4P^2 \rho l^2}{W V_m^2}$$

EE8403 MEASUREMENTS & INSTRUMENTATION LT P C 3 0 0 3

OBJECTIVES:

- To impart knowledge on the following Topics
- Basic functional elements of instrumentation
- Fundamentals of electrical and electronic instruments
- Comparison between various measurement techniques
- Various storage and display
- Various transducers and the data acquisition systems

UNIT I INTRODUCTION 9

Functional elements of an instrument – Static and dynamic characteristics – Errors in measurement – Statistical evaluation of measurement data – Standards and calibration .Principle and types of analog and digital voltmeters, ammeters.

UNIT II ELECTRICAL AND ELECTRONIC INSTRUMENTS 9

Principle and types of multi meters – Single and three phase watt meters and energy meters – Magnetic measurements – Determination of B-H curve and measurements of iron loss – Instrument transformers – Instruments for measurement of frequency and phase.

UNIT III COMPARATIVE METHODS OF MEASUREMENTS 9

D.C potentiometers, D.C (Wheat stone, Kelvin and Kelvin Double bridge) & A.C bridges (Maxwell, Anderson and Schering bridges), transformer ratio bridges, self-balancing bridges. Interference & screening – Multiple earth and earth loops - Electrostatic and electromagnetic Interference –Grounding techniques.

UNIT IV STORAGE AND DISPLAY DEVICES 9

Magnetic disk and tape – Recorders, digital plotters and printers, CRT display, digital CRO, LED, LCD & Dot matrix display – Data Loggers.

UNIT V TRANSDUCERS AND DATA ACQUISITION SYSTEMS 9

Classification of transducers – Selection of transducers – Resistive, capacitive & inductive Transducers – Piezoelectric, Hall effect, optical and digital transducers – Elements of data acquisition system – Smart sensors-Thermal Imagers.

TOTAL : 45 PERIODS

OUTCOMES:

- To acquire knowledge on Basic functional elements of instrumentation.
- To understand the concepts of Fundamentals of electrical and electronic instruments.
- Ability to compare between various measurements techniques.
- To acquire knowledge on various storage and display devices.
- To understand the concepts various transducers and the data acquisition systems.
- Ability to model and analyze electrical and electronic Instruments and understand the operational features of display Devices and Data Acquisition System.

TEXT BOOKS:

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2. J. B. Gupta, 'A Course in Electronic and Electrical Measurements', S. K. Kataria& Sons, Delhi, 2013.
3. Doebelin E.O. and Manik D.N., Measurement Systems – Applications and Design, Special Indian Edition, McGraw Hill Education Pvt. Ltd., 2007.

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2. D.V.S. Murthy, 'Transducers and Instrumentation', Prentice Hall of India Pvt Ltd, 2015.
3. David Bell, ' Electronic Instrumentation & Measurements', Oxford University Press,2013.
4. Martin Reissland, 'Electrical Measurements', New Age International (P) Ltd., Delhi, 2001.
5. Alan. S. Morris, Principles of Measurements and Instrumentation, 2nd Edition, Prentice Hall of India, 2003.

Subject code: EE8403 **Year/semester :II/04**

Subject Name: Measurements & Instrumentation Subject Handler: Dr.Prajith Prabhakar

UNIT I INTRODUCTION 9

Functional elements of an instrument – Static and dynamic characteristics – Errors in measurement – Statistical evaluation of measurement data – Standards and calibration- Principle and types of analog and digital voltmeters, ammeters.

PART * A

Q.No	Questions
1.	**What is an error?**BTL 2 The algebraic difference b/w the indicated value and the true value of the quantity to be measured is called an error.
2.	**When static characteristic are important?(NOV/DEC 2010)**BTL 4 The instruments measure the quantity which do not vary with time, the static characteristic of an instruments play an important role.
3.	**When dynamic characteristic of an instruments are important?(April/May 2011)**BTL 4 The instruments are subjected to rapidly varying inputs then it is necessary to study the dynamic relations b/w input &output
4.	**What is an accuracy?(Apr/May 2015)**BTL 2 It is the degree of closeness with which the instruments reading approaches the true value of the quantity to be measure.
5.	**What is precision? (NOV/DEC 2013)**BTL 2 It is the measure of consistency or measurements. it denotes the amount by which the individual readings are departed about the average value of readings.
6.	**What is sensitivity?(NOV/DEC 2013)**BTL 2 It denotes the smallest change in the measured variable to which the instruments to be responds. The units of sensitivity are in mm/unit quantity to be measure. $\text{Sensitivity}= \frac{\text{Change in output (response) of the instrument}}{\text{Change of input (or) measured variable}}$
7.	**Define Threshold?((NOV/DEC 2009)**BTL 1 If the i/p quantity is slowly varied from zero onwards, the o/p does not vary until some min value of the i/p is reached.
8.	**Define resolution?(NOV/DEC 2009)**BTL 1 It is the smallest increment of quantity being measured which can be certainly detected by an instrument.
9.	**What is linearity?(Apr/May 2015)**BTL 2 It is the ability of an instrument to reproduce the input characteristic symmetrically & linearly.
10	**Define tolerance?**BTL 2 The max allowable error in the measurement is specified in terms of a value is called tolerance.
11	**What is fidelity?(May/June 2014)**BTL 2 It indicates how much faithfully the system reproduces the changes in the input. it is the ability of an instruments to produce a wave shape identical to the wave shape of an input with respect to time.
12	**What is an absolute instrument?(Apr/May 2015)**BTL 2 The instrument which gives the magnitude of the quantity to be measure in termers of the physical constant of the instruments is called absolute instruments.
	Mention the basic requirements of measurement. (May/June 2011)BTL 3 • The standard used for comparison purpose must be accurately defined and should be

13	commonly accepted. • The apparatus used and the method adopted must be provable.
14	**Explain the function of measurement system.(Nov/Dec 2011)**BTL 3 The measurement system consists of a transducing element which converts the quantity to be measured in an analogous form. The analogous signal is then processed by some intermediate means and is then fed to the end device which presents the results of the measurement.
15	**The expected value of the voltage across a resistor is 40V. However the measurement gives a value of 39V. Calculate the absolute error.(May/June 2013)**BTL 5 Absolute error= At-Am Expected value or true value,(At)= 40V Measured value or recorded value (Am)= 39V E= 40-39 =1 V.
16	**Mention the types of instruments.** BTL 4 The 3 types of instruments are • Mechanical Instruments • Electrical Instruments and • Electronic Instruments.
17	**Give the applications of measurement systems. (Apr/May 2011)**BTL 4 The instruments and measurement systems are used for • Monitoring of processes and operations. • Control of processes and operations. • Experimental engineering analysis.
18	**Why calibration of instrument is important?(NOV/DEC 2013)**BTL 3 The calibration of all instruments is important since it affords the opportunity to check the instrument against a known standard and subsequently to errors in accuracy.
19	**Mention the calibration procedure.**BTL 4 Calibration procedure involves a comparison of the particular instrument with either a primary standard or a secondary standard with a higher accuracy than the instrument to be calibrated or an instrument of known accuracy.
20	**Define Calibration. What is the significance of calibration? (Apr/May 2010) (Nov/Dec 2013)** BTL 1 It is the process by which comparing the instrument with a standard to correct the accuracy. • Visual inspection for various defects • Installation according to the specification • Zero adjustment.
21	**Define Drift. Mentions its Classifications.** BTL 1 It is defined as for a given input, the measured values do not vary with tome. Drift is rarely apparent and must be carefully guarded against by continuous inspection. • Zero drift • Span drift and sensitivity drift • Zonal drift
22	**Define fidelity.**BTL 1 It is the ability of an instrument to produce a wave shape identical to wave shape of input with respect to time.

PART * B

1. **Describe the static and dynamic characteristics of measuring instrument.(13M)(Apr/May 2011)(Nov 2018)**BTL 2

Answer page : 1.8- J.Gnanavadivel

Static characteristics: (7M)

- Accuracy: The closeness with which an instrument reading approaches the true value of the quantity being measured.
- Precision:It is a measure of reproducibility of the measurements, i.e., given a fixed value of a quantity, precision is a measure of the degree of agreement with in a group of measurements.
- Static sensitivity: If the input is slowly increased from some arbitrary (non-zero) input value, it will again be found that output does not change at all until a certain increment is exceeded.
- Reproducibility: It is the degree of closeness with which a given value may be repeatedly measured. It may be specified in terms of units for a given period of time.
- Drift: Gradual change in instruments measurements.
- Static error: Numerical differences between true value of a quantity and its value as obtained by measurement.
- Dead zone: It is defined as the largest change of input quantity for which there is no output of the instrument.

Dynamic Characteristics: (6M)

- Speed of response: The rapidity with which an instrument responds changes in measured quantity.
- Measuring lag: The difference between the true and measured value with no static error.
- Fidelity: Delay in the response of an instrument to changes in the measured variable.
- Dynamic error: The degree to which an instrument indicates the changes in the measured variable without dynamic error (faithful reproduction).

2. **Discuss in detail various types of errors associated in measurement and how these errors can be minimized? (13M) (Nov 2007)(Nov 2018)**BTL 3

Answer page : 1.35- J.Gnanavadivel

Error: (2M)

The algebraic difference b/w the indicated value and the true value of the quantity to be measured is called an error.

Types: (11M)

- Static error: It is defined as the difference between the measured value and the true value of the quantity under measurement.
- Gross errors: is due to human fault.

- Systematic errors:
    1. Instrumental errors
    2. Environmental errors
    3. Observational errors
- Random errors: due to causes that cannot be directly established.
- Hysteresis error: Hysteresis is a non---coincidence of loading and unloading curves. Hysteresis in a system arises due to the fact that all the energy put into the stressed parts when loading is not recoverable upon unloading.

3.

Write briefly about Instrument Standards.(13M) (Apr 2008)BTL 3

Answer page : 1.33- J.Gnanavadivel

Standard in measurement: (3M)

A standard in measurements is a physical representation of an unit of measurement. The term standard is applied to a piece of equipment having a known measure of physical quantity. They are used for the purpose of obtaining the values of the physical properties of other equipments by comparison methods.

Classifications of Standards (10M)

- **International Standards**:Defined by International Agreement.Represent the closest possible accuracy attainable by the current science and technology
- **Primary standards:**Maintained at the National Std Lab (different for every country) Function: the calibration and verification of secondary std Each lab has its own secondary std which are periodically checked and certified by the National Std Lab. For example, in Malaysia, this function is carried out by SIRIM.
- **Secondary standards:**Secondary standards are basic reference standards used by measurement and calibration laboratories in industries. Each industry has its own secondary standard. Each laboratory periodically sends its secondary standard to the National standards laboratory for calibration and comparison against the primary standard.
- **Working standards:** Used to check and calibrate lab instrument for accuracy and performance. For example, manufacturers of electronic components such as capacitors, resistors and many more use a standard called a working standard for checking the component values being manufactured.

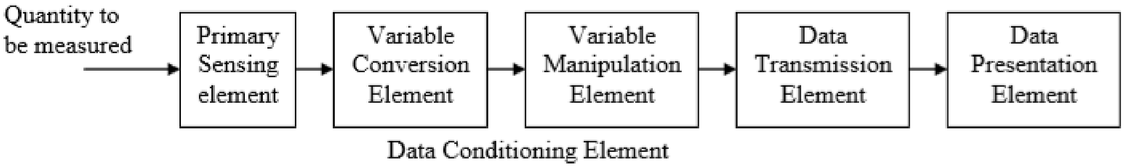
4.

What are the basic blocks of a generalized instrumentation System. Draw the various blocks and explain their functional elements of an instrument. (13M) (Nov 2007)BTL 2

Answer page : 1.6- J.Gnanavadivel

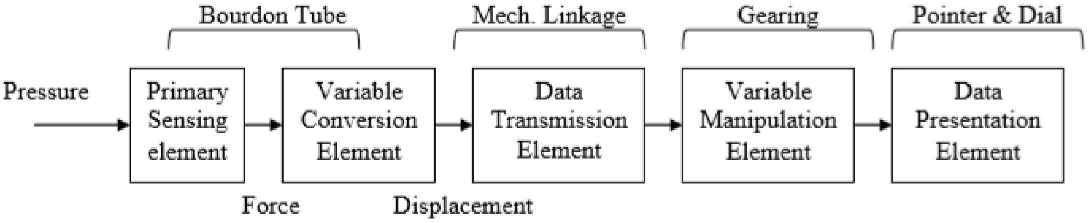
- Block diagram **(6M)** & explanation (**7M**)
- **Primary sensing element:** The quantity under measurement makes its first contact with the primary sensing element of a measurement system. In other words the measurand is first detected by primary sensor. This act is then immediately followed by the conversion of measurand into an analogous electrical Signal.
- **Variable Conversion Element:** The output of the primary sensing element may be

electrical signal of any form. It may be a voltage, a frequency or some other electrical parameter. Sometimes this output is not suited to the system.



Functional Elements of Measurement System

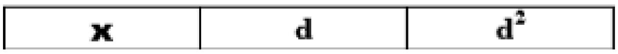
- **Variable Manipulation Element:** The function of this element is to manipulate the signal presented to it preserving the original nature of the signal. Manipulation here means only a change in numerical value of the signal. For example, an electronic amplifier accepts a small voltage signal as input and produces an output signal which is also voltage but of greater magnitude.
- **Data Presentation Element:** The information about the quantity under measurement has to be conveyed to the personnel handling the instrument or the system for monitoring, control, or analysis purposes.



Schematic Diagram of a Bourdon Tube Pressure Gauge

5. **The following 10 observations were recorded when measuring a voltage 41.7, 42.0, 41.8, 42.0, 42.l, 41.9, 42.0, 41.9, 42.5 and 41.8 volt. Find Mean, Standard Deviation, The probable error of mean and range. (13M)**BTL 4

Answer page : 1.52- J.Gnanavadivel



x	d	d^2

41.7	-0.27	0.0729
42.0	+0.03	0.0009
41.8	-0.17	0.0289
42.0	+0.03	0.0009
42.1	+0.13	0.0169
41.9	-0.07	0.0049
42.0	+0.03	0.0009
41.9	-0.07	0.0049
42.5	+0.53	0.2809
41.8	-0.17	0.0289
$\Sigma x = 419.7$		$\Sigma d^2 = 0.441$

(i). Mean length $\overline{X} = \frac{\Sigma x}{n} = \frac{419.7}{10} = 41.97$ Volt

(ii). StadardDeviation $\sigma = \sqrt{\frac{d^2}{n-1}} = \sqrt{\frac{0.441}{(10-1)}} = 0.22$ Volt

(iii). Probable Error of one Reading $r_1 = 0.6745s = 0.15Volt$

(iv). Probable Error of Mean $r_m = \frac{r_1}{\sqrt{n-1}} = \frac{0.15}{\sqrt{9}} = 0.05Volt$

(v). Range = 42.5 − 41.7 = 0.8Volt

6.

How is the statistical evaluation of measurement data performed? (13M) (May/June 2013)

BTL 4

Answer page : 1.47- J.Gnanavadivel

- Statistical evaluation introduction and explanation (**13M**)

Out of the various possible errors, the random errors cannot be determined in the ordinary process of measurements. Such errors are treated mathematically. The mathematical analysis of the various measurements is called statistical analysis of the data.

- **Arithmetic mean & median:** When the n umber of readings of the same measurement are taken, the most likely value from the set of measured value is the arithmetic mean of the number of readings taken. The arithmetic mean value can be mathematically obtained as,

$$\bar{X} = \frac{X_1 + X_2 + \cdots + X_n}{n} = \frac{\sum X}{n}$$

  This mean is very close to true value, if number of readings is very large.
- **Average deviation**: The deviation tells us about the departure of a given reading from the arithmetic mean of the data set.The average deviation is defined as the sum of the absolute values of deviations divided by the number of readings. This is also called mean deviation.
- **Histogram:** There is a scatter of the data about some central value, when a number of multi sample observations are taken experimentally.

- **Range:** The simplest possible measure of dispersion is the range which is the difference between greatest and least values of data.

7.

Describe the different calibration procedure of measuring instrument. (13M) (Apr/May 2011)

BTL 4

Answer page : 1.54- J.Gnanavadivel

CALIBRATION : (3M)

Calibration is the process of making an adjustment or marking a scale so that the readings of an instrument agree with the accepted & the certified standard. In other words, it is the procedure for determining the correct values of measurand by comparison with the measured or standard ones. The calibration offers a guarantee to the device or instrument that itis operating with required accuracy, under stipulated environmental conditions.

Calibration methodologies: (10M)

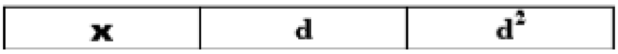
- Primary calibration
- Secondary calibration
- Direct calibration
- Indirect
- Routine

PART*C

1

The following 10 observations were recorded when measuring a voltage 41.7, 42.0, 41.8, 42.0, 42.l, 41.9, 42.0, 41.9, 42.5 and 41.8 volt. Find Mean, Standard Deviation, The probable error of mean and range. (15M)BTL 4

Answer page : 1.52- J.Gnanavadivel



x	d	d^2

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$\Sigma x = 419.7$		$\Sigma d^2 = 0.441$

$$(i).\ Mean\,length\ \overline{X} = \frac{\Sigma x}{n} = \frac{419.7}{10} = 41.97\ Volt$$

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$$(v).\ Range = 42.5 - 41.7 = 0.8Volt$$

2

Describe the static and dynamic characteristics of measuring instrument. (15M) (Apr/May 2011) BTL 4

Answer page : 1.8- J.Gnanavadivel

Static characteristics: (8M)

- Accuracy: The closeness with which an instrument reading approaches the true value of the quantity being measured.
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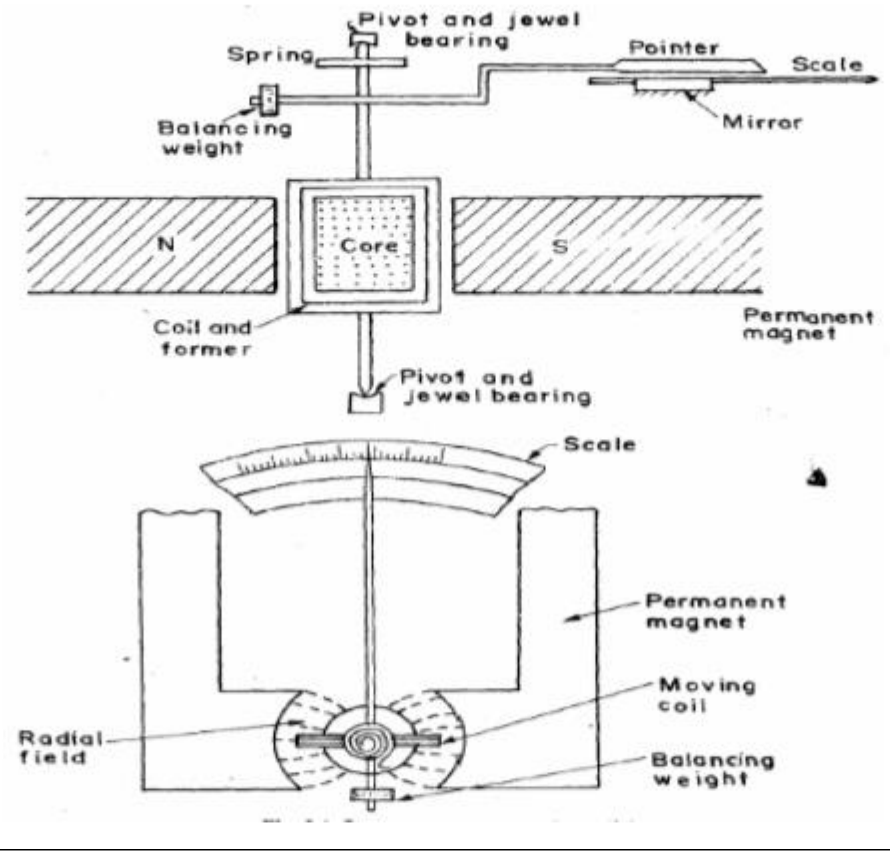
UNIT II ELECTRICAL AND ELECTRONIC INSTRUMENTS 9

Principle and types of multi meters – Single and three phase watt meters and energy meters – Magnetic measurements – Determination of B-H curve and measurements of iron loss – Instrument transformers – Instruments for measurement of frequency and phase.

PART * A

Q.No	**Questions**
1.	**State the essentials torque required for successful operation of instruments? (Nov/Dec 2009)** BTL 4 - Deflecting torque - Controlling torque - Damping torque
2.	**Why scale of gravity is non-uniform?(Apr/May 2015)** BTL 4 The quantity is to measure is proportional to sin rather than in gravity control which is not a uniform. Hence scale calibrated is not in uniform.
3.	**What is the basic principle of PMMC instruments?** BTL 2 A current carrying coil placed in the permanent magnet field experiences a force, proportional to the current it carries.
4.	**List the possible cause of errors in moving iron instruments?(Apr/May 2015)** BTL 3 - Hysteresis errors. - Temperature errors. - Stray magnetic field errors - Frequency & eddy current errors
6.	**What is loading effect?(Nov/Dec 2011)** BTL 2 The low sensitive instruments is used in high resistances circuit then its gives a lower reading than the true reading.
7.	**State the precautions to be taken while using d.c. voltmeter?** BTL 4 The voltmeter resistances are very high & it should always be connected across the circuit or component whose voltage is to be measure.
8.	**What are the requirements of a multiplier? (Nov/Dec 2010)** BTL 2

	• Their resistances should not change with time. • They should not non-inductively wound for a.c.meters.
9.	**Which torque is absence in energy meter?** BTL 3 The controlling torque is absence in energy metering energy meter continues rotation of disc is required & it is not necessary to reset it to zero every time & hence controlling torque is absence.
10	**What are the constructional parts of dynamometer type wattmeter?** BTL 2 • Fixed coil • Moving Coil • Current limiting resister • Helical spring • Spindle attached with pointer • Graduated scale
11	**Name the errors caused in Dynamometer type wattmeter.(Nov/Dec 2013)** BTL 2 • Error due to pressure coil inductance • Error due to pressure coil capacitance • Error due to methods of connection • Error due to stray magnetic fields • Error due to eddy current.
12	**Name the methods used for power measurement in three phase circuits.(Nov/Dec 2010)** BTL 2 • Single wattmeter method • Two wattmeter method • Three wattmeter method.
13	**What are the special features to be incorporated for LPF wattmeter? (Nov/Dec 2013)** BTL 2 • Pressure coil circuit • Compensation for Pressure coil current • Compensation for Pressure coil inductance.
14	**Define creeping.(May/June 2014)**BTL 1 Slow but continuous rotation of disc when pc is energized and cc is not energized.
16	**Name the types of instruments used for making voltmeter and ammeter. (Nov/Dec 2013)** BTL 2 • PMMC type • Moving iron type • Dynamometer type • Hot wire type • Electrostatic type • Induction type.
17	**State the disadvantages of PMMC instruments.(Apr/May 2015)** BTL 4 • Cannot be used for ac m/s

	• Some errors are caused by temperature variations.
18	**State the applications of PMMC instruments.(May/June 2012)** BTL 2 • m/s of dc voltage and current • Used in dc galvanometer.
19	**How the range of instrument can be extended in PMMC instruments.(Nov/Dec 2011)** BTL 4 • In ammeter by connecting a shunt resister • In voltmeter by connecting a series resister.
20	**State the advantages of Hot wire type instruments.(Apr/May 2015)** BTL 4 • Can be used for both dc and ac • Unaffected by stray magnetic fields • Readings are independent of frequency and waveform.
PART * B	
1.	**Describe the construction and working of permanent magnet moving coil instrument. Also derive the expression for deflection. 13M (Nov/Dec 2013)** BTL 3 Answer page: 2.14 – J.Gnanavadivel **Construction and working: (7m)** 

A moving-coil meter is a very commonly used form of analogue voltmeter because of its sensitivity, accuracy and linear scale, although it only responds to d.c. signals. As shown schematically in Figure 6.2, it consists of a rectangular coil wound round a soft iron core that is suspended in the field of a permanent magnet. The signal being measured is applied to the coil and this produces a radial magnetic field. Interaction between this induced field and the field produced by the permanent magnet causes a torque, which results in rotation of the coil.

Torque equation: (4m)

Deflecting torque Td= NBAI

N=number of turns of coil

B= Flux density in air gap

A= coil area

I= Current through moving coil

Final steady deflection Tc=Td

Advantages & disadvantages: (2m)

Advantages:

- The sensitivity is high
- Uniform scale
- Operating current is small

Disadvantages:

- Not suitable for AC measurements
- Ageing of PMMC introduces the errors
- Cost is high

2. **With a neat block diagram explain the working of a digital multimeter. (13M)** BTL 2

Answer page: 2.71 – J.Gnanavadivel

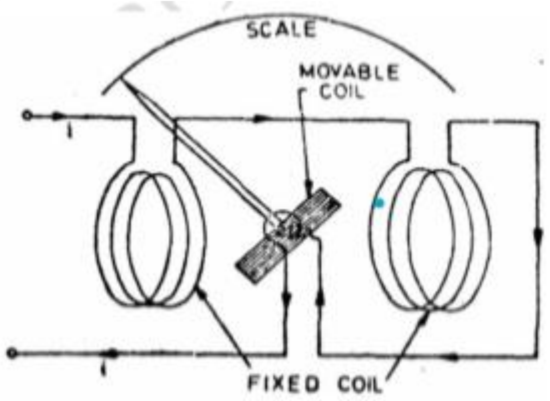
- Draw the circuit diagram of Digital multimeter& explain its working (10M)
- Digital multimeter is an instrument which can be used for measuring d.c and a.c voltages, direct and alternating currents, and resistances over several ranges.
- For measurement of a.c voltages and currents, the ac values are converted to dc value by using rectifier and filter circuits & corresponding dc volatges are measured using the basic circuit.
- Advantages & disadvantages(3m)

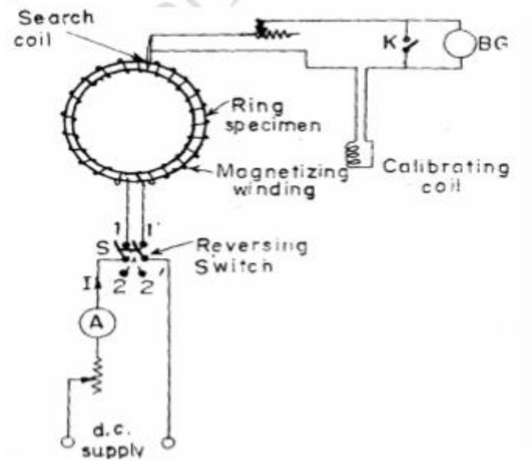
Adv

1. Highly accurate and the accuracy is around 0.03 %
2. Loading effect is nil because of high input impedance
3. Measurement speed is more

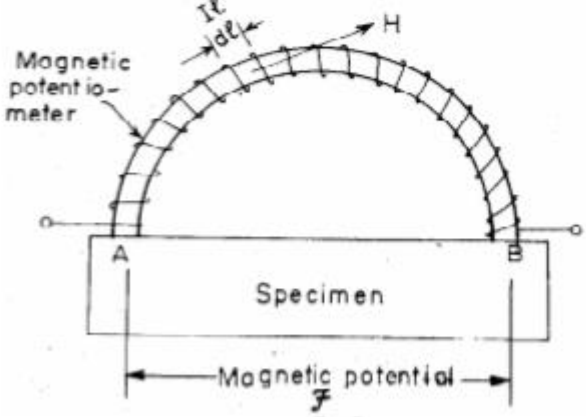
Dis-Adv:

1. Interruption of electric noise

	2. Requirement of external power supply **3.** Isolation problems occurs in DMM.
3.	**With a neat diagram explain the construction and working of electrodynamometer type instruments. Also derive its torque equation. (13M) (Nov/Dec 2010)**BTL 2 Answer page: 2.43 – J.Gnanavadivel - Circuit diagram (3M)  - Operating principle of Electrodynamoter instruments (4M) - Torque equation (4M) - Advantages and disadvantages (2M) <u>Adv</u> 1. As the coils are air cored, these instruments are free from hysteresis and eddy current losses. 2. They have a precision grade accuracy for frequencies from 40 HZ to 500 Hz. <u>Dis-Adv</u> 1. They have a low torque/ weight ratio hence have a low sensitivity 2. Increases frictional losses.
4.	**Explain the different methods of determination of B –H curve 13M (Nov/Dec 2011) (Nov/Dec 2010) (April/May 2011) (May /June2014)**BTL 2 Answer page: 2.124 – J.Gnanavadivel - **Types of test (3M)** 1. Ballistic test 2. A.C Testing 3. Steady state test - **Determination of B-H curve methods (10M)** 1. Measurements of flux density



2. Magnetic potentiometer

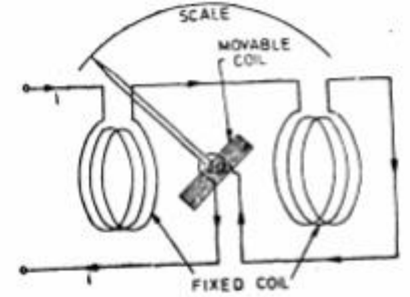


(Fig) Magnetic potentiometer

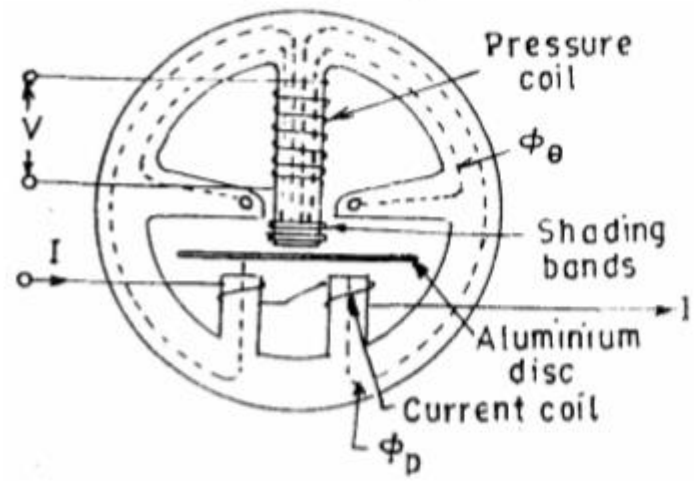
5. **With a neat block diagram explain the working of digital frequency meter& digital phase meter. 13M (Nov/Dec 2011) (Nov/Dec 2018)**BTL 2

Answer page: 2.115 – J.Gnanavadivel

- Circuit diagram & explanation (9M)

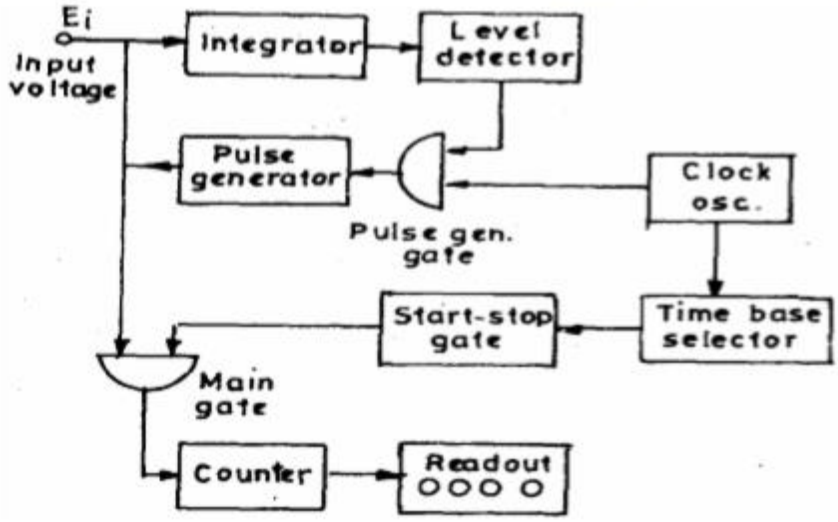


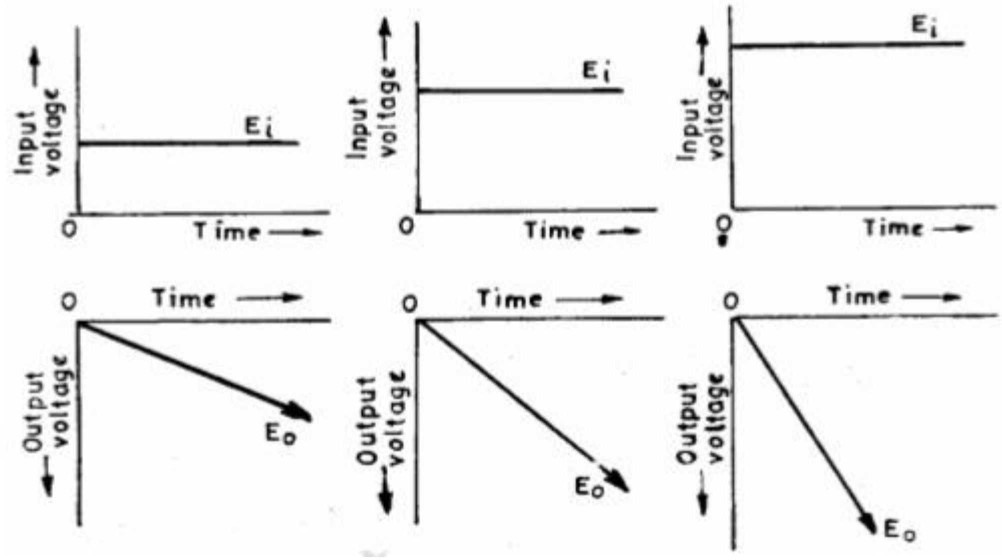
- Electrodynamic instruments are capable of service as transfer instruments.Indeed, their principal use as ammeters and voltmeters in laboratory and measurement work is for the transfer calibration of working instruments and as standards for calibration of other instruments as their accuracy is very high.
- Electrodynamometer types of instruments are used as a.c. voltmeters and ammeters both in

	the range of power frequencies and lower part of the audio power frequency range. They are used as watt-meters, and with some modification as power factor meters and frequency meters. • Advantages (2M) 1. Simple in construction 2. Simple operation 3. Gives an accurate measurement. • Dis-advantages of phase meter(2M) 1. Poor accuracy **2.** The phase difference of 180 out of phase or inphase condition only can be detected. Other phase angles cannot be measured.
6.	**Give the construction and principle of operation of single phase induction type energy meter. Also derive its torque equation. 13M (April/May 2011) Nov/Dec 2009) (May /June2018)** BTL 4 Answer page: 2.90 – J.Gnanavadivel • **Construction & working of single phase energy meter (6M)**  **(Fig) single phase energy meter** • **Explanation (4M)** 1. Driving system 2. Moving system 3. Braking system 4. Counting system/ Registering mechanism • **Errors caused by braking system & advantages (3M)**
7.	**Explain with neat diagram the working of linear ramp type & integrating type DVM. (13M) (April/May 2011)**BTL 2

Answer page: 2.55 – J.Gnanavadivel

- **Ramp type DVM(6M)**
  1. The operating principle of a ramp type digital voltmeter is to measure the time that a linear ramp voltage takes to change from level of input voltage to zero voltage (or vice versa)
  2. This time interval is measured with an electronic time interval counter and the count is displayed as a number of digits on electronic indicating tubes of the output readout of the voltmeter.
- **Integrating type DVM (7M)**





8. **Explain the operating principle of Instrument Transformer and what are errors affecting its charactersistics. (13M) (April/May 2011) (Nov/Dec 2018)**BTL 2

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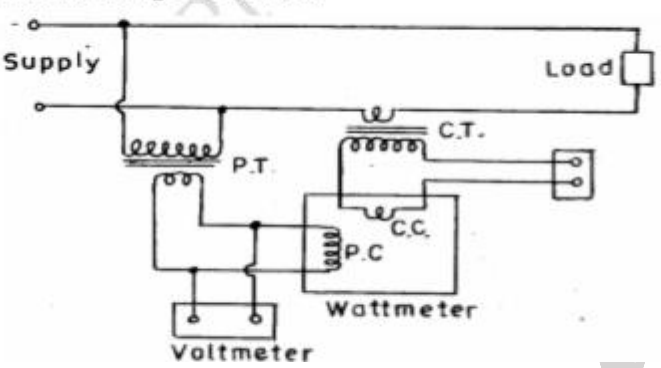
Answer page: 2.99 – J.Gnanavadivel

- **Instrument transformer circuit diagram (5M)**



- **Types & explanation (5M)**
  1. Current transformer
  2. Potential transformer
- **Equivalent circuit (3M)**
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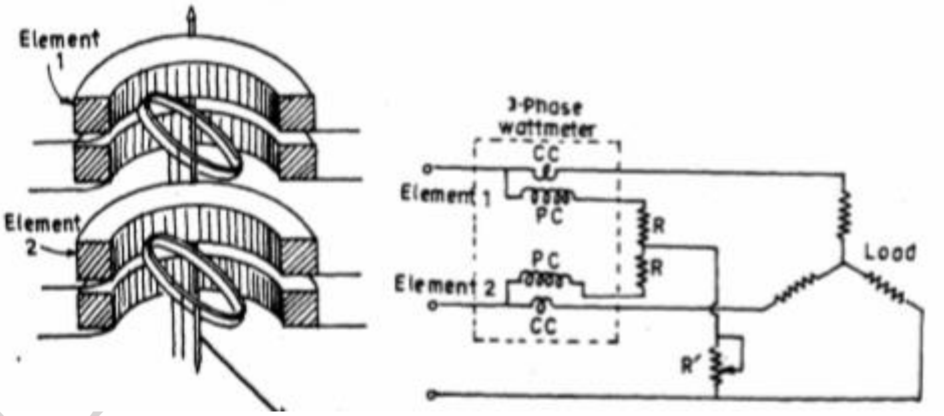
<tr><td>9.</td><td>
Explain the design of three phase wattmeter's and give the reactive power measurement in 3 phase circuits. (13M) BTL 2
Answer page: 2.87 – J.Gnanavadivel

- **Three phase wattmeter circuit diagram (5M)**



- **Explanation (5M)**
- **Advantages(3M)**
  1. Direct indication of three phase power
  2. High accuracy
</td></tr>
<tr><td></td><td>**Part * C**</td></tr>
<tr><td>1</td><td>
i)A PMMC ammeter gives reading of 40mA when connected across two opposite corners of a bridge rectifier, the other two corners of which are connected in series with a capacitors to 100 K, 50Hz supply. Determine the capacitance. (8M) BTL 3

Since PMMC ammeter gives average reading,
</td></tr>
</table>

Average value of current Iav= 40mA

Assuming sinusoidal wave i.e. form factor is 1.11

RMS value of current, Irms= 1.11*40

= 44.4 ma.

Neglecting resistance of the instrument and assuming the capacitance connected is C farads

Irms= V/xc= 2πfCV

C= Irms/2πfCV = 1413pF.

ii) The coil of instrument has 42.5 turns. The mean width of the coil is 2.5 cm and the axial length of the coil is 2 cm. If the flux density is 0.1 wb/m2, calculate the torque on the moving coil Nm. (7M) BTL 3

Given:

N= 42.5 Turns

B= 0.1 wb/m2

L=2 cm

D= 2.5 cm

Assume current i= 20mA

T= NBAi

$= 42.5 * 0.1 * 2.5 * 20 * 10^{-3}$

= 0.425N-M.

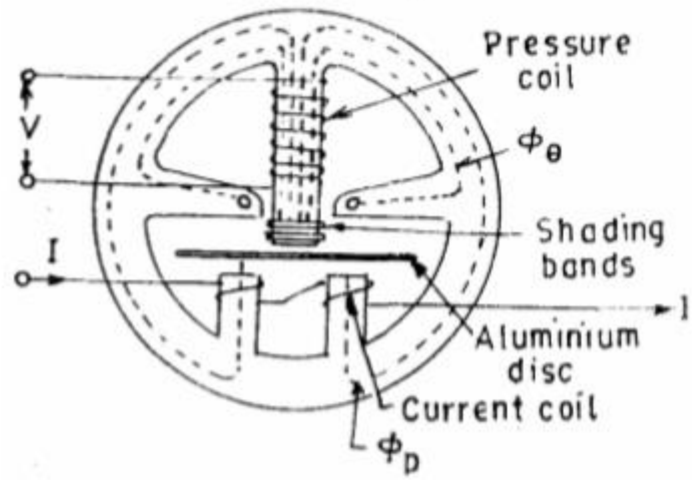
2

Give the construction and principle of operation of single phase induction type energy meter. Also derive its torque equation. (15M) (April/May 2011) Nov/Dec 2009) (May /June2014).

BTL 3

Answer page: 2.90 – J.Gnanavadivel

- **Construction & working of single phase energy meter (6M)**



(Fig) single phase energy meter

- **Explanation (9M)**
  1. Driving system
  2. Moving system

	3. Braking system 4. Counting system/ Registering mechanism

UNIT III COMPARATIVE METHODS OF MEASUREMENTS 9
D.C potentiometers, D.C (Wheat stone, Kelvin and Kelvin Double bridge) & A.C bridges (Maxwell, Anderson and Schering bridges), transformer ratio bridges, self-balancing bridges. Interference & screening – Multiple earth and earth loops - Electrostatic and electromagnetic Interference –Grounding techniques.

PART * A

Q.No	**Questions**
1.	**What is potentiometer?**BTL 2 A potentiometer is an instrument designed to measure an unknown voltage by comparing it with a known voltage.
2.	**Define standardization.** BTL 1 It is the process by which adjusting the current flows through the potentiometer coil to make the voltage across the std cell is equal.
3.	**State the applications of potentiometer.(Nov/Dec 2011)** BTL 5 • Used for m/s of unknown emf • Used for ammeter calibration • Used for Voltmeter calibration • Used for wattmeter calibration
4.	**What are the practical difficulties in ac potentiometers?(Apr/May2011)** (BTL 2) • More complicated • Accuracy is seriously affected • Difficulty is experienced in standardization.
5.	**State the advantages of ac potentiometers.(Apr/May 2015)** BTL 5 • Can be used for m/s of both magnitude and phase angle • Can be used for m/s of inductance of the coil. • It is used in m/s of errors in CTS
6.	**State the applications of ac potentiometers.(Nov/Dec 2010)**BTL 5 • M/s of self-inductance.

	• Ammeter calibration • Voltmeter calibration • Wattmeter calibration.
7.	**Name the bridge circuits used for the m/s of self-inductance. (Nov/Dec 2011)**BTL 2 • Maxwell's bridge • Maxwell-Wein Bridge • Anderson bridge • Hay's bridge.
8.	**Name the bridge circuits used for the m/s of mutual inductance.(May/June 2014)** BTL 2 • The Heaviside Campbell Bridge • The Campbell Bridge.
9.	**Name the ac sources used in ac bridges.(Nov/Dec 2012)** BTL 2 • AC supply with step-down transformer • Motor driven alternator • Audio frequency and radio frequency oscillator.
10	**Name the sources of errors in ac bridge (May/June 2014)**BTL 2 • Errors due to stray magnetic fields • Leakage errors • Eddy current errors • Residual errors • Frequency and waveform errors.
11	**Define Q-factor of the coil.** B TL 1 It is the ratio between Power stored in the coil to the power dissipated in the coil
12	**Name the faults that occur in cables.(Apr/May 2010)** BTL 2 • Break down of cable insulation • Short circuit fault • Open conductor fault.
13	**Mention different types of resistance.(Apr/May 2015)** BTL 2 • Low resistance • Medium resistance • High resistance
14	**Name the methods used for low resistance measurement.(Apr/May 2010)** BTL 2 • Ammeter – voltmeter method • Potentiometer method • Kelvin double bridge method • Ohm meter method
15	**Name the methods used for medium resistance measurement.(Nov/Dec 2009)** BTL 2 • Ammeter – voltmeter method • Substitution method • Wheatstone bridge method • Carey fosters bridge method.
16	**Where high resistance measurements is required?(Nov/Dec 2009)** BTL 2 • Insulation resistance of cables

	• High resistance circuit elements • Volume resistivity of a material • Surface resistivity.
17	**State the applications of ac potentiometers.(Nov/Dec 2010)** BTL 5 • Measurements of self-inductance. • Ammeter calibration • Voltmeter calibration • Wattmeter calibration.
18	**State the advantages of Kelvin double bridge method.** BTL 5 Errors owing to contact resistance, resistance of leads can be eliminated by using This Kelvin double bridge.
19	**Name the sources of errors in ac bridge measurements. (May/June 2014)** BTL 2 • Errors due to stray magnetic fields • Leakage errors • Eddy current errors • Residual errors • Frequency and waveform errors.
20	**How the earth resistance is measured.** BTL 5 By using earth megger the value of surface earth resistance can be measured.
21	**Name the faults that occur in cables.(Apr/May 2010)** BTL 2 • Break down of cable insulation • Short circuit fault • Open conductor fault.
22	**Name the methods used for low resistance measurement.(Apr/May 2010)** BTL 2 • Ammeter – voltmeter method • Potentiometer method • Kelvin double bridge method • Ohm meter method.
23	**Name the methods used for medium resistance measurement.(Nov/Dec 2009)** BTL 2 • Ammeter – voltmeter method • Substitution method • Wheatstone bridge method • Carey fosters bridge method.
24	**Where high resistance m/s is required?(Nov/Dec 2009)** BTL 2 • Insulation resistance of cables • High resistance circuit elements • Volume resistivity of a material • Surface resistivity.
PART * B	

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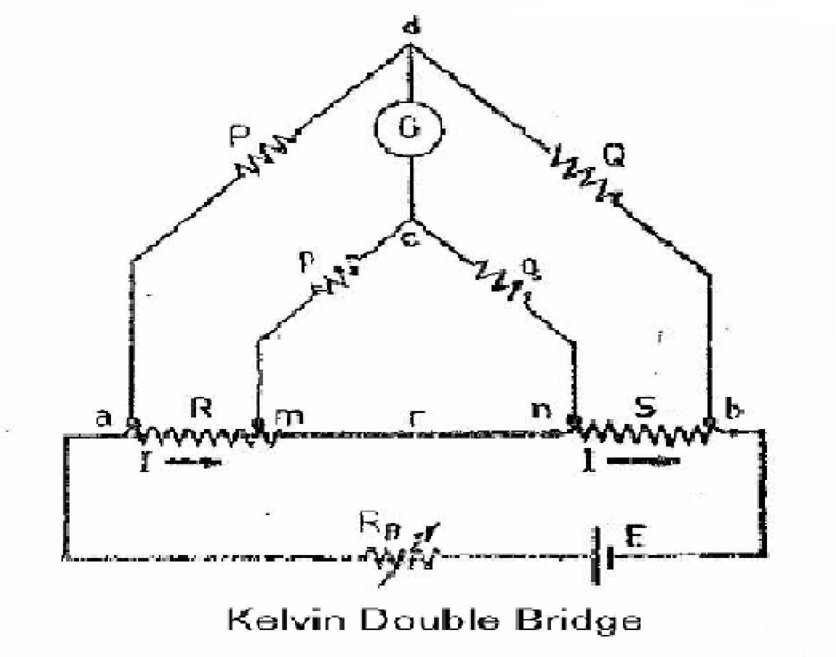
Explain the theory and working principle of Kelvin’s double bridge method for the measurement of low resistance. Derive the relation for finding unknown resistance. (13M)(NOV/DEC 2011)(MAY/JUNE 2014) (APR/MAY 2015) (APR/MAY 2010) BTL 2

Answer page: 3.30 – M.Sudakaran Lakshmi publications

- Kelvin’s double bridge method circuit diagram & explanation (10M)



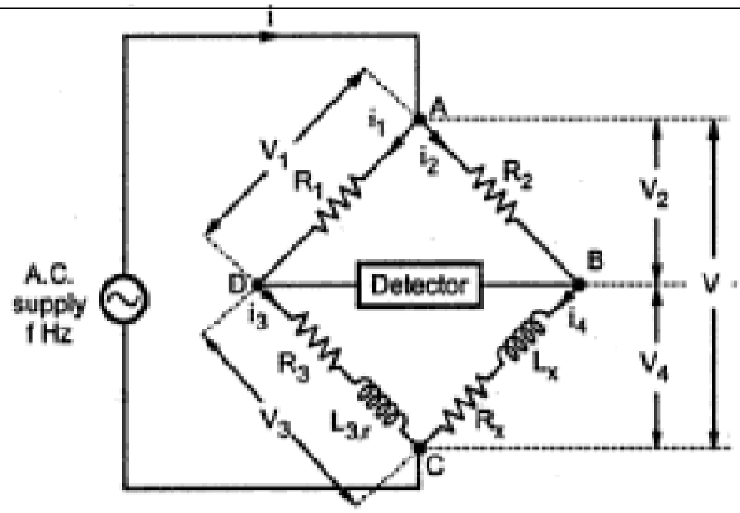
Kelvin Double Bridge

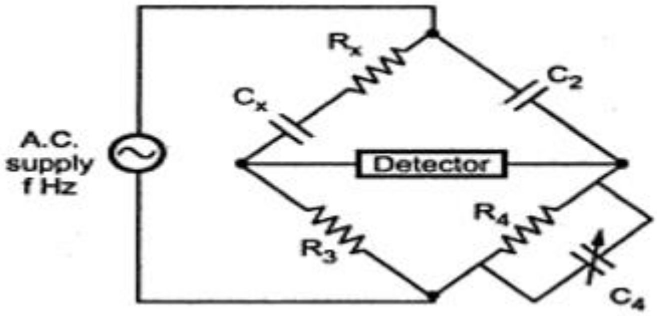
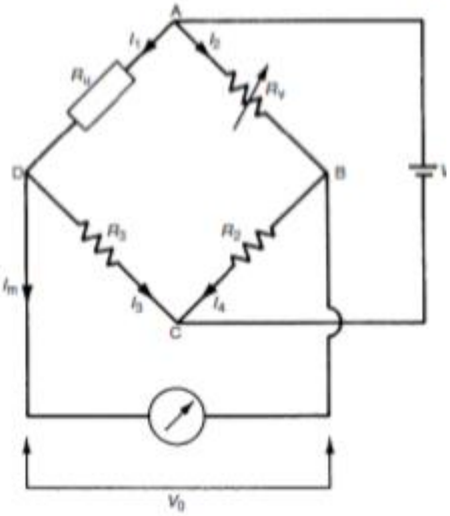
- Kelvin’s bridge principle is not a practical way of desired result. There is some difficulty for determining the galvanometer connections. To avoid this difficulty, two resistances p & q can be connected between point’s m and n.
- The ratio p/q is made equal to P/Q
- R= P/Q.S
- Advantages & disadvantages(3m)

2. **Explain how inductance is measured by using Maxwell’s bridge .Derive the condition for balance. (13M) (NOV/DEC 2013) (MAY/JUNE 2014)** BTL 2

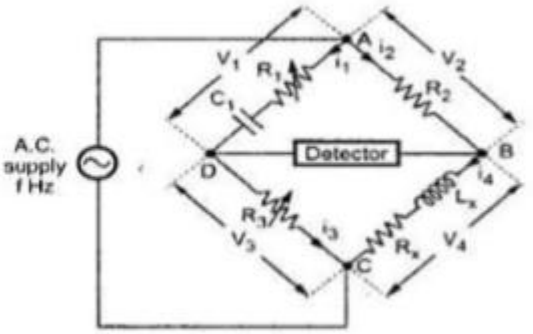
Answer page: 3.41 – J.Gnanavadivel Anuradha Publications

Maxwell’s inductance bridge circuit diagram & explanation (10M)

	 • It is used to measure both a given inductance (with a Q between 1 and 10) and its series resistance by comparison to a standard capacitances. • Capacitors are easy to shield and they produce almost no external field of their own. • The balance is independent of frequency. • Using Q-factor for a series L-R equivalent circuit, the series resistances can be found from Rx=wLx/Q • Advantages & disadvantages(3m) Adv: • The frequency does not appear in any of the two equations. • The two balance equations are independent, if the values of R1 & C1 as variable elements. Dis adv: • This bridge is limited to measurement of low Q coils • It requires a variable standard capacitor which may be very expensive if calibrated to a high degree of accuracy.
3.	**Explain the working principle of Anderson's bridge and also derive its balance equations. (13M)** BTL 2 Answer Page: 3.46 - J.Gnanavadivel Anuradha Publications • Andersons bridge circuit diagram & explanation (10M) • Advantages & disadvantages (3M) **Adv:** • A fixed capacitor can be used instead of a variable capacitors in the case of Maxwell's bridge. • This bridge may be used for accurate determination of capacitance in terms of inductance. **Dis-Adv:** • The Anderson's bridge is more complex than its prototype Maxwell's bridge. • An additional junction increases the difficulty of shielding the bridge.
4.	**Explain the working principle of Schering Bridge and also derive its balance equations. (13M) (APR/MAY 2011)**BTL 2 Answer Page: 3.39 - J.Gnanavadivel Anuradha Publications • Schering bridge circuit diagram & explanation (10M)

	 - It is one of the most important AC bridges, is used extensively for measurement of capacitors with a low dissipation factor. - Besides capacitances and dissipation factors it also measures the insulating properties of the electrical cables (for phase angle very close to 90^o) and equipment's. - Advantages (3M) 1. The balance equation is independent of frequency. 2. It is used for measuring the insulating properties of electrical cables and equipmemts.
5.	**Explain the working principle of Wheatstone Bridge and also derive its balance equations. (13M) (APR/MAY 2011) (NOV/DEC 2012)**BTL 2 Answer Page: 3.19 - J.Gnanavadivel Anuradha Publications - Wheatstone bridge circuit diagram & explanation (5M& 8M)  - The simplest form of bridge is for the purpose of measuring resistance and is called Wheatstone's bridge. - This bridge is widely used for precision measurement of resistance from 1Ω to the low mega ohm range. - It is the most accurate method available for measuring and is popular for laboratory use. - Here the bridge is balanced when the potential difference across C & D is zero. $I_1R_1= I_2R_2$ - The unknown resistor is R_4or Rx can be found as follows: $Rx= R_4= R_2/R_1* R_3$ - The resistors r1 & r2 are called ratio arms and resistor r3 is called standard arm of the

	bridge.
6	**Mention the importance of grounding. Explain the different techniques of grounding. (13M) (NOV/DEC 2011) (NOV/DEC 2013) (APR/MAY 2018)** BTL 4 Answer Page: 3.19 - J.Gnanavadivel Anuradha Publications • Grounding techniques(3M) 1. Single point grounding 2. Use of differential input amplifier 3. Input guarding 4. Using doubly shielded cables • Single point grounding diagram (3M) 1. Circuit diagram 2. Limitations: single point grounding is impractical for the systems in which various units like power supply, amplifier etc. are located too fair. • Use of differential input amplifiers: (3M) 1. Circuit diagram 2. Limitations: It is not applicable to the case where Ecm is so high that it exceeds the permissible level of input of differential amplifiers. • Input guarding & Doubly shielded cables: (4M) 1. Circuit diagram 2. Rules for input guarding technique: connect the guard shield to the cable shield. Connect the cable shield to the transducer signal shield.
7	**Explain in detail the electrostatic and electromagnetic interference. (13M) (NOV/DEC 2011) (NOV/DEC 2013)(APR/MAY 2010)** BTL 2 Answer Page: 3.72 - J.Gnanavadivel Anuradha Publications • Sources of electromagnetic interferences are (3M) 1. Gas discharges in fluorescent lamp 2. Sparking in electric switches, relays 3. Arcing in electric switches relays etc • Formation of group loop diagram(4M) • Causes of ground loop current (3M) 1. Potential difference between two grounding points 2. Inductive interferences due to stray magnetic field and RF waves. 3. Sometimes capacitive interference also form a ground loop. • Common mode and series mode voltages (3M)
	PART*C
1	**A whetstones bridges is used to measure high resistance S whose ratio arms are 10000Ω & 10 ohm. The adjustable arm has a maximum value of 10000 ohm. A battery of 20 V, emf and negligible resistances forms the junction ratio arms to the opposite corner. What is the maximum resistance which can be measured? (15M)** BTL 4 Answer page: 3.24 - J.Gnanavadivel Anuradha Publications

	R1/R2= 10000/10 Smax=R3max=10000 ohm We know that, R4= R3.R2/R1 Maximum value of R4 that can be measured = 10000/10 * 10000= 10Mohm.
2	**Discuss briefly how Hay's Bridge can be used for the measurement of inductance. Why hay's bridge is suited for measurement of inductance of high Q coils. (15M) (NOV/DEC 2011).** BTL 4 Answer page: 3.42 - J.Gnanavadivel Anuradha Publications • Circuit diagram and explanation(10M)  • Hay bridge or opposite-angle bridge is used for the measurement of high –Q inductors(Q>10) • The hay bridge differs from Maxwell in that it has a standard capacitor in the arm opposite to the unknown inductor. • Unlike the capacitance and Maxwell inductance bridges, balance is dependent on frequency. • Advantages: (3M) 1. This bridges gives very simple expressions for unknown inductances for high Q coils, and is suitable for the coils having Q>10. **2.** It also gives a simple expression for Q factor, Q= 1/ wC2R2.

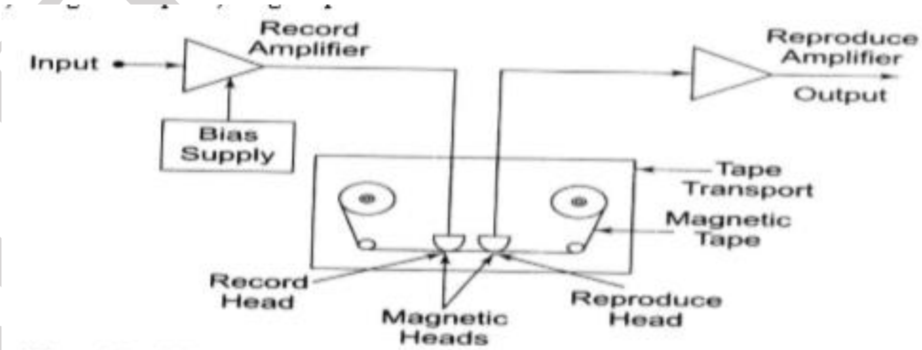
UNIT IV STORAGE AND DISPLAY DEVICES 9 Magnetic disk and tape – Recorders, digital plotters and printers, CRT display, digital CRO, LED, LCD & Dot matrix display – Data Loggers.	
PART * A	
Q.No	**Questions**
1.	**What are X-Y recorders?(Nov/Dec 2012)** BTL 2 It is used to record one variable varying with other variable. It consists two separate self-balancing potentiometers and the resulting motion of the pen gives a plot on a graph for variation of one variable with other.

2.	**What are digital display devices?(Apr/May 2011)** BTL 2 The devices which provides a visual display of numbers, letters , symbols of an electrical input are called digital display devices.
3.	**What is LED?(Nov/Dec 2010)** BTL 2 It is semiconducting p-n junction diode capable of emitting electromagnetic radiation when it is in forward bias. The emission depends on semi conducting materials.
4.	**What is the principle of operation of LCD? (Nov/Dec 2011)** BTL 2 LCDs do not emit pr generate light but alter externally illumination & when electrical signal is applied modulated light.
5.	**What are the methods used for magnetic tape recording? (Nov/Dec 2011)** BTL 2 • Direct recording • Frequency modulation recording • Pulse duration modulation recording
6.	**What are the main parts of CRT?(Nov/Dec 2011)** BTL 2 • electron gun • deflection system • fluorescent screen • glass tube or envelope
7.	**What are the advantages of digital storage oscilloscope? (Nov/Dec 2009)** BTL 2 • It is easier to operate and has more capability. • The storage time is infinite. • The cursor measurement is possible.
8.	**Distinguish between LED & LCD. (Nov/Dec 2013) (May/June 2012)** BTL 5

LED	LCD
High power consumption	Low power consumption
Costlier	Cheaper
Faster	Slower
Small in size	Bigger in size
High efficiency as emitters of electromagnetic radiation	Low power dissipation and low operating speed

9.	**What are the functions of data logger? (May/June 2012)** BTL 2 Basic function of data logger is to automatically make the record of the readings of the various instruments located at different part of the plant. Data logger measures and records data very quickly and accurately without any efforts. Measurement errors are eliminated completely.
10	**What are the various components of recording instruments? (May/June 2013)** BTL 2 The following are some of the basic components of recording instrument.

	• Recording head • Magnetic head • Reproducing head • Tape transport mechanism • Conditioning devices
11	**Reason out why todays commercial LED monitor have become more popular than their LCD counterparts? (May/June 2013)** BTL 5 • LEDs are miniature in size and they can be stacked together to form numeric and alphanumeric display in high density matrix. • LEDs have a high efficiency as emitters of electromagnetic radiations, and it require moderate power for this operation, and switching time is less than 1 nanosecond.
12	**Mention any two storage devices. (May/June 2011)** BTL 2 **Primary magnetic storage** • Diskettes • Hard disks (bpth fixed and removable) • High capacity floppy disks • Disk cartridges • Magnetic tape **Primary optical storage** • Compact disk read only memory(CD ROM) • Digital Video Disk Read only Memory (DVD ROM) • CD Recordable(CD R) • CD Rewritable (CD RW) • Photo CD
13	**Differentiate the functions of printers and plotters.(May/June 2011)** BTL 4 The difference is that the former are devices whose purpose is to print letters, numbers and characters in text readable form, while the latter print diagrams with continuous lines.
14	**What is meant by phosphorescence?**BTL 2 The property of phosphor material continuing to emit light after its excitation source has been removed is called phosphorescence.
15	**What are the different types of printers?**BTL 2 • Drum wheel printers • Daisy wheel printers • Line printers • Drum printers • Dot-matrix printer • Non-Impact Dot-Matrix Printer
16	**Define Transducers.** BTL 1 It is device which controls the physical quantity into a proportional electrical signal which is given as an input to the digital data acquisition system.
17	**What is the magnetic principle used in computer data storage?**BTL 2 Voltage induced on the tape is proportional to the rate of changes of flux linkages. $E \alpha N.d\theta/dt$
18	**Mention the methods of recording**. BTL 2 • Direct recording • F.M recording

	- Pulse duration modulation recording (PDM).
19	**A 3-1/2 digit voltmeter is used for measurement. What is its resolution? How it would display a reading of 12.57 V in 100 V scale? (Apr/May 2017)** BTL 4 Resolution: R= $1/10^n$ The resolution of a DVM is determined by the m=number of full digit used. N= 3, R=0.001 Resolution on 100v scale= 0.001*100=0.1 12.57 on 100V= 12.57*0.1 Display as= 1.257
20	**Why is a delay line used in the vertical section of an oscilloscope?(Apr/May 2017)** BTL 2 The circuit is used to, delay the signal for a period of time in the vertical section of CRT. The input signal is not applied directly to the vertical places because the parts of the signal gets lost, when the delay time not used. Therefore, the input signal is delayed by a period of time.
PART * B	
1.	**With neat diagram, explain the basic components and working principle of magnetic tape recorders. (13M) (NOV/DEC 2012) (NOV/DEC 2014)(APR/MAY 2012) (MAY/JUNE 2018)** BTL 2 Answer Page: 4.1 – J.Gnanavadivel • Components of tape recorder & explanation (7M) 1. Recording head 2. Magnetic tape 3. Reproducing head 4. Tape transport mechanism 5. Conditioning devices  Fig. 12.10(a) — Elementary Magnetic Tape Recorder • Methods of Working principle of magnetic tape recorder(6M) 1. Direct recording 2. FM recording(Frequency Modulation) 3. PDM recording(Pulse duration modulation)
2.	**i) Explain the segmental display and dot matrices display for numeric and alpha numeric displays.(10M)** BTL 2

Answer Page: 4.51 – J.Gnanavadivel

- **Types of segmental display & explanation (7M)**
  1. Segmental gas discharge display
  2. Segmental LCD and LED display
- Segmental gas discharge display work on the principle of gas discharge glow, similar to the case of Nixie tubes. They are mostly available in 7 segment or 14 segment form, to display numeric and alphanumeric characters.
- In segmental LED display, it is usual to employ a single LED for each segment. For conventional 7 segment LED display the wiring pattern is simplified by making one terminal common to all LED's and other terminal corresponding to different segments.
- **Dot matrix display (3M)**

  Excellent alphanumeric characters can be displayed by using dot matrix LED's with an LED at each dot location. Commonly used dot matrices for the display of prominent characters are 5x7, 5x8, and 7x9.

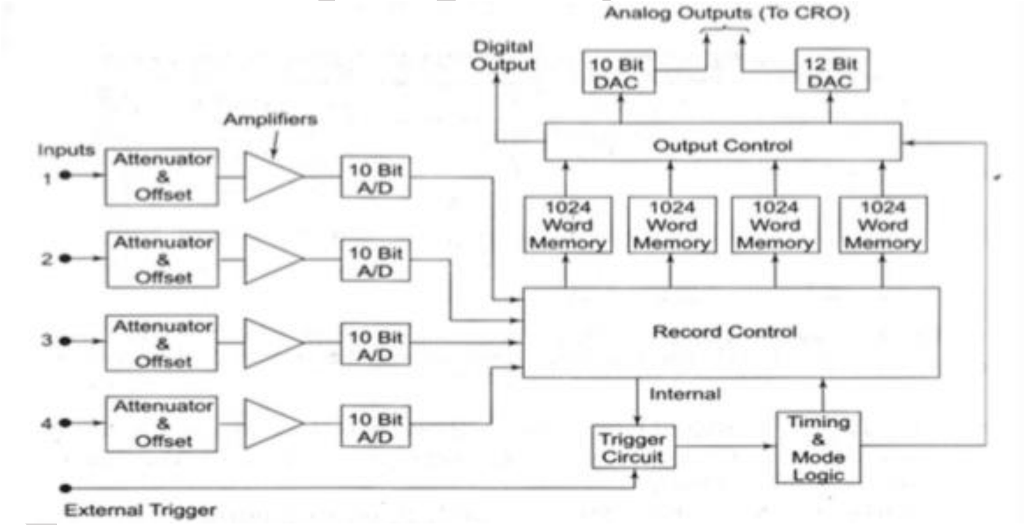
ii) Write short notes on data logging. (3M)

The data loggers are used to automatically make a record of the readings of instruments located at different parts of the plants. It measures and records data effortlessly as quickly , as often as accurately desired.

3. **Draw and explain the block diagram of digital CRO. (13M) (Nov 2018)**BTL 2

Answer Page: 4.42 – J.Gnanavadivel

- Block diagram of digital CRO (7M)



- Working (6M)

  The input is amplified and attenuated with input amplifier as in any oscilloscope. The sample and hold circuit effectively snaps a picture of the voltage level. The output of S/H circuit is connected to an ADC. CRT accepts only the analog signals and thus the signal in the digital memory is converted in to an analog signal by means of digital to analog converter.

4. **Describe the construction and working of LCDs. Mention the difference between light scattering and field effect types of LCDs, also explain the advantages of LCDs. (13M)** BTL 4

Answer Page: 4.47 – J.Gnanavadivel

- Types of LCD (2M)
  1. Dynamic scattering type
  2. Field effect type
- Construction & operation (7M)

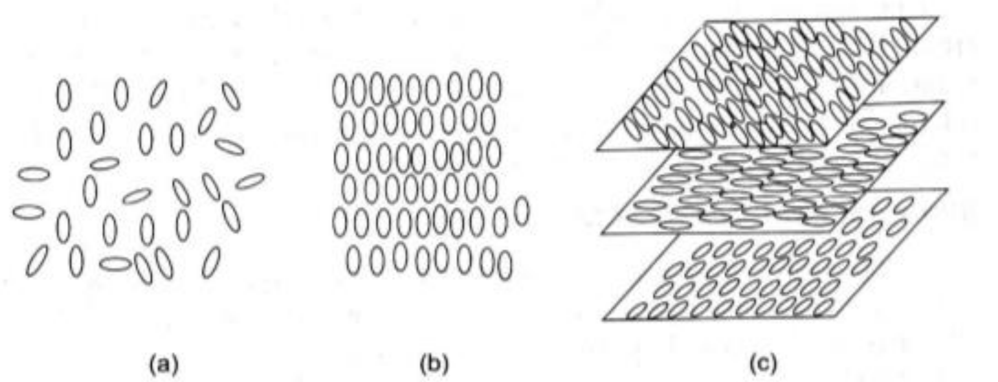


Fig. 2.11 Liquid Crystal Materials (a) Ordinary Liquids (b) Nematic Liquid Crystal (c) Cholesteric Liquid Crystal

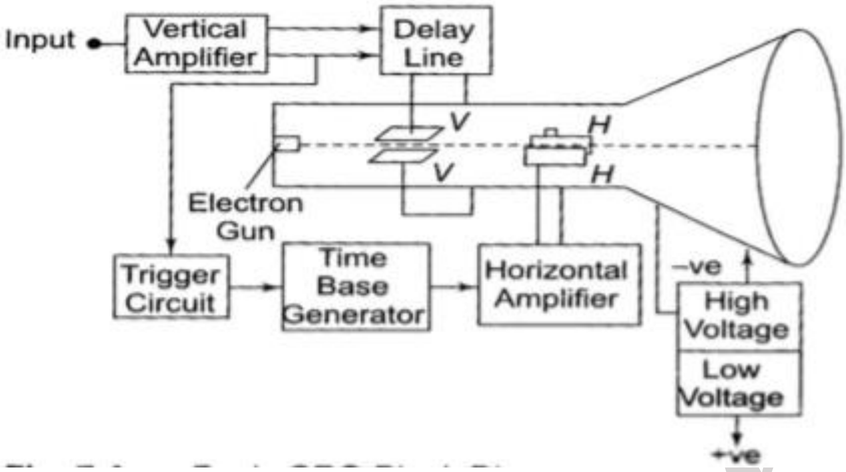
- Advantages: (1M)
  1. Low cost
  2. Low power consumption
  3. It requires very low voltage
- Disadvantages(1M)
  1. Life time is very less compared with LED
  2. Response time is more compared with LED
  3. They occupy large area
  4. Reliability is quite low.
- Applications(2M)
  1. Digital watches to indicate time, day and date etc
  2. Electronic toys and calculators
  3. Instrument display.

5.

Describe about cathode ray oscilloscope and the components of CRT in detail. (13M)
Nov/Dec 2013,2104 BTL 4

Answer Page: 4.47 – J.Gnanavadivel

- Block diagram of oscilloscope (5M)
- Components of general purpose CRO & explanation (8M)
  1. CRT
  2. Vertical amplifier
  3. Delay line
  4. Horizontal amplifier
  5. Time base generator
  6. Trigger circuit
  7. Power supply



6.

Discuss briefly about the applications of oscilloscope. (13M) (APR/MAY 2012)BTL 3
Answer Page: 4.38 – J.Gnanavadivel

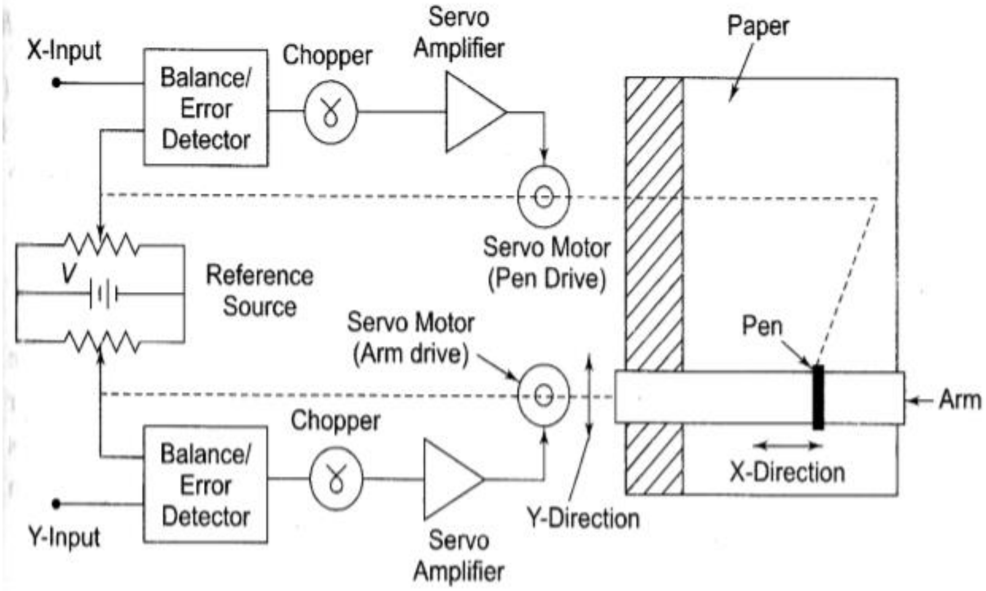
- Introduction (2M)
  The oscilloscope is an extremely flexible and versatile instrument, it can be used to measure a number of parameters associated with DC and AC signals. Using a single channel oscilloscope, it is capable of making measurements of voltage, current, time, frequency and rise/ fall time.
- Voltage measurement (4M)
  1. Oscilloscope are best suited for the measurement of peak and peak-to- peak values of AC voltage waveform, although DC coupled oscilloscopes also permits the display and measurements of an AC signal with a DC component.
  2. The signal to be measured is connected to the vertical input via the probe. The vertical sensitivity, time base, coupling and trigger controls are set to provide a stable display that covers as many vertical divisions as possible without exceeding the limits of the screen.
- Current measurements (4M)
  1. There are two ways to measure current with an oscilloscope. Alternating and direct current can be measured by looking at the voltage across a known values of resistances and applying ohms law.
  2. Application of this technique is limited by the need for one side of resistor and oscilloscope to be ground potential.
- Lissajous method of frequency measurement (3M)

If two different signals are both sine waves, the Lissajous method can be used to determine the frequency ratio of the two signals. If frequency of one of signals are known the other can be easily determined.

7.

Draw and explain the block diagram of X-Y recorder. 13M (MAY/JUNE 2014) BTL 2
Answer Page: 4.10 – J.Gnanavadivel

- Block diagram & explanation (10M)



- In most research fields, it is often convenient to plot the instantaneous relationship between two variables [y= f(x)], rather than to plot each variable separately as a function of time. In such cases, x-y recorder is used in which one variable is plotted against another variable.
- The motion of the recording pen in both the axes is driven by servo- system, with reference to a stationary chart paper. The movement in x and y directions is obtained through a sliding pen and moving arm arrangement.
- Applications(3M)
  1. Speed torque characteristics of motors
  2. Regulation curves of power supply
  3. Plotting stress – strain curves , hysteresis curves etc.

UNIT V TRANSDUCERS AND DATA ACQUISITION SYSTEMS 9

Classification of transducers – Selection of transducers – Resistive, capacitive & inductive Transducers – Piezoelectric, Hall effect, optical and digital transducers – Elements of data acquisition system – Smart sensors-Thermal Imagers.

PART * A

Q.No	Questions
1.	**What are the basic requirements of a descending order of speed? (Apr/May 2017)** BTL 2 Linearity: The input –output characteristics should be linear. Raggedness: It should be capable for with standing overload Residual deformation: There should be no deformations on removal of load after long period of time.
2.	**Arrange the following ADC in the descending order of speed. (Apr/May 2017)** BTL 3 **(a) Integrating type** **(b) Counter type** **(c) Successive approximation type** **(d) Flash type** (a) Counter type (b) Integrating type (c) Successive approximation type (d) Flash type
3.	**What are the factors to be considered for selection of transducers?(May/June2016)** BTL 2 • Environment conditions • Operating range • Sensitivity • Electrical characteristics • Accuracy
4.	**List the types of analog to digital converter? (May/June 2016)** BTL 4 • Flash type ADC • Successive approximation ADC • Counter type ADC • Dual slope ADC
5.	**What is transducer? Give example. (Nov/Dec 2015)**BTL 2 A transducer is a device that converts one form of energy to another. Usually a transducer converts a signal in one form of energy to a signal in another. Example: LVDT, RTD, Thermocouple.
6.	**What is meant by resolution for analog digital converter? (Nov/Dec 2015)** BTL 2 Resolution is defined as the smallest measurable input change.
7.	**Write the desired properties of thermocouple metals.(Apr/May 2015)** BTL 3 • It should withstand high temperature • It must possess high melting point.
8.	**What are the two ways that the DAS are used to measure and record analog signals? (Apr/May 2015)** BTL 2 • Signals may originate from direct measurement of electrical quantities. • Signals may originate from transducers such as transducer or thermocouples.

9.	**What is an active transducer?(Nov/Dec 2012)** BTL 2 An element which produces electrical signal in the form of voltage or current d.c. or a.c. without using external power, when stimulated by any form of physical quantity is called an active transducer.
10	**What do you mean by sensor & transducer?(Apr/May 2011)** BTL 2 It is define as devices which produce a measurable response to change in a physical quantity. The transducer is devices which transform the output of a sensor to an electrical o/p.
11	**What is the application of thermistor?(May/June 2014)** BTL 2 • The sensitivity of thermistor is large • High sensitivity & high relativity • Use for thermal conduction measurements..
12	**Which elements used in resistances thermometer?(Apr/May 2015)** BTL 3 • Platinium, • copper, • nickel
13	**What is shaft encoder?(Nov/Dec 2010)** BTL 2 It's a rotational displacement transducer which is used to measure the angular motion of a body about axis of rotation. it works on the principle whose displacement is to measure when rotates.
14	**What is R-2Rladder? (Apr/May 2015)** BTL 2 For D/A conversion the shunt resistors are used to generate n binary weighted currents. These resistors look like a ladder hence called R-Rladder
15	**What is piezo-electric effect?**BTL 2 A Piezoelectric material is one in which an electric potential appears across certain surfaces of the crystals if the dimensions of the crystals are changed by the application of a mechanical force this potential is produced by the displacement of charges. This effect is reversible. This phenomenon is known as piezoelectric effect.
16	**What is strain gauge?**BTL 2 It is a passive transducer which convert the mechanical elongation and compression into change in resistance.
17	**Define gauge factor?**BTL 1 It is defined as unit change in resistance for per unit change in length of the strain gauge wire.
18	**What is LVDT? List the advantages?**BTL 2 It is a passive transducers which is used to measure the linear displacement into electrical signal voltage. • High output • High efficiency • Low power consumption into electrical signal voltage
19	**What are the classifications of encoder?**BTL 2 • Tachometer transducers • Incremented transducers • Absolute transducers
20	**List the types of strain gauge.**BTL 3 • Bounded strain gauge • Unbounded strain gauge • Metallic strain gauge

- Foil type strain gauge
- Semiconductor strain gauge

PART * B

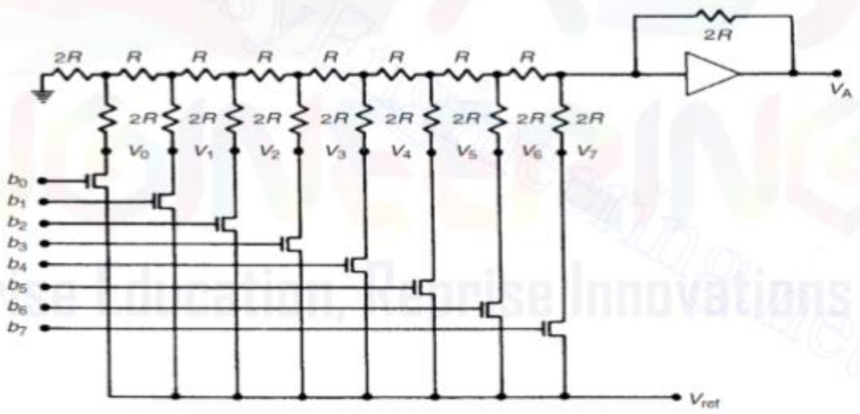
1\. **Explain the binary weighted resistor technique of D/A conversion. (13M) (MAY/JUNE 2014)**

BTL 3

Answer Page: 5.92 - J.Gnanavadivel

- Binary weighted resistor DAC block diagram & Explanation (6M & 7M)

Digital-to-analogue conversion is much simpler to achieve than analogue-to-digital conversion and the cost of building the necessary hardware circuit is considerably less. It is required wherever a digitally processed signal has to be presented to an analogue control actuator or an analogue signal display device. A common form of digital-toanalogue converter is illustrated in Figure 5.24. This is shown with 8 bits for simplicity of explanation, although in practice 10 and 12 bit D/A converters are used more frequently. This form of D/A converter consists of a resistor-ladder network on the input to an operational amplifier.



$$V_7 = V_6 = V_4 = V_2 = V_{\text{ref}}; \quad V_5 = V_3 = V_1 = V_0 = 0$$

The analogue output from the converter is then given by:

$$V_A = V_{\text{ref}} + \frac{V_{\text{ref}}}{2} + \frac{V_{\text{ref}}}{8} + \frac{V_{\text{ref}}}{32}$$

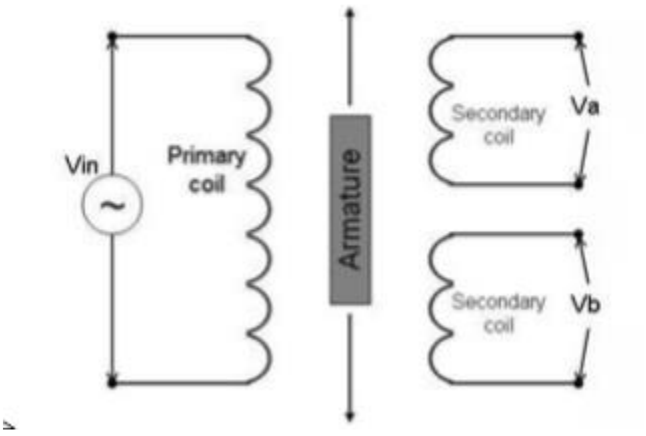
2\. **Explain the construction and working of LVDT with a neat sketch. (13M) (Apr/May 2017)**

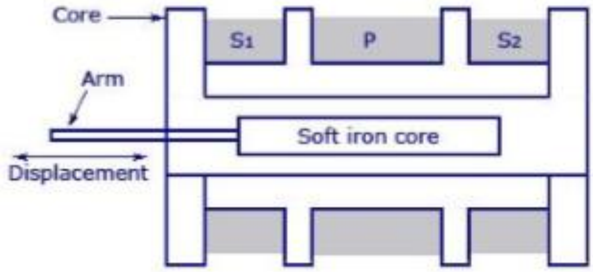
BTL 2

Answer Page: 5.31 – J.Gnanavadivel

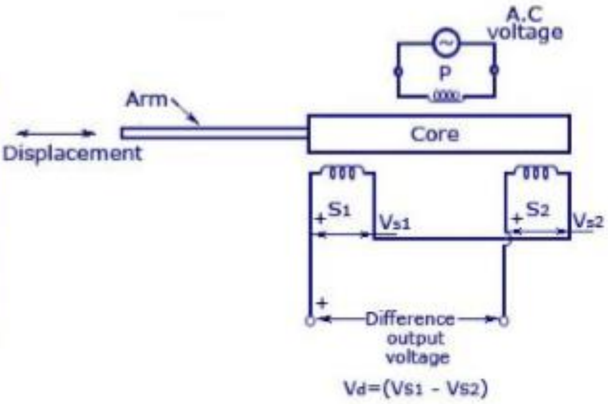
- **Construction & working of LVDT** (6M & 7M)
- An LVDT, or Linear Variable Differential Transformer, is a transducer that converts a linear displacement or position from a mechanical reference (or zero) into a proportional electrical signal containing phase (for direction) and amplitude information (for distance).
- The LVDT operation does not require electrical contact between the moving part (probe or core rod assembly) and the transformer, but rather relies on electromagnetic coupling; this and the fact that they operate without any built-in electronic circuitry are the primary

reasonswhy LVDTs have been widely used in applications where long life and high reliability under severe environments are a required, such as Military/Aerospace applications.





Construction of LDVT



Circuit Connection

3.

Explain schematic block diagram of a general data acquisition system and give its objectives. (13M) (MAY/JUNE 2014) (APR/MAY 2015)(Nov 2018)BTL 2

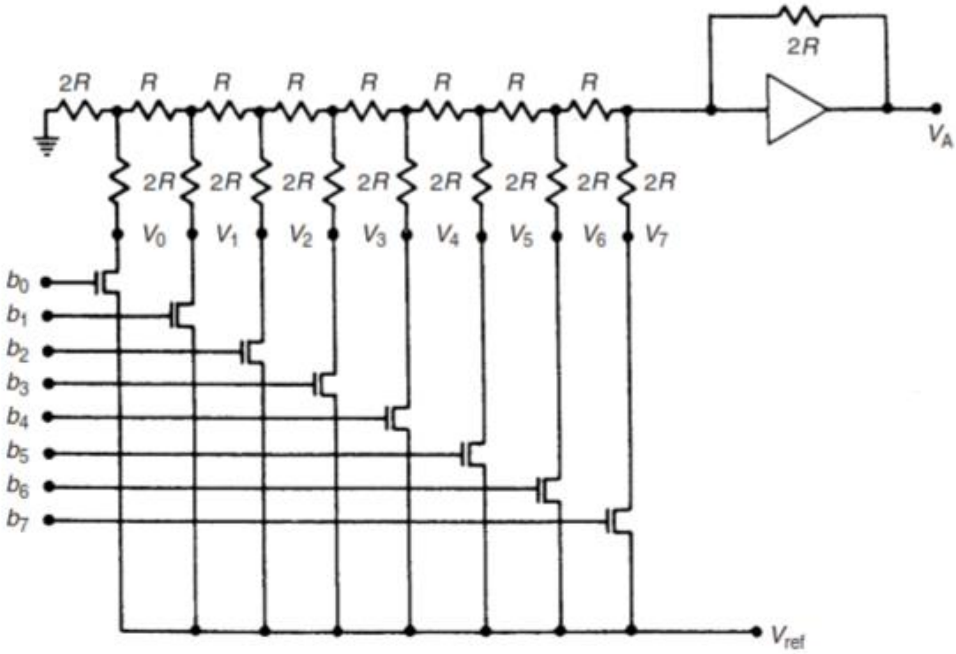
- Objectives (2M)
  1. It must acquire the necessary data, at correct speed and at the correct time.
  2. Use of all data efficiently to inform the operator about the state of plant
  3. It must be flexible and capable of being expanded for future requirements.
- Classifications & explanations(11M)
  1. Analog data acquisition system:
     a. Transducer
     b. Signal conditioner
     c. Multiplexing
     d. Calibrating equipments
     e. Visual display devices
     f. Analog recorders
  2. Digital data acquisition system:
     a. It handles the analog signals
     b. It performs measurement

c. It converts analog signal into digital data and handles it.
d. It performs internal programming and control.

4.

Discuss R-2R& inverter R-2R ladder type D/A converter. (13M) (APR/MAY 2015)
BTL 3
Answer page : 5.93 & 5.95 – J.Gnanavadivel

- R-2R ladder type converter circuit diagram (5M)



- Explanation(8M)
- Digital-to-analogue conversion is much simpler to achieve than analogue-to-digital conversion and the cost of building the necessary hardware circuit is considerably less. It is required wherever a digitally processed signal has to be presented to an analogue control actuator or an analogue signal display device.
- This is shown with 8 bits for simplicity of explanation, although in practice 10 and 12 bit D/A converters are used more frequently. This form of D/A converter consists of a resistor-ladder network on the input to an operational amplifier.

$$V_A = V_7 + \frac{V_6}{2} + \frac{V_5}{4} + \frac{V_4}{8} + \frac{V_3}{16} + \frac{V_2}{32} + \frac{V_1}{64} + \frac{V_0}{128}$$

- V0 to V7 are set at either the reference voltage level Vref or at zero volts according to whether an associated switch is open or closed. Each switch is controlled by the logic level of one of the bits 0 – 7 of the 8 bit binary signal being converted. A particular switch is open if the relevant binary bit has a value of 0 and closed if the value is 1.

5.

Explain the successive approximation type ADC. (13M) (MAY/JUNE 2014) BTL 3

Answer Page: 5.73 –J.Gnanavadivel

- Block diagram (5M)
- Working operation (5M)
    1. When start command is given, SAR sets MSB, d1=1 with all other bits to zero sp that the trail code is 1000 0000. The output Vd from DAC is now compared with

analog input Va. If Va>Vd, then 1000 0000 is less than correct digital representation.

2. This procedure is, repeated for all subsequent bits (i.e., from MSB to LSB), one at a time until all bits positions have been tested.

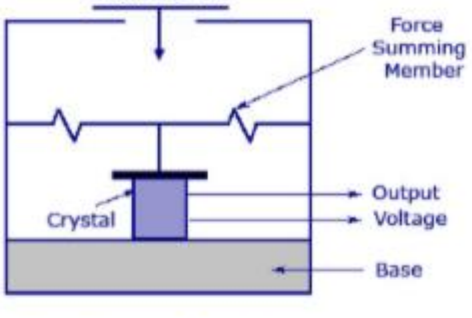
- Advantages: (3M)
  1. High resolution
  2. It is very versatile
  3. High speed

6.

Explain the principle of piezo electric transducers and name any two piezo electric materials. (13M) (May/JUNE 2009) (APR/MAY 2015) (Nov 2018) BTL 3

Answer Page: 5.45 – J.Gnanavadivel

- **Piezo electric diagram & Principle of operation (10M)**
  1. Piezoelectric transducers produce an output voltage when a force is applied to them. They are frequently used as ultrasonic receivers and also as displacement transducers, particularly as part of devices measuring acceleration, force and pressure.
  2. In ultra- sonic receivers, the sinusoidal amplitude variations in the ultrasound wave received are translated into sinusoidal changes in the amplitude of the force applied to the piezoelectric transducer.
  3. In a similar way, the translational movement in a displacement transducer is caused by mechanical means to apply a force to the piezoelectric transducer.
  4. Piezoelectric transducers are made from piezoelectric materials. These have an asymmetrical lattice of molecules that distorts when a mechanical force is applied to it.
  5. This distortion causes a reorientation of electric charges within the material, resulting in a relative displacement of positive and negative charges.
  6. The charge displacement induces surface charges on the material of opposite polarity between the two sides. By implanting electrodes into the surface of the material, these surface charges can be measured as an output voltage.
  7. For a rectangular block of material, the induced voltage is given by:
     V = kFd/A



Piezo-Electric Transducer

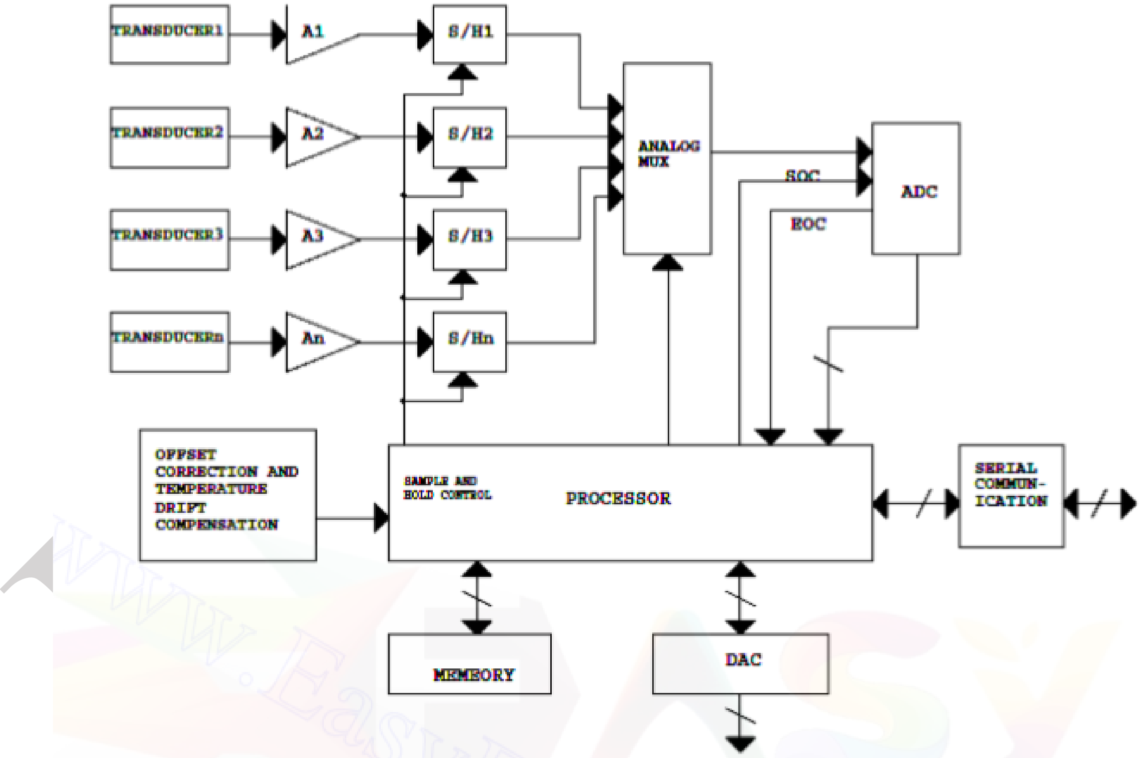
- Modes of operation , advantages & dis-advantages (3M)

7.

Explain in detail about smart sensors. (13M) (May/JUNE 2009)BTL 3

Answer Page : 5.100 – J.Gnanavadivel

- General architecture of smart sensors & explanation (6M & 7M)
- One can easily propose a general architecture of smart sensor from its definition, functions. From the definition of smart sensor it seems that it is similar to a data acquisition system, the only difference being the presence of complete system on a single silicon chip. In addition to this it has on–chip offset and temperature compensation. A general architecture of smart sensor consists of following important components:
- Sensing element/transduction element,
- Amplifier,
- Sample and hold,
- Analog multiplexer,
- Analog to digital converter (ADC),
- Offset and temperature compensation,
- Digital to analog converter (DAC),
- Memory,
- Serial communication and
- Processor



GENERAL ARCHITECTURE OF SMART SENSOR

PART * C

1

Explain the various types of ADC with suitable sketches. (15M) BTL 3

Answer page : 5.71 – J.Gnanavadivel

- **Classifications(5M)**

1. Direct type

	2. Indirect type - Direct types are classified as 1. Flash (comparator) type converter 2. Staircase type converter 3. Tracking or servo converter 4. Successive approximation type converter - **Indirect type are classified as** **1.** Charge balancing analog to digital converter **2.** Dual slope analog to digital converter - **Explanation of each type (10M)**
2	**Discuss in detail about(APR/MAY 2015)** BTL 4 **(i)Optical encoder (5M)** **(ii)Resistive encoder(5M)** **(iii)Shaft encoder.(5M)** Answer page : 5.56 – J.Gnanavadivel - **Optical encoder: (**5M) 1. A photo sensor and a light source is placed on the two slides of the sector. 2. The displacement is applied to the sector and therefore changes the amount of light falling on the photo electric sensor. 3. The pattern of the illuminated sensor then carries the information to the location of the sector. - Resistive encoder : (5M) 1. In this method a pattern can be used is the resistive electric encoder. Here, the shaded arears are made up of conducting material and the unshaded areas of insulating material. 2. In this method, sliding contacts are used for making the contacts. - Shaft encoder : (5M) 1. A shaft encoder is a mechanical converter that translates the angular position of the shaft into digital number. It is equivalent to an analog to digital converter. **2.** Another method of conversion is the analog variable into an electrical analog signal and then converts this into digital signals.
3	**Explain different strain gauges with the principle of operation. (15M) (May/JUNE 2009)** BTL 3 Answer page : 5.16 – J.Gnanavadivel - Working principle (5M) 1. A strain gauge is an example of a passive transducer that uses the variation in electrical resistances in wires to sense the strain produced by a force on the wires. 2. If a metal conductor is stretched or compressed, its resistances changes on account of the fact that both length and diameter of conductor change. 3. Theory and operating principle of resistance strain gauge derivation (10M)

EE8451 LIC & APPLICATIONS 3 0 0 3

OBJECTIVES:

To impart knowledge on the following topics

- Signal analysis using Op-amp based circuits.
- Applications of Op-amp.
- Functional blocks and the applications of special ICs like Timers, PLL circuits, regulator Circuits.
- IC fabrication procedure.

UNIT I IC FABRICATION 9

IC classification, fundamental of monolithic IC technology,epitaxial growth, masking and etching, diffusion of impurities. Realisation of monolithic ICs and packaging. Fabrication of diodes, capacitance, resistance, FETs and PV Cell.

UNIT II CHARACTERISTICS OF OPAMP 9

Ideal OP-AMP characteristics, DC characteristics, AC characteristics, differential amplifier; frequency response of OP-AMP; Basic applications of op-amp – Inverting and Non-inverting Amplifiers, summer, differentiator and integrator-V/I & I/V converters.

UNIT III APPLICATIONS OF OPAMP 9

Instrumentation amplifier and its applications for transducer Bridge, Log and Antilog Amplifiers-Analog multiplier & Divider, first and second order active filters, comparators, multivibrators, waveform generators, clippers, clampers, peak detector, S/H circuit,–D/A converter (R- 2R ladder and weighted resistor types), A/D converters using opamps.

UNIT IV SPECIAL ICs 9

Functional block, characteristics of 555 Timer and its PWM application - IC-566 voltage controlled oscillator IC; 565- phase locked loop IC, AD633 Analog multiplier ICs.

UNIT V APPLICATION ICs 9

AD623 Instrumentation Amplifier and its application as load cell weight measurement - IC voltage regulators –LM78XX, LM79XX; Fixed voltage regulators its application as Linear power supply – LM317, 723 Variability voltage regulators, switching regulator- SMPS - ICL 8038 function generator IC.

TOTAL : 45 PERIODS

OUTCOMES:

- Ability to acquire knowledge in IC fabrication procedure
- Ability to analyze the characteristics of Op-Amp

  To understand the importance of Signal analysis using Op-amp based circuits.
- Functional blocks and the applications of special ICs like Timers, PLL circuits, regulator Circuits.
- To understand and acquire knowledge on the Applications of Op-amp
- Ability to understand and analyse, linear integrated circuits their Fabrication and Application.

TEXT BOOKS:

1. David A. Bell, ‘Op-amp & Linear ICs’, Oxford, 2013.
2. D. Roy Choudhary, Sheil B. Jani, ‘Linear Integrated Circuits’, II edition, New Age, 2003.
3. Ramakant A.Gayakward, ‘Op-amps and Linear Integrated Circuits’, IV edition, Pearson Education, 2003 / PHI. 2000.

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1. Fiore,"Opamps & Linear Integrated Circuits Concepts & applications", Cengage, 2010.
2. Floyd ,Buchla,"Fundamentals of Analog Circuits, Pearson, 2013.
3. Jacob Millman, Christos C.Halkias, 'Integrated Electronics - Analog and Digital circuits system', McGraw Hill, 2003.
4. Robert F.Coughlin, Fredrick F. Driscoll, 'Op-amp and Linear ICs', Pearson, 6th edition,2012.
5. Sergio Franco, 'Design with Operational Amplifiers and Analog Integrated Circuits', Mc Graw Hill, 2016. Muhammad H. Rashid,' Microelectronic Circuits Analysis and Design' Cengage Learning, 2011

Subject Code:EE8451 **Year/Semester: II /04**
Subject Name: LIC & APPLICATION **Subject Handler: D. Joshua**

UNIT I - IC FABRICATION

IC classification, fundamental of monolithic IC technology, epitaxial growth, masking and etching, diffu of impurities. Realization of monolithic ICs and packaging. Fabrication of diodes, capacitance, resistanc and PV Cell.

PART * A

Q.No.	Questions
1.	**Define an Integrated circuit.** BTL1 An integrated circuit(IC) is a miniature, low cost electronic circuit consisting of active and passive components fabricated together on a single crystal of silicon. The active components are transistors and diodes and passive components are resistors and capacitors.
2	**What are the basic processes involved in fabricating ICs using planar technology?** BTL1 • Silicon wafer (substrate) preparation • Epitaxial growth • Oxidation • Photolithography • Diffusion • Ion Implantation • Isolation technique Metallization • Assembly processing & packaging
3	**List out the steps used in the preparation of Si – wafers**. BTL1 • Crystal growth &doping • Ingot trimming grinding • Ingot slicing • Wafer policing etching • Wafer cleaning
4	**Define virtual ground of OP-Amp.** BTL1 A virtual ground is a ground which acts like a ground. It is a point that is at the fixed ground potential (0v), though it is not practically connected to the actual ground or common terminal of the circuit.
5	**What are the advantages and limitations of ion implantation?** BTL1 **Advantages:** • Accurate control over doping • Very good reproducibility • Precise resistance value • A room temperature process **Limitations:** • Annealing at higher temperature is required for avoiding the crystal damage • The possibility of doping implanting through various layers of wafer.

6	**Why IC 741 is not used for high frequency applications?** BTL2 IC741 has a low slew rate because of the predominance of capacitance present in the circuit at higher frequencies. As frequency increases the output gets distorted due to limited slew rate.
7	**In practical op-amps, what is the effect of high frequency on its performance?** BTL2 The open-loop gain of op-amp decreases at higher frequencies due to the presence of parasitic capacitance. The closed-loop gain increases at higher frequencies and leads to instability.
8	**Define input offset voltage**. BTL1 A small voltage applied to the input terminals to make the output voltage as zero when the two input terminals are grounded is called input offset voltage.
9	**Define input offset current. State the reasons for the offset currents at the input of the op-amp**. BTL1 The difference between the bias currents at the input terminals of the op-amp is called as input offset current. The input terminals conduct a small value of dc current to bias the input transistors. Since the input transistors cannot be made identical, there exists a difference in bias currents.
10	**Define sensitivity**. BTL1 Sensitivity is defined as the percentage or fractional change in output current per percentage or fractional change in power-supply voltage.
11	**What are the limitations in a temperature compensated zener-reference source**? BTL2 A power supply voltage of at least 7 to 10 V is required to place the diode in the breakdown region and that substantial noise is introduced in the circuit by the avalanching diode.
12	**Define CMRR of an op-amp. (DEC 09)** BTL1 The relative sensitivity of an op-amp to a difference signal as compared to a common –mode signal is called the common –mode rejection ratio. It is expressed in decibels. CMRR= Ad/Ac
13	**What are the applications of current sources?** BTL1 Transistor current sources are widely used in analog ICs both as biasing elements and as load devices for amplifier stages.
14	**Justify the reasons for using current sources in integrated circuits.** BTL4 • Superior insensitivity of circuit performance to power supply variations and temperature. • More economical than resistors in terms of die area required providing bias currents of small value. • When used as load element, the high incremental resistances of current source results in high voltage gain at low supply voltages.
15	**What is the advantage of widlar current source over constant current source?** BTL1 Using constant current source output current of small magnitude (micro amp range) is not attain able due to the limitations in chip area. Widlar current source is useful for obtaining small output currents. Sensitivity of widlar current source is less compared to constant current source.
16	**Mention the advantages of Wilson current source.** BTL1 • Provides high output resistance. • Offers low sensitivity to transistor base currents.

17	**Mention the advantages of integrated circuits over discrete components. (May2010)** BTL1 • Miniaturization and hence increased equipment density. • Cost reduction due to batch processing. • Increased system reliability due to the elimination of soldered joints. • Improved functional performance. • Matched devices. • Increased operating speeds. • Reduction in power consumption.
18	**Define sheet resistance. (May 2010)** BTL1 Sheet resistance is defined as the resistance in ohms /square offered by the diffused area.
19	**What is the use of buried n+ layer in monolithic IC transistor? (MAY 2010)** BTL1 The buried n+ layer provides a low resistance path in the active collector region for the flow of current.
20	**What is active load? Where it is used and why? (MAY/JUNE 2010)** BTL1 The active load realized using current source in place of the passive load in the collector arm of differential amplifier makes it possible to achieve high voltage gain without requiring large power supply voltage.
21	**Why open loop OP-AMP configurations are not used in linear applications? (May/June 2010)** BTL2 The open loop gain of the op-amp is not a constant and it varies with changing the temperature and variations in power supply. Also the bandwidth of the open loop op-amp is negligibly small. For thi reasons open loop OP-AMP configurations are not used in linear applications.
22	**What are the two common methods for obtaining integrated capacitors? (May 2010)** BTL2 • Monolithic junction capacitor • Thin-film capacitor
23	**Define slew rate. (MAY 2010)** BTL1 The slew rate is defined as the maximum rate of change of output Voltage caused by a step input voltage. An ideal slew rate is infinite which means that op- amp's output voltage should change instantaneously in response to input step voltage.
24	**What causes slew rate? (DEC 09)** BTL1 There is a capacitor with-in or outside of an op-amp to prevent oscillation. The capacitor which prevents the output voltage from responding immediately to a fast changing input.
25	**What happens when the common terminal of V+ and V- sources is not grounded? (DEC 09)** BTL1 If the common point of the two supplies is not grounded, twice the supply voltage will get applied and it may damage the op-amp.
	PART * B
1	**Explain various steps involved in silicon wafer preparation. (10M)** BTL2 **Answer: page 5 - 6 LIC D. Roy Choudhury** Crystal growth and doping (2M) Ingot trimming and grinding (2M) Ingot slicing (2M)

	Wafer polishing and etching (2M) Wafer cleaning (2M)
2	**Brief about the fundamentals of monolithic IC technology. (13M)** BTL2 **Answer: page 3 - 4 LIC D. Roy Choudhury** Monolithic IC – single piece of single crystal silicon (1M) Advantage of IC – Reducing cost of production (1M) Fabrication of discrete devices – Transistor, diode (3M) Planar technology – various processes through a single plane (2M) Four distinct layers (6M) Layer no 1 – p-type silicon substrate Layer no 2 – thin n-type material Layer no 3 – very thin SiO2 layer Layer no 4 – Al layer – interconnection purpose
3	**Explain Epitaxial growth and oxidation in detail. (13M) (APR/MAY 2015)(Nov/Dec 2016)** BTL2 **Answer: page 6 – 7 LIC D. Roy Choudhury** Epitaxial growth (8M) Epitaxy – arrangement of atoms in single crystal fashion – upon single crystal substrate Chemical reaction – hydrogen reduction of silicon tetrachloride Phosphine – n-type Bi-borane – p-type Reaction chamber – long cylindrical quartz tube Oxidation (5M) SiO2 – hard protective coating Selective etching SiO2 Chemical reaction Thermal oxidation – grow oxide layer
4	**Brief the process involved in Photolithography. (13M)(Nov/Dec 2016)** BTL2 **Answer: page 7 – 9 LIC D. Roy Choudhury** Photolithography (8M) Fabrication of 10000 transistors Uses UV light exposure Device dimension sub-micron range Two processes Photographic mask Photo etching Precision drafting machine – coordinatograph (3M) Photosensitive emulsion – Kodak Photo Resist Dry etching process – plasma etching X-Ray and Electron Beam Lithography (2M)
5	**Elaborate diffusion and techniques involved in Ion Implantation. (13M)(Apr/May 2016)** BTL2 **Answer: page 9 - 10 LIC D. Roy Choudhury** Diffusion (7M)

	Diffusion of impurities in silicon chip High temperature furnace Boron oxide, Boron chloride Phosphorus pentoxide, Phosphorus oxychloride Diffusion laterally & vertically Ion Implantation (6M) Beam of high energy dopant ions Energies between 20KV to 250KV Advantage – performs at low temperature Accelerating potential and beam current electrically controlled
6	**Explain various Isolation techniques in a fabrication process. (13M)** BTL2 **Answer: page 10 – 11 LIC D. Roy Choudhury** Electrical isolation necessary between different components (1M) Techniques Pn junction isolation (6M) P+ type impurities selectively diffused Diodes reverse biased provide electric isolation Isolation islands – different components fabricated Transition capacitance at isolation pn junctions Dielectric isolation (6M) Silicon dioxide, ruby completely surrounds Both physical and electrical isolation Pnp and npn transistor within same silicon substrate possible More expensive Application – Aerospace, military
7	**Explain metallization and Assembly processing and packaging. (13M)(Apr/May 2015)(Apr/May 2016)** BTL2 **Answer: page 11 – 12 LIC D. Roy Choudhury** Metallization (7M) Thin metal film layer – interconnections Aluminium advantages – good conductor, easy to deposit, good mechanical bonds, low resistance Non rectifying – ohmic contact Vacuum evaporation chamber Very high power density electron beam focused Very high temperature and it starts vaporizing Evaporated molecules hit the substrate and condense Assembly processing and packaging (6M) Each wafer contains several 100 chips Scribing and cleaving used for separation 3 different package configurations Metal can package Ceramic flat package Dual – in – line package
	PART *C

1	**Explain the fabrication of field effect transistor. (15M)(Apr/May 2015)(Nov/Dec 2016)(Apr/May 2016)** BTL2 **Answer: page 27 – 29 LIC D. Roy Choudhury** JFET Fabrication (5M) Epitaxial layer – n channel of JFET P+ gate in n-channel by diffusion or ion implantation N+ regions – drain source contact regions – good ohmic contact MOSFET Fabrication (5M) Enhancement type Depletion type Metallic gate G separates from semiconductor channel by SiO2 Extremely high input resistance Polysilicon gate (5M) Polycrystalline silicon doped with phosphorus conducts Gate electrode instead Aluminium Silicon gate MOS transistors
2	**Brief about multi emitter transistor fabrication and integrated Schottky Barrier diode. (15M)(Apr/May 2015)** BTL2 **Answer: page 19 – 22 LIC D. Roy Choudhury** Multi emitter transistor (5M) N+ emitter diffused at three places in p-type base Possible to save chip area Enhance component density Schottky Transistor (5M) Switching should be very fast Schottky diode – use as a clamp between base & collector Schottky Barrier diode (5M) Metal to semiconductor junctions – ohmic or rectifying Ohmic contact – lead attach to semiconductor Rectifying contact – metal semiconductor diode
3	**Elaborate various steps involved in the fabrication of a typical circuit. (15M)(Apr/May 2017)** BTL2 **Answer: page 13 – 16 LIC D. Roy Choudhury** Step 1: Wafer preparation (2M) Step 2: Epitaxial growth (2M) Step 3: oxidation (2M) Step 4: Isolation diffusion (2M) Step 5: Base diffusion (2M) Step 6: Emitter diffusion (2M) Step 7: aluminium metallization (3M) Capacitor, diode, transistor, resistor

Subject Code:EE8451 **Year/Semester: II /04**
Subject Name: LIC & APPLICATION **Subject Handler: D. Joshua**

UNIT II - CHARACTERISTICS OF OPAMP

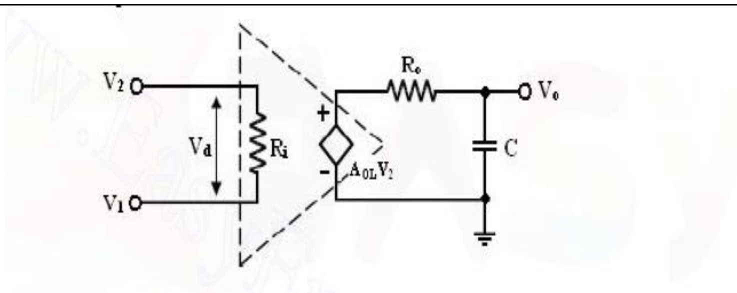
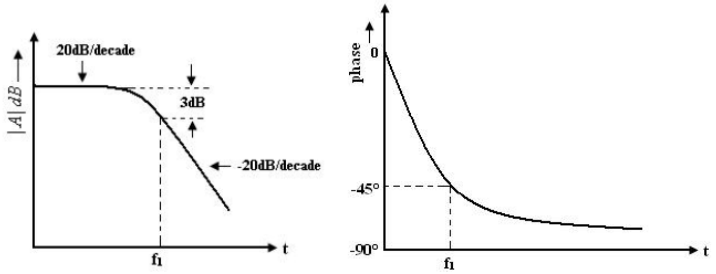
Ideal OP-AMP characteristics, DC characteristics, AC characteristics, differential amplifier; frequency response of OP-AMP; Basic applications of op-amp – Inverting and Non-inverting Amplifiers, summer, differentiator and integrator-V/I & I/V converters.

PART * A

Q.No.	Questions
1.	**Mention some of the linear applications of op – amps. (DEC 09)** BTL 2 • Adder, sub tractor, • Voltage –to current converter, • current –to- voltage converters, • Instrumentation amplifier, • Analog computation • power amplifier
2	**Mention some of the non – linear applications of op-amps.** BTL 2 • Rectifier, peak detector, • clipper, clamper, • sample and hold circuit, • log amplifier, anti –log amplifier
3	**What are the areas of application of non-linear op- amp circuits?** BTL 1 • Industrial instrumentation • Communication • Signal processing
4	**What is voltage follower?(MAY 2010)** BTL 1 A circuit in which output follows the input is called voltage follower.
5	**Define input offset voltage**. BTL1 A small voltage applied to the input terminals to make the output voltage as zero when the two input terminals are grounded is called input offset voltage.
6	**Define input offset current. State the reasons for the offset currents at the input of the op-amp**. BTL1 The difference between the bias currents at the input terminals of the op-amp is called as input offset current. The input terminals conduct a small value of dc current to bias the input transistors. Since the input transistors cannot be made identical, there exists a difference in bias currents.
7	**What are the applications of V-I converter?** BTL 1 • Low voltage dc and ac voltmeter • LED • Zener diode tester
8	**Define slew rate. (MAY 2010)** BTL1 The slew rate is defined as the maximum rate of change of output Voltage caused by a step input

	voltage. An ideal slew rate is infinite which means that op- amp's output voltage should change instantaneously in response to input step voltage.
9	**Write transfer function of op amp as an integer. (MAY 2010)** BTL 1 The transfer function of the integer is │A│=1/ωR1cf
10	**What do you mean by a precision diode?** BTL 1 The major limitation of ordinary diode is that it cannot rectify voltages below the cut – in voltage of the diode. A circuit designed by placing a diode in the feedback loop of an op – amp is called the precision diode and it is capable of rectifying input signals of the order of milli volt.
11	**Why IC 741 is not used for high frequency applications?** BTL2 IC741 has a low slew rate because of the predominance of capacitance present in the circuit at higher frequencies. As frequency increases the output gets distorted due to limited slew rate.
12	**In practical op-amps, what is the effect of high frequency on its performance?** BTL2 The open-loop gain of op-amp decreases at higher frequencies due to the presence of parasitic capacitance. The closed-loop gain increases at higher frequencies and leads to instability.
13	**What causes slew rate? (DEC 09)** BTL1 There is a capacitor with-in or outside of an op-amp to prevent oscillation. The capacitor which prevents the output voltage from responding immediately to a fast changing input.
14	**What is active load? Where it is used and why? (MAY/JUNE 2010)** BTL1 The active load realized using current source in place of the passive load in the collector arm of differential amplifier makes it possible to achieve high voltage gain without requiring large power supply voltage.
15	**What are the limitations of the basic differentiator circuit?** BTL 1 • At high frequency, a differentiator may become unstable and break into oscillations • The input impedance decreases with increase in frequency , thereby 0making the circuit sensitive to high frequency noise.
16	**Write down the condition for good differentiation.** BTL 1 • For good differentiation, the time period of the input signal must be greater than or equal to Rf C1 • T > R f C1 Where, Rf is the feedback resistance • Cf is the input capacitance
17	**Define CMRR of an op-amp. (DEC 09)** BTL1 The relative sensitivity of an op-amp to a difference signal as compared to a common –mode signal is called the common –mode rejection ratio. It is expressed in decibels. CMRR= Ad/Ac
18	**What are the applications of current sources?** BTL1 Transistor current sources are widely used in analog ICs both as biasing elements and as load devices for amplifier stages.
19	**Justify the reasons for using current sources in integrated circuits.** BTL4 • Superior insensitivity of circuit performance to power supply variations and temperature. • More economical than resistors in terms of die area required providing bias currents of small value.

	• When used as load element, the high incremental resistances of current source results in high voltage gain at low supply voltages.
20	**Define input offset voltage**. BTL1 A small voltage applied to the input terminals to make the output voltage as zero when the two input terminals are grounded is called input offset voltage.
21	**Define input offset current. State the reasons for the offset currents at the input of the op-amp**. BTL1 The difference between the bias currents at the input terminals of the op-amp is called as input offset current. The input terminals conduct a small value of dc current to bias the input transistors. Since the input transistors cannot be made identical, there exists a difference in bias currents.
22	**Define sensitivity**. BTL1 Sensitivity is defined as the percentage or fractional change in output current per percentage or fractional change in power-supply voltage.
23	**What are the characteristics of a comparator?** BTL 1 • Speed of operation • Accuracy • Compatibility of the output
24	**What is a filter?** BTL 1 Filter is a frequency selective circuit that passes signal of specified band of frequencies and attenuates the signals of frequencies outside the band.
25	**What are the demerits of passive filters?** BTL 1 Passive filters works well for high frequencies. But at audio frequencies, the inductors become problematic, as they become large, heavy and expensive. For low frequency applications, more number of turns of wire must be used which in turn adds to the series resistance degrading inductor’s performance ie, low Q, resulting in high power dissipation.
	PART * B
1	**Describe the AC performance characteristics of an operational amplifier. (8M)(Nov/Dec 2016)** BTL2 **Answer: page 112 – 115 LIC D. Roy Choudhury** Frequency Response (2M) Infinite Bandwidth at ideal condition. At higher frequencies practical op-amp gain rolls off. High frequency op-amp circuit figure 1.18 (2M)

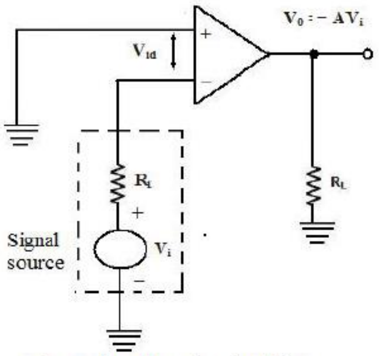
	 **Fig 1.18 Equivalent circuit of practical circuit** Magnitude characteristics (2M) Phase Characteristics (2M) The magnitude and phase angle characteristics: 1. For frequency f<< f_1 the magnitude of the gain is 20 log A_{OL} in db. 2. At frequency f = f_1 the gain in 3 dB down from the dc value of A_{OL} in db. This frequency f_1 is called corner frequency. 3. For f>> f_1 the fain roll-off at the rate off -20dB/decade or -6dB/decade. 
2	**What is slew rate? Discuss the methods of improving slew rate. (10M) (Nov/Dec 2008), (May/June 2009), (Nov/Dec 2009)(Apr/May 2015)** BTL2 **Answer: page 123 – 125 LIC D. Roy Choudhury** • Slew rate limits Op-amp speed • Capacitor prevents output voltage from responding immediately. (2M) $\frac{dV_C}{dt} = \frac{I}{C}$ (3M) • Maximum rate of change of output voltage • Slew rate = 0.5 $v/10^{-6}s$ (2M) • SR = 2fVm $v/10^{-6}s$ (3M) $f_{max}\ (Hz) = \frac{slew\ rate}{6.28XV_m} X\ 10^6$
3	a**) What is an active load? Explain differential amplifier with active load. (6M) (May/June 2009)** b) **Explain pole-zero compensation (7M) (Nov/Dec 2008)** (BTL2) **Answer: page 77 – 78, 120 – 122 LIC D. Roy Choudhury** • Differential amplifier with active load (4M) • Circuit behaves as a transconductance amplifier. • Gain proportional to load resistor Rc. • Two limitations to increase Rc. • Requires large chip area

	• Quiescent drop across it increases. • I_L=$I_1 - I_2$ = $g_m(V_1 - V_2)$ = g_mV_d (2M) **Pole zero compensation** (4M) • Transfer function A alters • Add both pole and a zero • Zero at higher frequency than pole • $Z_1 = R_1 \; and \; Z_2 = R_2 + 1/$(jωC2) (2M) • A' = $\frac{V_0}{V_I}$ = $\frac{V_0}{V_2}$.$\frac{V_2}{V_i}$ (1M)
4	**Describe the DC performance characteristics of operational amplifier. (13M) (Nov/Dec 2014)(Nov/Dec 2016)** BTL 2 **Answer: page 104 – 111 LIC D. Roy Choudhury** • Input Bias current (3M) $I_B = \frac{I_B^+ + I_B^-}{2}$ Input Offset Voltage (3M) $V_O = (1 + \frac{R_f}{R_1})V_{ios}$ Input Offset current (3M) $I_{os} = I_B^+ - I_B^-$ $V_o = R_f I_{os}$ Thermal drift (4M) Bias current, offset current, offset voltage change with temperature. Current drift expressed $nA/°C$ Voltage drift expressed $mV/°C$ Careful PCB, forced air cooling – reduce thermal drift
5	**Discuss the frequency compensation in operational amplifier. (13M) (May/June 2009)(Apr/May 2015)(Apr/May 2017) (Apr/May 2016)** BTL2 **Answer: page 119 – 122 LIC D. Roy Choudhury** • Dominant pole compensation • External frequency compensation method (1M) $A' = \frac{V_o}{V_i}$ (2M) $f_d = \frac{1}{2\pi RC}$ (2M) • $f_d < f_1 < f_2 < f_3$ (2M) • Pole zero compensation • External frequency compensation method (1M) • Transfer function A alters • Add both pole and a zero (1M) • Zero at higher frequency than pole (1M) • $Z_1 = R_1 \; and \; Z_2 = R_2 + 1/jwc_2$ (2M) • A' = $\frac{V_0}{V_I}$ = $\frac{V_0}{V_2}$.$\frac{V_2}{V_i}$ (1M)
6	**Draw the inverting and non-inverting amplifier circuits of an op-amp in closed loop configuration. Obtain the expressions for the closed loop gain in these circuits. (10M)**

(Nov/Dec 2017) BTL2

Answer: page 43 – 48 LIC D. Roy Choudhury

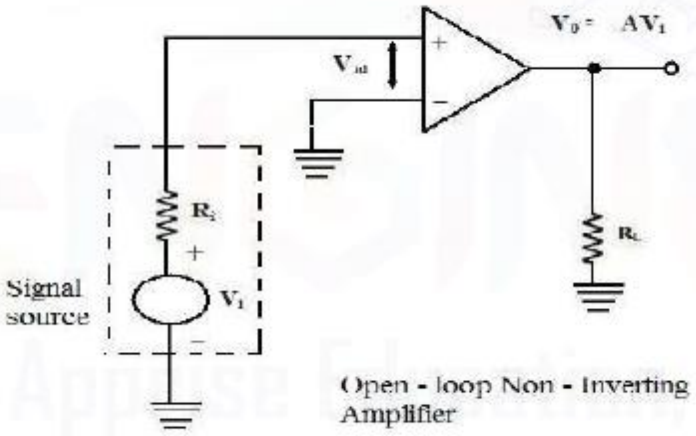
Inverting amplifier (5M)



Open - loop Inverting Amplifier

$A_{CL} = \frac{Vo}{Vi} = -\frac{R_f}{R_1}$ where, A = closed loop gain

Non – Inverting amplifier (5M)



Open - loop Non - Inverting Amplifier

$A_{CL} = \frac{Vo}{Vi} = 1 + \frac{R_f}{R_1}$ where A = closed loop gain

7 **Write in detail about summing amplifier. (13M)(Apr/May 2017) (Apr/May 2016)** BTL2

Answer: page 135 – 137 LIC D.Roy Choudhury

Inverting summing amplifier figure 2.13 (7M)

V_o = - ($\frac{V1+V2+V3}{3}$)

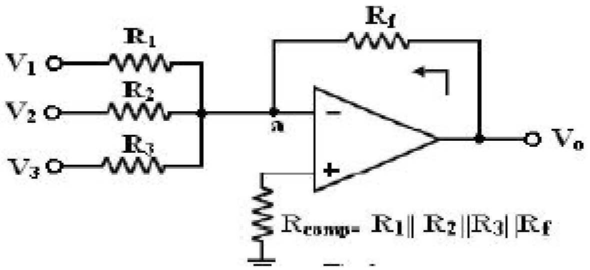


Fig. 2.13 inverting summer

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Non inverting summing amplifier figure 2.14 (6M)

$V_o = (1 + \frac{Rf}{R})V_a$

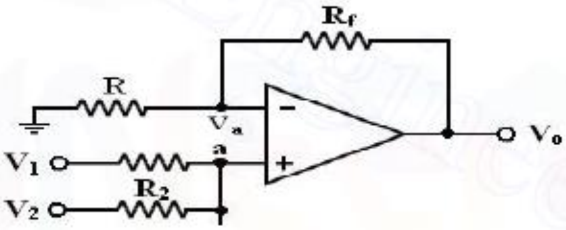

Fig.2.14 Non inverting summer

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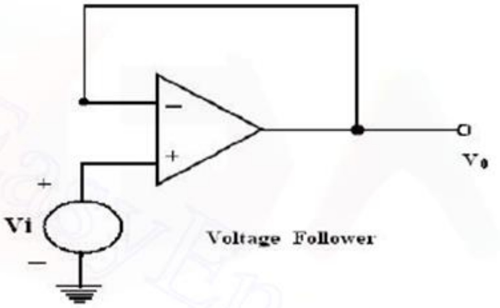
Explain voltage follower with neat sketch. (8M) BTL2
Answer: page 49 – 50 LIC D.Roy Choudhury
Rf = 0, R1 = ∞ (1M)
Non inverting amplifier (1M)
Output voltage follows input voltage (1M)
Buffer for impedance matching (1M)
Connect a high impedance source to a low impedance load (1M)
Diagram : (3M)



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PART *C

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Sketch the basic circuit using op-amp to perform the mathematical operation of differentiation and explain. What are the limitations of an ordinary op-amp differentiator? Draw and explain the circuit of a practical differentiator that will eliminate these limitations. (Nov/Dec 2016) (Apr/May 2016)
With neat diagram explain Integrator circuit. (15M) (May/June 2012)(Apr/May 2015) BTL3**.**
Answer: page 164 – 170 LIC D.Roy Choudhury
Differentiator circuit and waveform figure 2.24,2.25 (7M)
Contains capacitor at input
$V_o = -R_f C_1 \frac{dv_i}{dt}$

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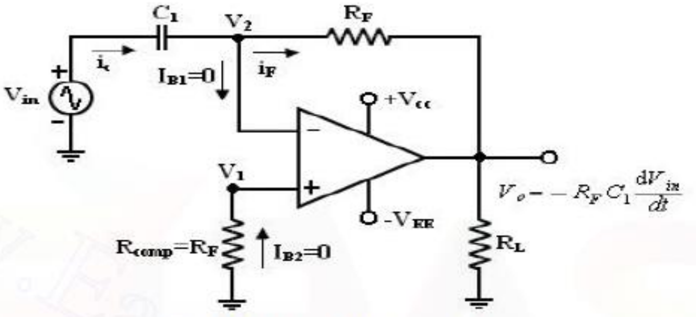


Fig 2.24 Basic Differentiator

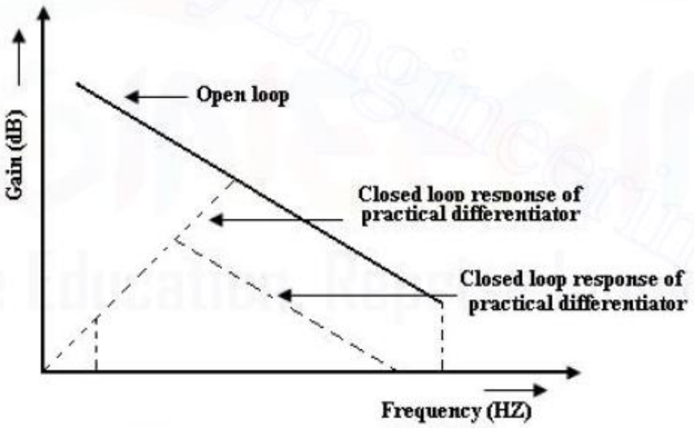


Fig. 2.25 Frequency response of differentiator

Integrator circuit figure 2.21 (8M)

Integrator – simple low pass RC circuit

Inverting integrator

$A = \frac{1}{wR_1C_f}$

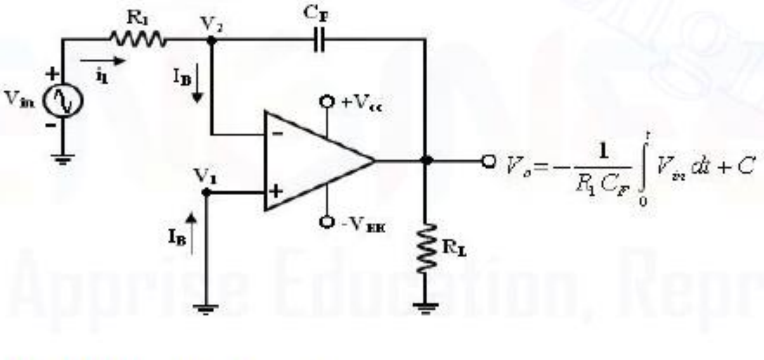


Fig 2.21 Integrator Circuit

$$i_1 = I_B + i_f$$

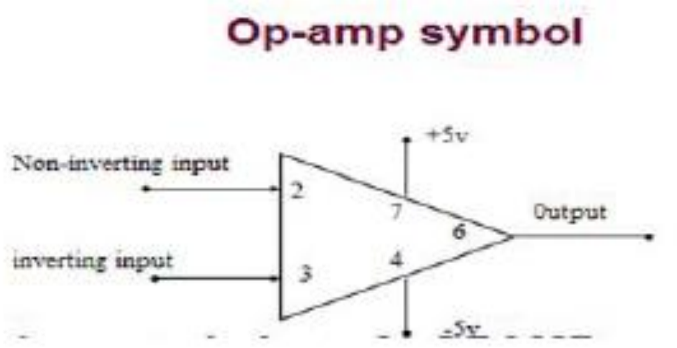
Since I_B is negligible small, $i_1 = i_F$

2

Explain about Ideal Op-amp in detail with suitable diagrams.(15M) (Apr/May 2018) BTL 2

Answer: page 41 – 48 LIC D. Roy Choudhury

Ideal op-amp (6M)



Ideal characteristics (1M)
Open loop voltage gain A=∞ (2M)
Input impedance Ri = ∞ (2M)
Output impedance Ro = 0 (2M)
Bandwidth BW = ∞ (1M)
Zero offset V0 = 0, when V1=0, V2=0
Vd = V1 – V2 (1M)

3

a)Draw and explain the circuit of a voltage to current converter if the load is (i) floating (4M) (ii) Grounded (4M) (May/June 2012)(Apr/May 2017)

b) Draw and explain the circuit of a current to voltage converter. (7M)(Apr/May 2015) BTL3

Answer: page 146 – 147 LIC D.Roy Choudhury

Floating load figure 2.7 (4M)
Output voltage Vo = 2V1
Vo = Vi + Vo – Ilr
Where Vi = iLR
Application – LED, zener diode tester, low voltage dc, ac voltmeter

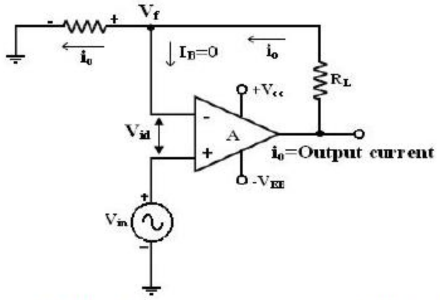
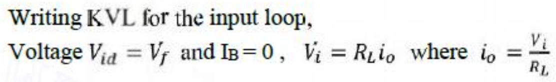
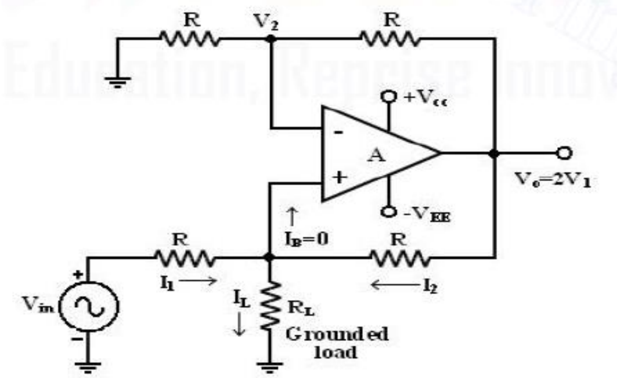


Fig. 2.7 Voltage to Current Converter with floating loads (V/I):


Writing KVL for the input loop,
Voltage $V_{id} = V_f$ and $I_B = 0$, $V_i = R_L i_o$ where $i_o = \frac{V_i}{R_L}$

With grounded load: **(4M)**



Current to voltage converter figure 2.9 (7M)

$$R= R_f$$

$$I_1 +I_2=I_L$$

$$(V_i+V_a)/R + (V_o –V_a)/R= I_L$$

$$V_o = (V_i +Vo - I_L R)/2 \text{ and gain } =1+ R/R= 2.$$

$$\therefore V_i = I_L R \; ; I_L = V_i/R$$

Current to Voltage Converter (I –V):

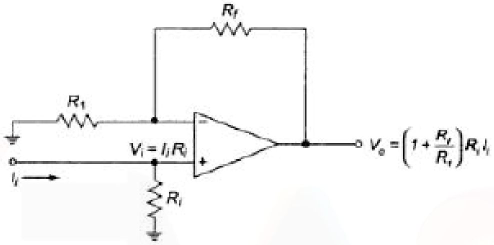


Fig. 2.9 Non inverting current to voltage convertor

Subject Code: EE8451 **Year/Semester: II /04**
Subject Name: LIC & APPLICATION **Subject Handler: D. Joshua**

UNIT III - APPLICATIONS OF OPAMP

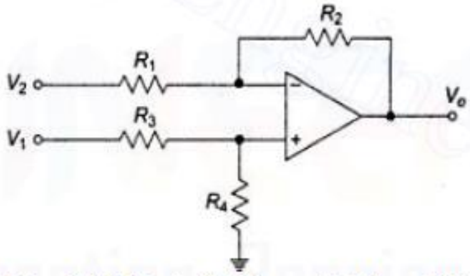
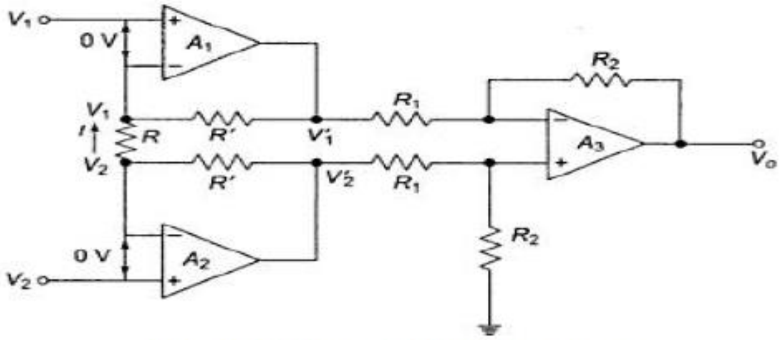
Instrumentation amplifier and its applications for transducer Bridge, Log and Antilog Amplifiers- An
Divider, first and second order active filters, comparators, multivibrators, waveform generators, clippe
detector, S/H circuit, D/A converter (R- 2R ladder and weighted resistor types), A/D converters using opan

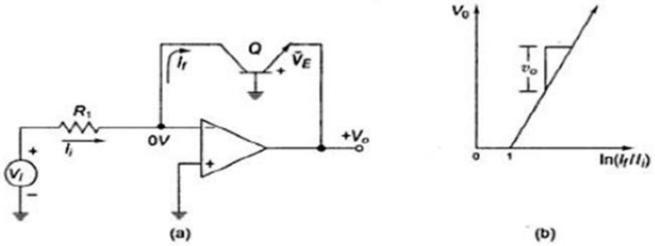
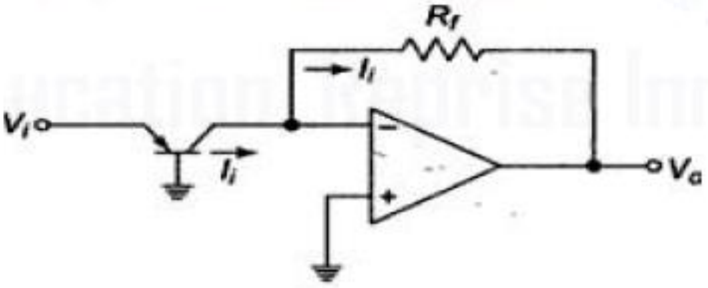
PART * A

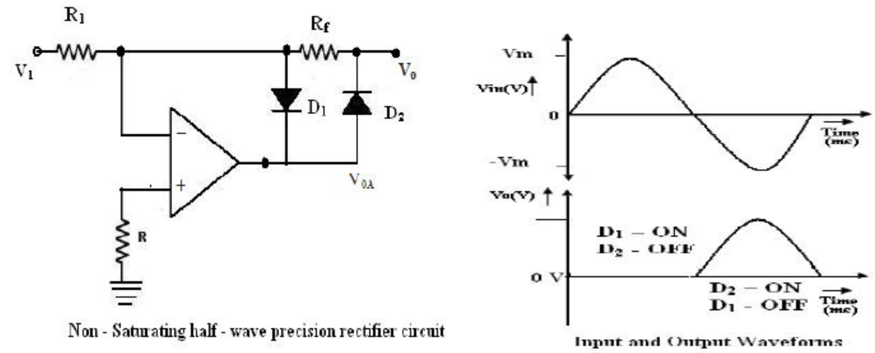
Q.No.	Questions
1.	**List the basic building blocks of PLL.** BTL1 • Phase detector/comparator • Low pass filter • Error amplifier • Voltage controlled oscillator
2	**Define FSK modulation.(MAY 2010)** BTL1 FSK is a type of frequency modulation in which the binary data or code is transmitted by means of a carrier frequency that is shifted between two fixed frequency namely mark(logic1) and space frequency(logic 0).
3	**What is analog multiplier?(MAY 2010)** BTL1 A multiplier produces an output $\boldsymbol{V_0}$, which is proportional to the product of two inputs $\boldsymbol{V_x}$ and $\boldsymbol{V_y}$. $\boldsymbol{V_0}$ =K $\boldsymbol{V_x}$ $\boldsymbol{V_y}$
4	**List out the various methods available for performing for analog multiplier.** BTL1 • Logarithmic summing technique • Pulse height /width modulation technique • Variable trans conductance technique • Multiplication using gilbert cell • Multiplication technique using trans conductance technique
5	**Mention some areas where PLL is widely used. (DEC 2009)** BTL1 • Radar synchronizations • Satellite communication systems • Air borne navigational systems • FM communication systems • Computers.
6	**What are the three stages through which PLL operates?** BTL1 • Free running • Capture • Locked/ tracking
7	**Define lock-in range of a PLL. (MAY 2010)** BTL1 The range of frequencies over which the PLL can maintain lock with the incoming signal is called the lock-in range or tracking range. It is expressed as a percentage of the VCO free running frequency.
8	**Define capture range of PLL. (MAY 2010)** BTL1

	The range of frequencies over which the PLL can acquire lock with an input signal is called the capture range. It is expressed as a percentage of the VCO free running frequency.
9	**Write the expression for FSK modulation.(MAY 2010)** BTL1 The expression for FSK modulation is, **Δvf=f2-f1/k0**
10	**Define free running mode .(MAY 2010)** BTL1 An interactive computer mode that allows more than one user to have simultaneous use of a program.
11	**For perfect lock, what should be the phase relation between the incoming signal and VCO output signal?** BTL2 The VCO output should be 90 degrees out of phase with respect to the input signal.
12	**Give the classification of phase detector.** BTL1 • Analog phase detector . • Digital phase detector
13	**What is a switch type phase detector?** BTL1 An electronic switch is opened and closed by signal coming from VCO and the input signal is chopped at a repetition rate determined by the VCO frequency. This type of phase detector is called a half wave detector since the phase information for only one half of the input signal is detected and averaged.
14	**What are the problems associated with switch type phase detector?** BTL1 • The output voltage V_e is proportional to the input signal amplitude. This is undesirable because it makes phase detector gain and loop gain dependent on the input signal amplitude. • The output is proportional to cosφ making it non linear.
15	**What is a voltage controlled oscillator?** BTL1 Voltage controlled oscillator is a free running multi vibrator operating at a set frequency called the free running frequency. This frequency can be shifted to either side by applying a dc control voltage and the frequency deviation is proportional to the dc control voltage
16	**Define Voltage to Frequency conversion factor.** BTL1 Voltage to Frequency conversion factor is defined as, Kv = fo / Vc= 8fo /Vcc Where, Vc is the modulation voltage fo frequency shift.
17	**What is the purpose of having a low pass filter in PLL?** BTL1 • It removes the high frequency components and noise. • Controls the dynamic characteristics of the PLL such as capture range, lock-in range, band-width and transient response. • The charge on the filter capacitor gives a short- time memory to the PLL
18	**Discuss the effect of having large capture range.** BTL2 The PLL cannot acquire a signal outside the capture range, but once captured, it will hold on till the frequency goes beyond the lock-in range. Thus, to increase the ability of lock range, large capture range is required. But, a large capture range will make the PLL more susceptible to noise and undesirable signal.
19	**Mention some typical applications of PLL.** BTL1

	• Frequency multiplication/division • Frequency translation • AM detection • FM demodulation • FSK demodulation.
20	**What is a compander IC? Give some examples.(DEC 2009)** BTL1 The term commanding means compressing and expanding. In a communication system, the audio signal is compressed in the transmitter and expanded in the receiver. Examples: LM 2704- LM 2707; NE 570/571.
21	**What are the merits of companding?** BTL1 • The compression process reduces the dynamic range of the signal before it is transmitted. • Companding preserves the signal to noise ratio of the original signal and avoids non linear distortion of the signal when the input amplitude is large. • It also reduces buzz,bias and low level audio tones caused by mild interference.
22	**List the applications of analog multipliers.(May/June 2013)** BTL1 • Analog computer • Analog signal processing • Automatic gain control • True RMS converter • Analog filter (especially voltage-controlled filters) • PAM-pulse amplitude modulation
23	**In what way VCO is different from other oscillator. (May/June 2012)** BTL2 • To adjust the output frequency to match (or perhaps be some exact multiple of) an accurate external reference. • Where the oscillator drives equipment that may generate radio-frequency interference, adding a varying voltage to its control input can disperse the interference spectrum to make it less objectionable. See spread spectrum clock.
24	**List the applications of NE565. (Nov/Dec2010)** BTL1 • Frequency multiplier • FM Demodulator is the applications of NE565.
25	**Why the VCO is called voltage to frequency converter? (Nov/Dec 2012)** BTL1 The VCO provides the linear relationship between the applied voltage and the oscillation frequency. Applied voltage is called control voltage. The control of frequency with the help of control voltage is also called voltage to frequency conversion. Hence VCO is also called voltage to frequency converter.
	PART * B
1	**With neat sketch explain the operation of a 3 op-amp instrumentation amplifier. (13M) (Nov/Dec 2014) (Apr/May 2015) (May/June 2016)** BTL 1 **Answer: page 141 – 144 LIC D.Roy Choudhury** • High gain accuracy (1M)

	• High CMRR (1M) • High gain stability with low temperature coefficient (1M) • Low dc offset (1M) • Low output impedance (1M) • $V_0 = \frac{R_2}{R_1}(V_1 - V_2)$ (2M) Instrumentation Amplifier figure 2.18, 2.19 (6M)  **Fig. 2.18 Basic Differential Amplifier**  **Fig. 2.19 Instrumentation Amplifier**
2	**With neat diagram explain logarithmic amplifier and antilogarithmic amplifier. (13M) (May/ June 2014) (Nov/Dec 2016)** BTL1 **Answer: page 155 – 159 LIC D.Roy Choudhury** Direct DB display on digital voltmeter, spectrum analyzer. (2M) Compress dynamic range of signal. (1M) Diagram: (5M)

	2.11 Log and Antilog Amplifier: **Log Amplifier:** $V_o = V_i ln\left(I_f / I_i\right)$  **Fig 2.28 Fundamental log-amp Circuit and its characteristics** $V_o = -\frac{kT}{q} ln\left(\frac{V_i}{R_1 I_S}\right) = -\frac{kT}{q} ln\left(\frac{V_i}{V_R}\right)$ Anti – log Amplifier: (5M)  $I_i = I_c = I_s(e^{\frac{\eta V_{BE}}{kT}})$ and $V_0 = R_f I_s(e^{\frac{\eta V_{BE}}{kT}})$
3	**With neat diagram explain the application of op-amp as precision rectifier, clipper and clamper. (13M) (May/ June 2014) (Apr/May 2017)**BTL2 **Answer: page 148 – 153 LIC D.Roy Choudhury** Typical applications of precision diode Half wave rectifier and waveform figure 2.41 (3M)



Non - Saturating half - wave precision rectifier circuit

Input and Output Waveforms

Fig. 2.41 Half wave rectifier and its operation

The circuit operation can mathematically be expressed as

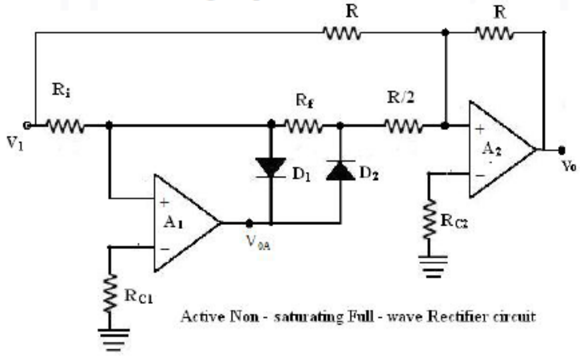
$V_0 = 0$ when $V_i > 0$ and

$V_0 = R_f/R_i V_1$ for $V_i < 0$

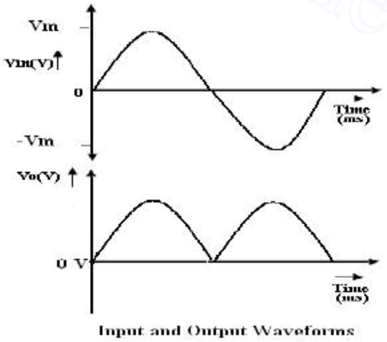
The voltage V_{OA} at the op amp output is $V_{OA} = -0.7V$ for $V_i > 0$

$V_{OA} = R_f/R_i V_1 + 0.7V$ for $V_i < 0$

Full wave rectifier (3M)

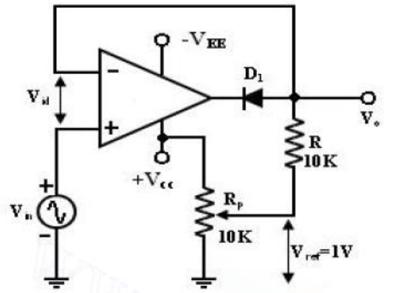
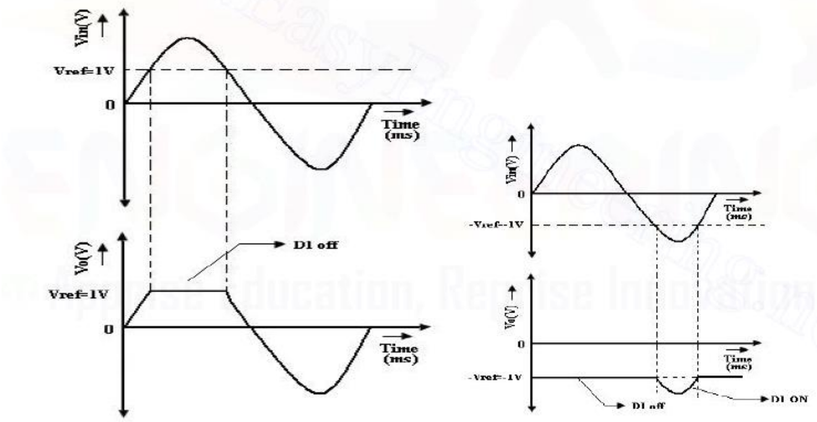
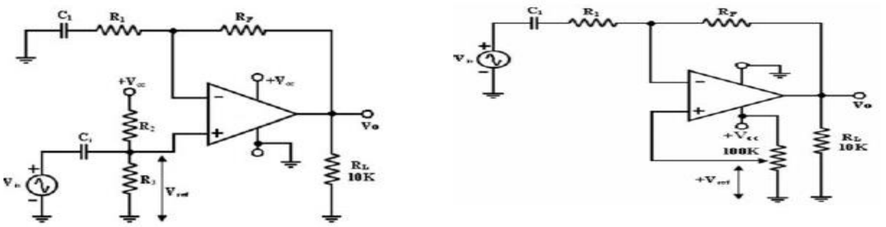
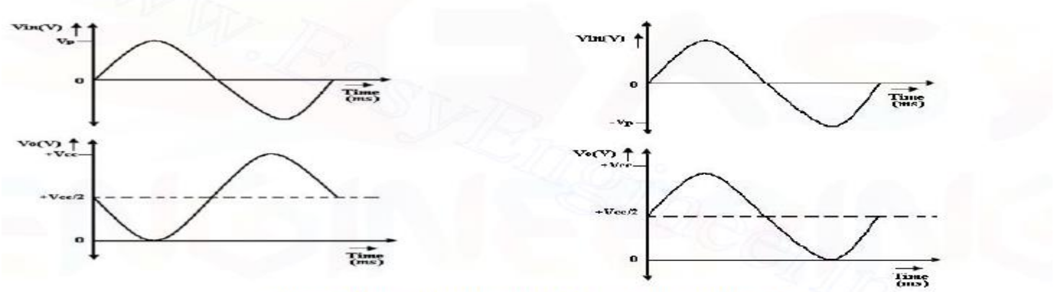


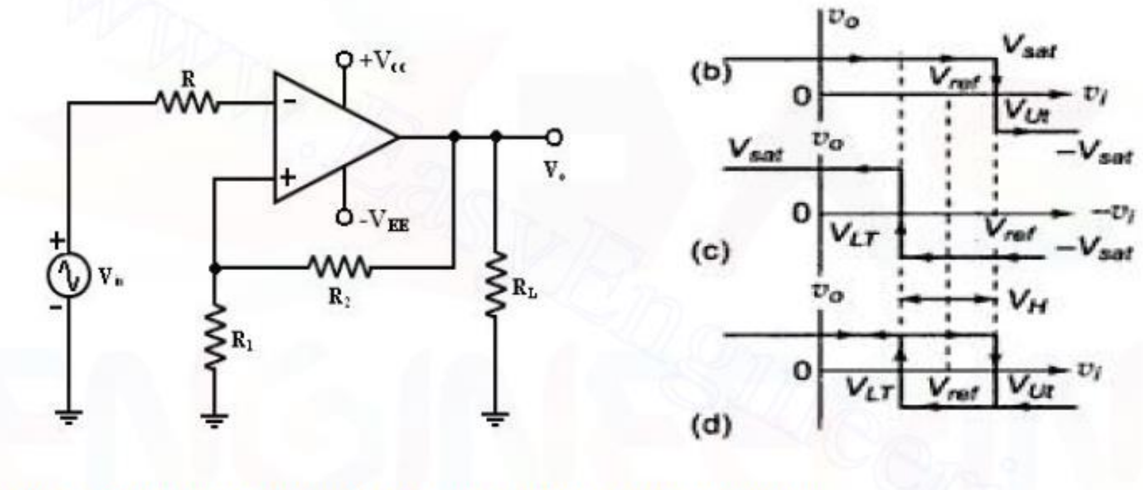
Active Non - saturating Full - wave Rectifier circuit

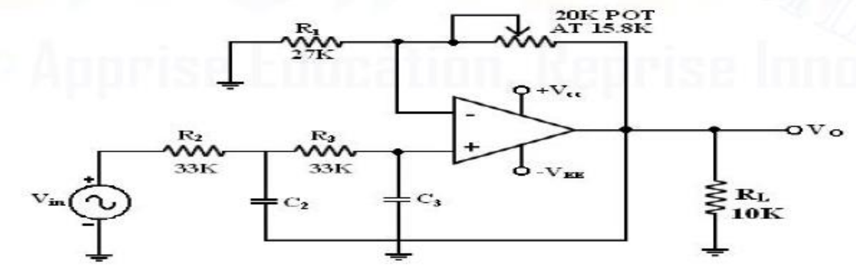
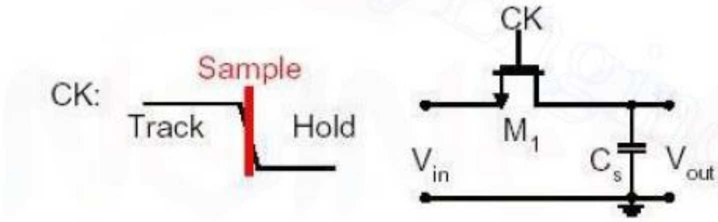


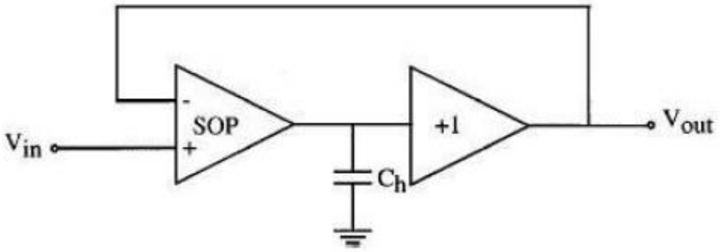
Input and Output Waveforms

Clipper and waveform figure 2.44,2.45 (7M)

	 **Fig. 2.44 Positive Clipper**  **Fig 2.45 Positive clipper input output waveforms** Clamper and waveform figure 2.48,2.49  **Fig.2.48 Positive –Negative campers**  **Fig.2.49 Input and output waveform with +Vref**
4	**With a neat circuit diagram explain the working of op-amp based Schmitt trigger and**

	triangular waveform generator. (8M) (Nov/Dec 2009) (Apr/May 2015) (Apr/May 2017) (May/June 2016) BTL2 **Answer: page 212 – 214 LIC D.Roy Choudhury** $V_{UT} = \frac{V_{ref}R_1}{R_1+R_2} + \frac{R_2V_{sat}}{R_1R_2}$ (1M) $V_{UT} = \frac{V_{ref}R_1}{R_1+R_2} - \frac{R_2V_{sat}}{R_1R_2}$ (1M) $V_H = V_{UT} - V_{LT}$ (2M) $V_H = \frac{2R_2V_{sat}}{R_1+R_2}$ Schmitt trigger figure 2.38 (4M)  **Fig.2.38 Schmitt Trigger circuit and hysteresis phenomenon**
5	**Design an op-amp based second order active low pass filter with cut off frequency 2KHz. (8M) (Nov/Dec 2011) (Apr/May 2017) (May/June 2016)** BTL3 **Answer: page 265 – 268 LIC D.Roy Choudhury** $V_o = A_oV_B$ (1M) V_B voltage at node B Step response, dampening coefficient, cause its effects Low pass filter figure 2.55 (3M)

	 **Fig. 2.55 second order LP Butterworth filter** Design: (4M) - Choose a value for a high cut off freq. (fHz). - To simplify the design calculations, set R2 = R3 = R and C2 = C3 = C then choose a value of C<=1μf. - Calculate the value of R *R* =1/2πfhC - Finally, because of the equal resistor (R2 = R3) and capacitor (C2 = C3) values, the pass band volt gain AF = 1 + RF / R1 of the second order had to be = to 1.586. RF = 0.586 R1. - Hence choose a value of R1 <=100kΩ. - Calculate the value of RF.
6	**i)Draw the diagram of sample and hold circuit. (7M)** **ii)State how you will reduce its hold mode drop. (6M)** BTL2 **Answer: page 153 - 154 LIC D.Roy Choudhury** Circuit Diagram: (4M)  During sample mode, the SOP behaves just like a regular op-amp, in which the value of the output follows the value of the input. (1M) During hold mode, the MOS transistors at the output node of the SOP are turned off while they are still operating in saturation, thus preventing any channel charge from flowing into the output of the SOP. (2M) In addition, the SOP is shut off and its output is held at high impedance, allowing the charge on *Ch* to be preserved throughout the hold mode. (2M) On the other hand, the output buffer of this S/H circuit is always operational during sample and hold mode and is always providing the voltage on *Ch* to the output of the S/H circuit. (1M) Circuit Diagram : (3M)



7

Discuss in detail about the following Digital to Analog & Analog to Digital conversion techniques.
i)Flash type ADC (6M) (Nov/Dec 2016)
ii)Weighted Resistor DAC. (7M) BTL1
Answer: page 358 – 360,349 - 351 LIC D.Roy Choudhury

Process extremely fast with a sampling rate of up to 1 GHz. (1M)

Resolution however, limited because of large number of comparators, reference voltages required. (1M)

Input signal fed simultaneously to all comparators. (1M)

Priority encoder then generates a digital output that corresponds with the highest activated comparator. (1M)

Diagram: (2M)

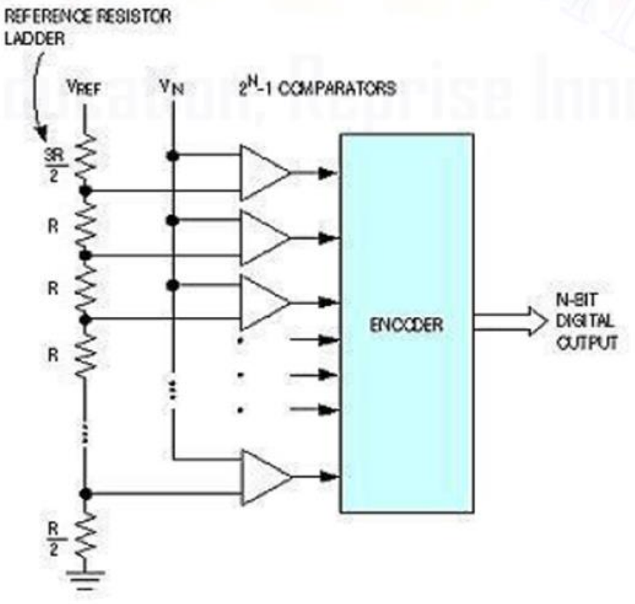


Fig.4.14 Flash ADC

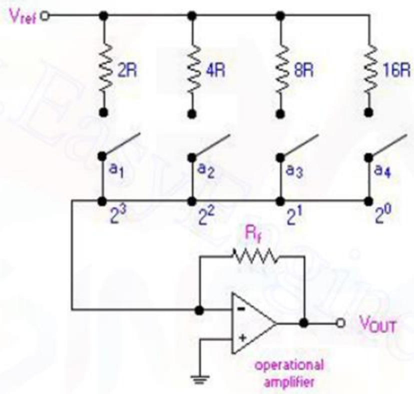
Weighted Resistor DAC:

For a n-bit DAC, the relationship between Vout and the binary input is as follows: (2M)

$$V_{OUT} = -\frac{V_{ref} R_f}{R} \sum_{i=1}^{n} \frac{a_i}{2^i}$$

The LSB, which is also the incremental step, has a value of - 0.625 V while the MSB or the full scale has a value of - 9.375 V. (1M)

Diagram: (4M)



8 **i)Estimate the working of R-2R ladder type DAC. (10M) (Apr/May 2015) (Apr/May 2017)**

ii)Compare binary weighted DAC with R-2R ladder network DAC. (3M) BTL1

Answer: page 352 – 353,349 - 351 LIC D.Roy Choudhury

Tabulation : (3M)

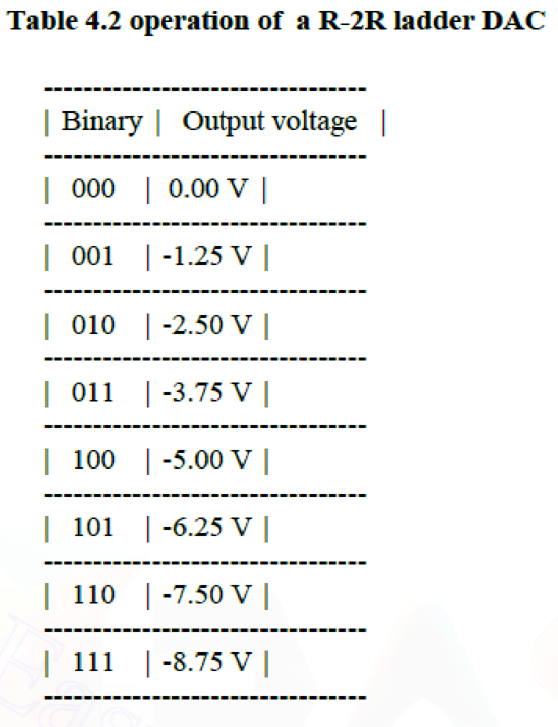
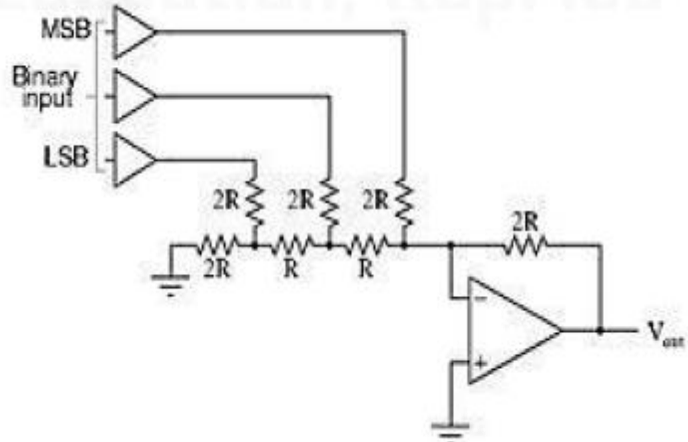


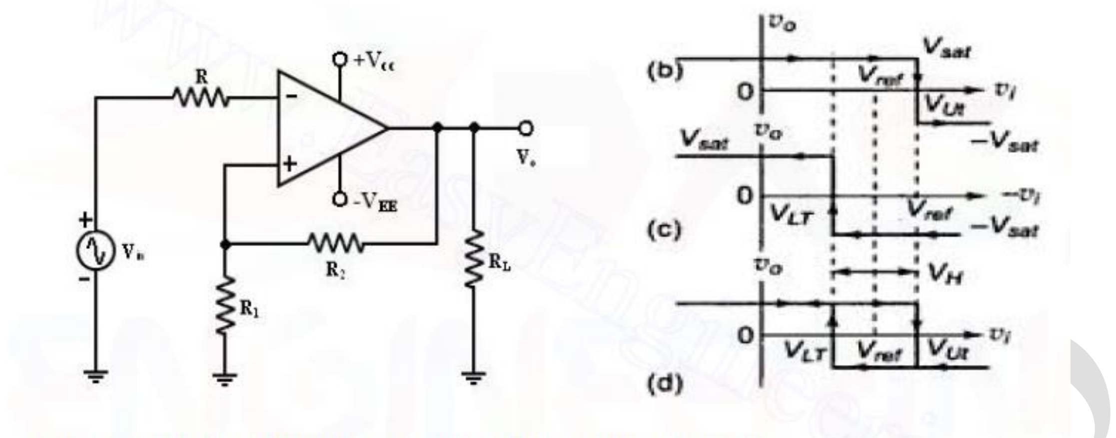
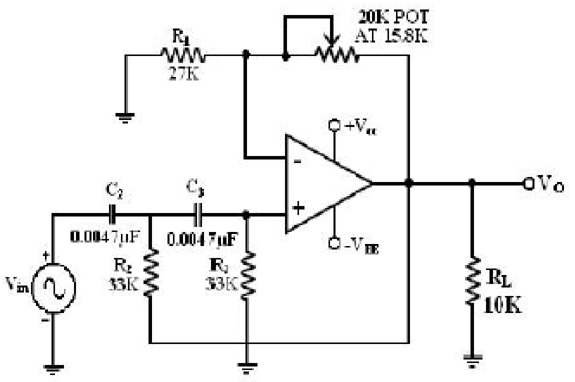
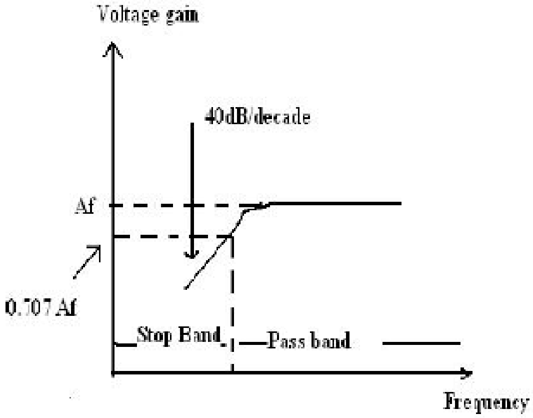
Table 4.2 operation of a R-2R ladder DAC

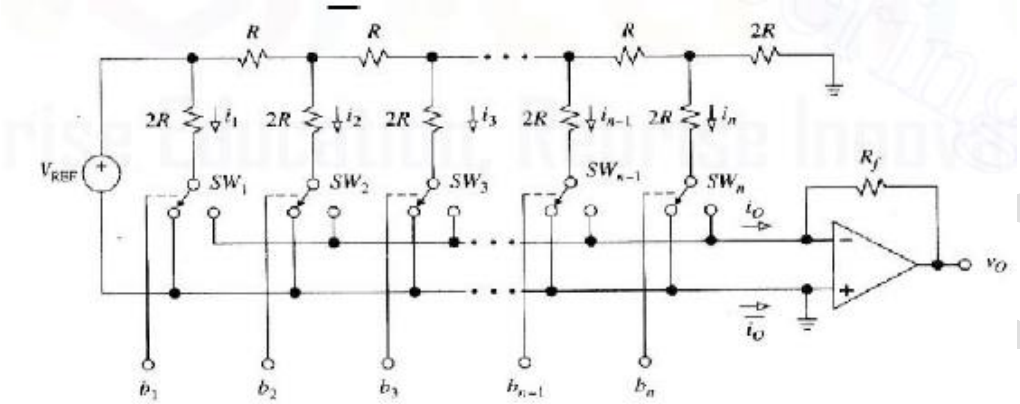
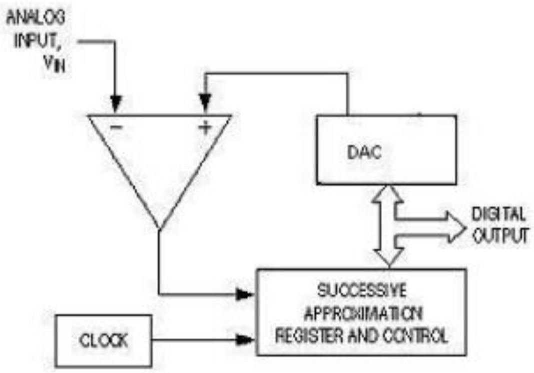
Binary	Output voltage
000	0.00 V
001	-1.25 V
010	-2.50 V
011	-3.75 V
100	-5.00 V
101	-6.25 V
110	-7.50 V
111	-8.75 V

Vout = - (VMSB + Vn + VLSB) = - (VRef + VRef/2 + VRef/ 4) (2M)

Diagram: (5M)

	 Enhancement of binary-weighted resistor DAC - R-2R ladder network. (1M) DAC utilizes Thevenin's theorem in arriving at desired output voltages. Disadvantage of the former DAC design - its requirement of several different precise input resistor values. (1M) one unique value per binary input bit. R-2R network consists of resistors with only two values - R and 2xR. (1M) If each input supplied either 0 volts or reference voltage, the output voltage will be an analog equivalent of the binary value of the three bits. VS_2 corresponds to the most significant bit (MSB) while VS_0 corresponds to the least significant bit (LSB).
	PART *C
1	**a) Explain the working of an op-amp based regenerative comparator circuit? (8M) (May/June 2012), (Nov/Dec 2011) (Apr/May 2015) (May/June 2016)** **b) Design an op-amp based second order active high pass filter with cut off frequency 2KHz. (7M) (Apr/May 2015)** BTL3 **Answer: page 212 – 215,265 - 267 LIC D.Roy Choudhury** $V_{UT} = \frac{V_{ref}R_1}{R_1+R_2} + \frac{R_2V_{sat}}{R_1R_2}$ (1M) $V_{LT} = \frac{V_{ref}R_1}{R_1+R_2} - \frac{R_2V_{sat}}{R_1R_2}$ (1M) $V_H = V_{UT} - V_{LT}$ (1M) $V_H = \frac{2R_2V_{sat}}{R_1+R_2}$ (1M) Schmitt trigger figure 2.38 (4M)

	 **Fig.2.38 Schmitt Trigger circuit and hysteresis phenomenon** II ORDER HPF: $V_o = A_oV_B$ (1M) V_B voltage at node B (1M) Step response, dampening coefficient, cause its effects (1M) Diagram: (4M)  
2	**Derive the Inverted or Current mode R-2R Ladder Digital to analog converter and explain. Examine the inverted R-2R ladder (refer above question) has R=Rf=10kΩ and VR=10V. Calculate the total current delivered to the op-amp and the output voltage when the binary input is 1110. (15M) (Apr/May 2015) (Apr/May 2017)** BTL3 Currents given as (4M) *i*1 = VREF/2R = (VREF/R) 2-1, *i*2 = (VREF)/2)/2R = (VREF/R) 2-2……… *in* = (VREF/R) 2-n. Relationship between the currents given as (4M) i2 = i1/2 i3 = i1/4 i4 = i1/8

	in = i1/ 2_{n-1} Using bits to identify status of switches, letting V0 = -Rf *io* gives V0 = - (Rf/R) VREF (b12-1 + b22-2+ ……….. + bn2-n) (7M) 
3	**With example explain the successive Approximation ADC Technique. (11M) (Nov/Dec 2016) (May/June 2016)** **Discuss the important specification of Data Converters. (4M)** **Answer: Page 361 - 363 LIC D.Roy Choudhury** Successive Approximation: (6M)  bit-weighting conversion, similar to a binary. (1M) Analogue value rounded to the nearest binary value below, (1M) Because the approximations are successive (not simultaneous), (2M) conversion takes one clock-cycle for each bit of resolution desired. (1M) ii)Data converters: input n bit binary word D (1M) reference voltage Vr (1M) analog output signal (1M) output of DAC – voltage or current (1M)

Subject Code:EC8451 **Year/Semester: II /04**
Subject Name: LIC & APPLICATIONS **Subject Handler: D.Joshua**

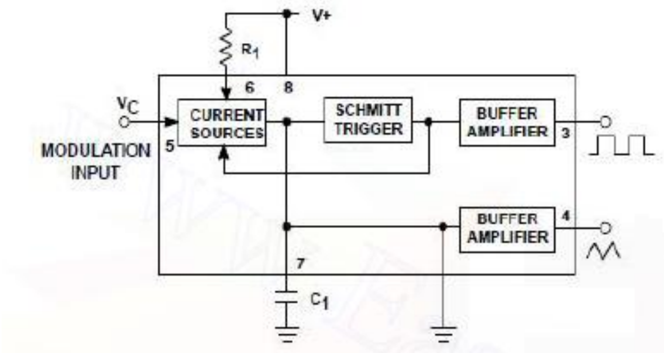
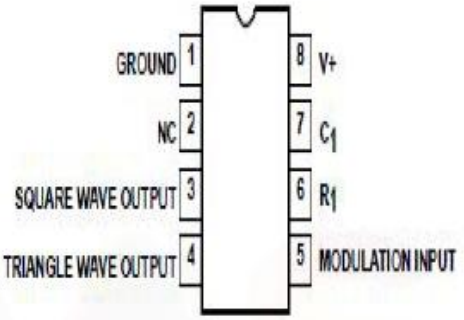
UNIT IV - SPECIAL ICs

Functional block, characteristics of 555 Timer and its PWM application - IC-566 voltage controlled oscillator IC; 565- phase locked loop IC, AD633 Analog multiplier ICs.

PART * A

Q.No.	Questions
1.	**Give the operation of basic sample and hold circuit.** BTL1 A typical sample and hold circuit stores electric charge in a capacitor and contains at least one fast FET switch and at least one operational amplifier. To sample the input signal the switch connects the capacitor to the output of a buffer amplifier. The buffer amplifier charges or discharges the capacitor so that the voltage across the capacitor is practically equal, or proportional to, input voltage. In hold mode the switch disconnects the capacitor from the buffer. The capacitor is invariably discharged by its own leakage currents and useful load currents, which makes the circuit inherently volatile, but the loss of voltage (voltage drop) within a specified hold time remains within an acceptable error margin.
2	**State the advantages and applications of sample and hold circuits.** BTL1 A sample and hold circuit is one which samples an input signal and holds on to its last sampled value until the input is sampled again. This circuit is mainly used in digital interfacing, analog to digital systems, and pulse code modulation systems.
3	**List the drawbacks of binary weighted resistor technique of D/A conversion.**BTL1 • Wide range of resistor values needed. • Difficulty in achieving and maintaining accurate ratios over a wide range of variations
4	**What is the advantage and disadvantages of flash type ADC?** BTL1 Flash type ADC is the fastest as well as the most expensive. The disadvantage is the number of comparators needed almost doubles for each added bit (For a n-bit convertor 2(n-1) comparators, 2n resistors are required).
5	**The basic step of a 9 bit DAC is 10.3 mV. If 000000000 represents 0Volts, what is the output for an input of 101101111?** BTL2 The output voltage for input of 101101111 is = 10.3 mV (1*28+0*27+1*26+1*25+0*24+1*23+1*22+1*21+1*20) = 10.3 * 10-3 * 367 = 3.78 V
6	**Find the resolution of a 12 bit DAC converter.** BTL1 Resolution (volts) = VFS/(212-1) = I LSB increment VFS – Full scale voltage
7	**What are the advantages and disadvantages of R-2R ladder DAC?** BTL1 **Advantages:** • Easier to build accurately as only two precision metal films are required. • Number of bits can be expanded by adding more sections of same R/2R values.
8	**What are the disadvantages of R-2R ladder DAC?** BTL1 In this type of DAC, when there is a change in the input, changes the current flow in the resistor which causes more power dissipation which creates non-linearity in DAC.
9	**Define Start of Conversion.** BTL1 This is the control signal for start of conversion which initiates A/D conversion process.

10	**Define End of Conversion.** BTL1 This is the control signal which is activated when the conversion is completed.
11	**What are the types of ADC?** BTL1 • Flash (comparator) type converter • Counter type converter • Tracking or servo converter • Successive approximation type converter
12	**What are the types of DAC?** BTL1 • Weighted resistor DAC • R-2R Ladder • Inverted R-2R Ladder
13	**What is the difference between direct ADC and integrating type ADC?** BTL1 The integrating type of ADC’s do not need a sample/Hold circuit at the input. It is possible to transmit frequency even in noisy environment or in an isolated form.
14	**Define Resolution.** BTL1 The resolution of a converter is the smallest change in voltage which may be produced at the output or input of the converter. Resolution (in volts)= VFS/2n-1=1 LSB increment. The resolution of an ADC is defined as the smallest change in analog input for a one bit change at the output.
15	**What is meant by Accuracy?** BTL1 It is the maximum deviation between the actual converter output & the ideal converter output.
16	**What is the purpose of DAC Monotonicity?** BTL1 A monotonic DAC is one whose analog output increases for an increase in digital input.
17	**Define Conversion time.** BTL1 It is defined as the total time required to convert an analog signal into its digital output. It depends on the conversion technique used & the propagation delay of circuit components. The conversion time of a successive approximation type ADC is given by T(n+1) where T---clock period Tc---conversion time no of bits.
18	**Define Relative accuracy.** BTL1 Relative Accuracy is the maximum deviation after gain & offset errors have been removed. The accuracy of a converter is also specified in form of LSB increments or % of full scale voltage.
19	**Define dither.** BTL1 Dither is very small amount of noise to add a before the A/D conversion.
20	**Define sampling period and hold period.** BTL1 Time duration of capacitor to sample and hold the equal value of voltage input period is called as sampling period and the time duration of voltage across the capacitor at constant time duration is called as hold period.
21	**Define the term settling time.** BTL1 It represents the time it takes for the output to settle within a specified band+-(1/2) LSB of its final value. It depends upon the switching time of the logic circuitry due to internal parasitic capacitances and inductances. Settling time ranges from 100ns to 10µs depending on word length and type of circuit used.

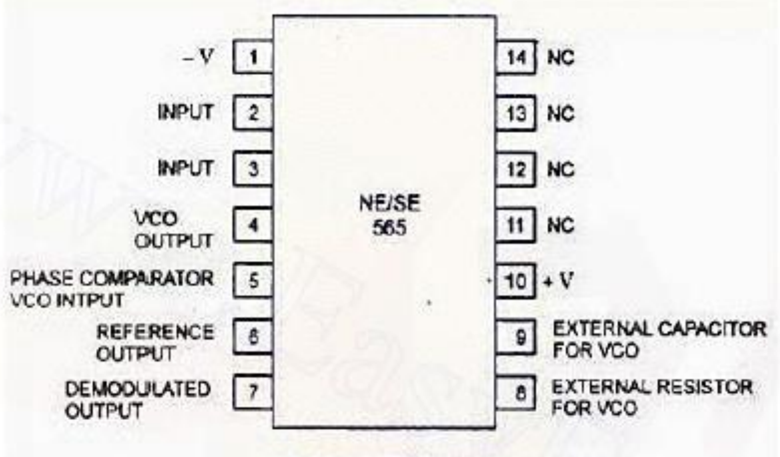
22	**Define conversion time.** BTL1 It is the time taken for the D/A converter to produce the analog output for the given binary input signal. It depends on the response time of switches and the output of the Amplifier. D/A converters speed can be defined by this parameter. It is also called as setting time.
23	**Define slew rate and state its significance. (Apr/May 2010)** BTL1 The circuit of successive approximation ADC consists of a successive approximation register (SAR), to find the required value of each bit by trial & error. With the arrival of START command, SAR sets the MSB bit to 1. The O/P is converted into an analog signal & it is compared with I/P signal. This O/P is low or high. This process continues until all bits are checked.
24	**What is the fastest ADC and why? (Nov/Dec 2010)** BTL1 The circuit of successive approximation ADC consists of a successive approximation register (SAR), to find the required value of each bit by trial & error. With the arrival of START command, SAR sets the MSB bit to 1. The O/P is converted into an analog signal & it is compared with I/P signal. This O/P is low or high. This process continues until all bits are checked.
25	**An 8 bit DAC has a resolution of 20mV/bit. What is the analog output voltage for the digital input code 00010110(the MSB is the left most bit)?(Apr/May 2010)** BTL2 The output voltage for input 00010110 is $=20 *0* 2^8 * 0* 2^7 * 0* 2^6 *1* 2^5 * 0* 2^4 *1* 2^3 *1* 2^2 * 0* 2^1$ =20 * 44 =880 Mv
	PART * B
1	**Explain the working of voltage controlled oscillator.(8M) (Nov/Dec 2009), (April/May 2010) (Apr/May 2015) (Nov/Dec 2016) (Apr/June 2016)** BTL2 **Answer: page 334 – 336 LIC D. Roy Choudhury** IC signetics NE/SE566 (4M)   Application – converts EEGs, EKGs to AF range. (4M) Fo changes with change in Rt, Ct, voltage at pin 5. Voltage to frequency conversion factor $K_v = \frac{\Delta f_o}{\Delta V_c}$ $K_v = \frac{8 f_o}{V_c}$

2

Draw the pin configuration of PLL IC 565. (8M) BTL1

Answer: page 337 – 342 LIC D. Roy Choudhury

Pin configuration: (4M)



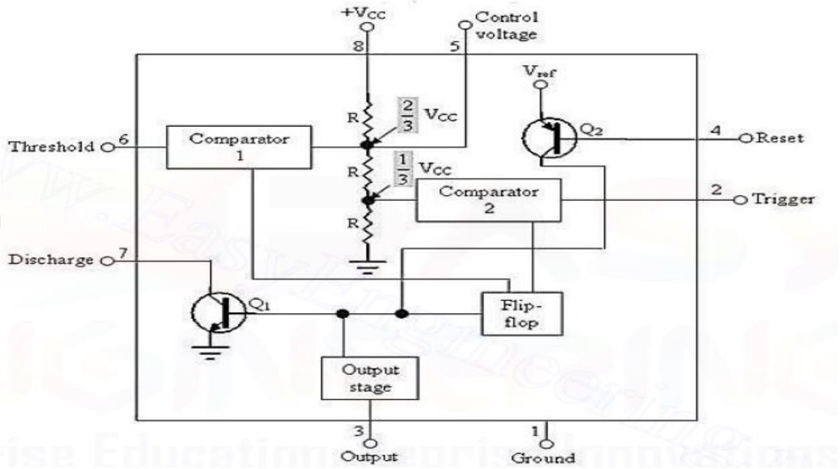
14-Pin DIP Package

- The important electrical characteristics of 565 PLL,
- Operating frequency range: 0.001Hz to 500 Khz.
- Operating voltage range: ±6 to ±12v (4M)
- Input level required for tracking: 10mv rms min to 3 Vpp max
- Input impedance: 10 K ohms typically.
- Output sink current: 1mA
- Output source current: 10 Ma

3

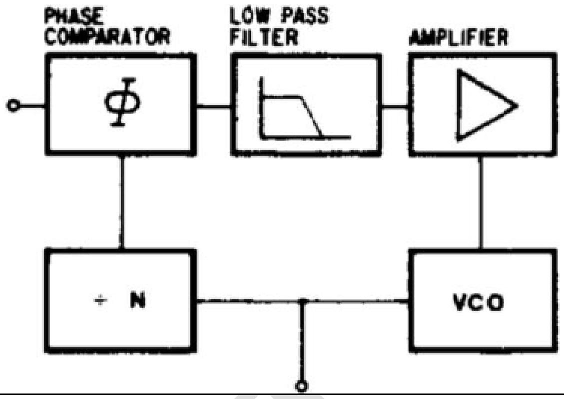
Explain IC 555 timer. (8M) (Apr/May 2017) BTL2

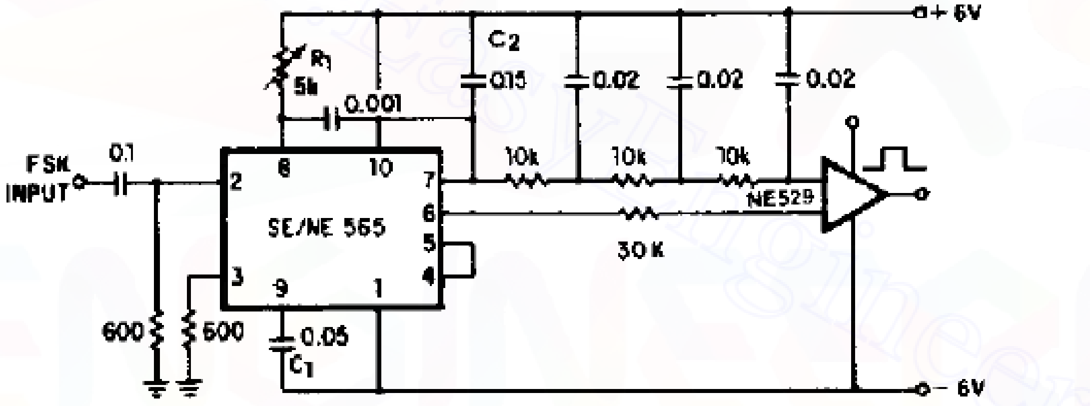
Diagram: (5M)

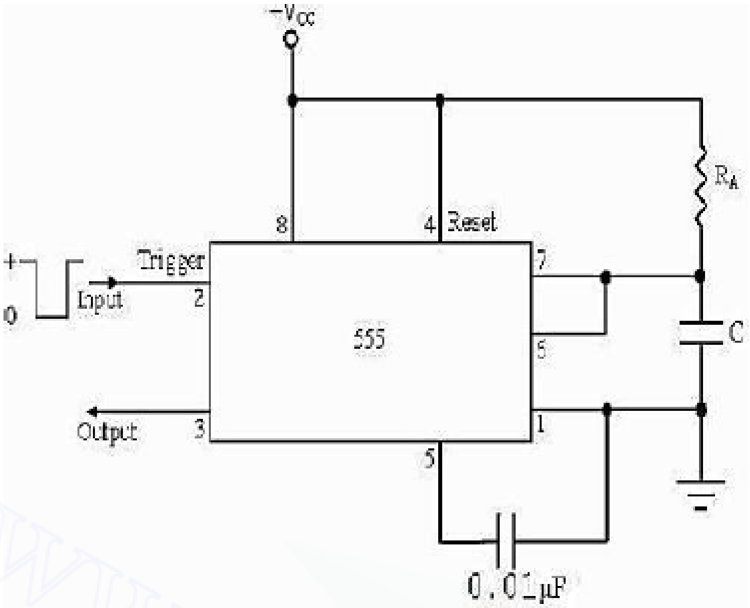
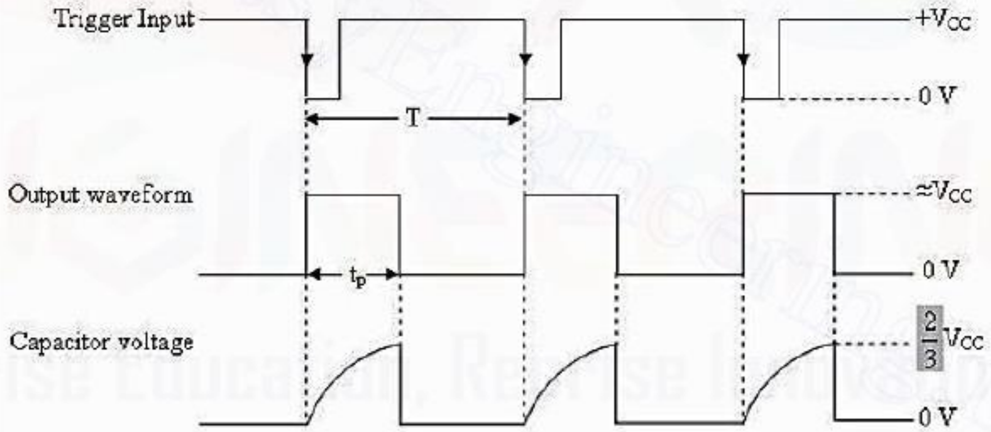


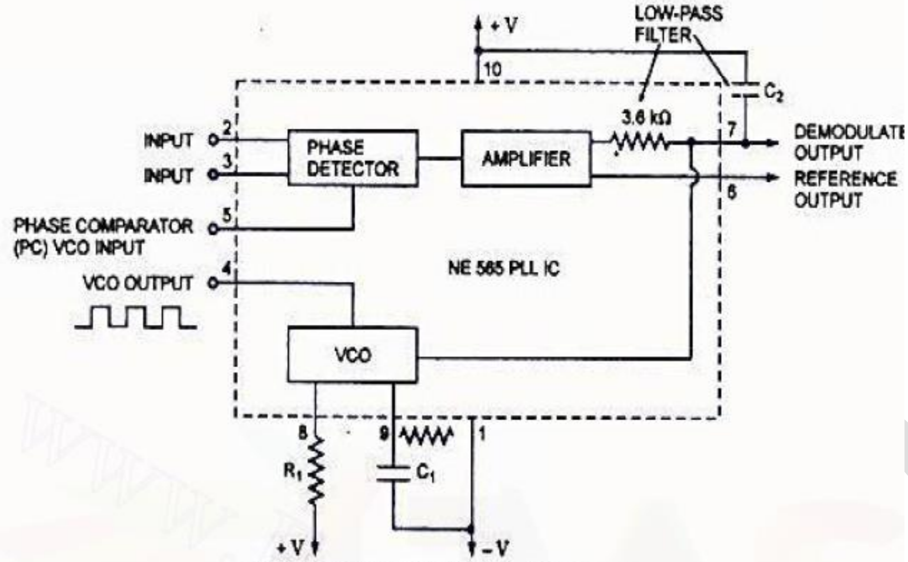
In the Stable state: (3M)

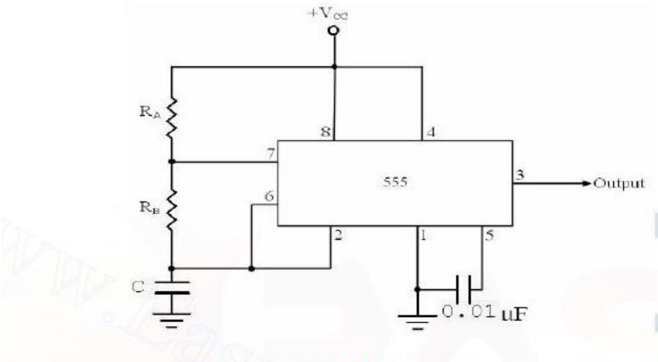
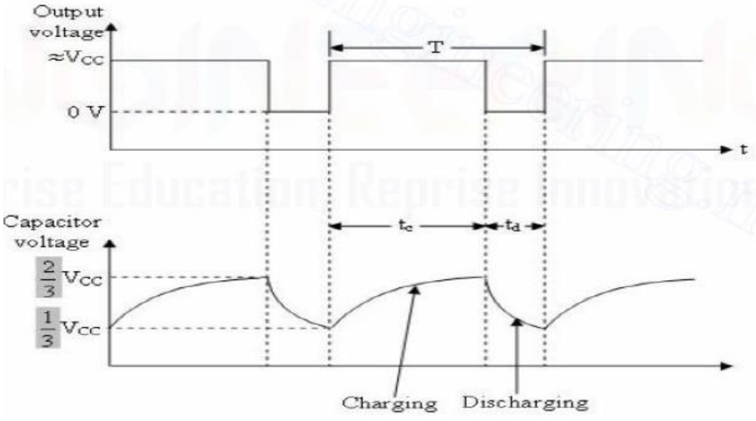
- The output of the control FF is high. This means that the output is low because of power amplifier which is basically an inverter. Q = 1; Output = 0
- At the Negative going trigger pulse:
- The trigger passes through (Vcc/3) the output of the lower comparator goes high & sets

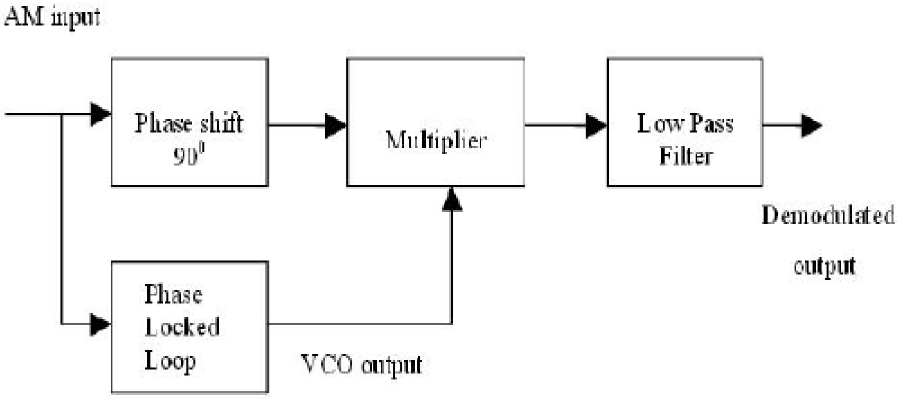
	the FF. Q = 1; Q = 0 • At the Positive going trigger pulse: It passes through 2/3Vcc, the output of the upper comparator goes high and resets the FF. Q = 0; Q = 1 • The reset input (pin 4) provides a mechanism to reset the FF in a manner which overrides the effect of any instruction coming to FF from lower comparator.
4	**Brief about PLL application Frequency multiplication / Division. (8M)(Apr/May 2015) (Apr/May 2017) (Nov/Dec 2016)** BTL2 **Answer: page 342 – 343 LIC D. Roy Choudhury** • Divide by N network • Frequency divider insert between the VCO & phase comparator. (2M) • Output of the divider locks to f IN. • VCO runs at multiple of input frequency. (2M) • Desired amount of multiplication obtains by selecting a proper divide-by-N network, • where N is an integer. Diagram: (4M) 
5	**Elaborate FSK demodulator with neat diagram. (8M)** BTL2 **Answer: page 344 – 345 LIC D. Roy Choudhury**. • Capacitive coupling - at input to remove dc line. (1M) • At input of 565, loop locks to input frequency & tracks it between 2 frequencies. • R1 & C1 determine the free running frequency of VCO, • 3 stages RC ladder filter - to remove carrier component from output. (2M) Diagram: (4M)

	 **Applications:** (1M) • Digital data communication, computer peripheral • Binary data transmits by means of carrier frequency - shifts between two preset frequencies. • This type of data transmission called frequency shift keying (FSK) technique. • The binary data retrieved by FSK demodulator.
6	**What are 555 timers? Explain the working of 555 timer as Monostable Multivibrator. Derive an expression for the frequency of oscillation with relevant waveforms. (10M) (Apr/May 2015) (Apr/May 2017)** BTL1 **Answer: page 312 - 317 LIC D.Roy Choudhury** Initially when the output is low, i.e. the circuit is in a stable state, transistor Q1 is ON & capacitor C is shorted to ground. (2M) The output remains low. During negative going trigger pulse, transistor Q1 is OFF, which releases the short circuit across the external capacitor C & drives the output high. (2M) Now the capacitor C starts charging toward Vcc through RA. (2M) When the voltage across the capacitor equals 2/3 Vcc, upper comparator switches from low to high. i.e. Q = 0, the transistor Q1 = OFF ; the output is high. Diagram & waveform: (4M)

	 
7	**Explain in detail the block diagram PLL. (13M)(Apr/May 2017)** BTL2 **Answer: page 338 – 339 LIC D. Roy Choudhury** Circuit Diagram: (7M)

	 NE/SE 565 PLL Block Diagram • Center frequency of the PLL - free running frequency of the VCO, given by • fOUT = 1.2/ 4*R*1*C*1 (2M) • where R1&C1 - an external resistor & a capacitor connected to pins 8 & 9. • VCO free-running frequency fOUT adjusts externally with R1 & C1 to be at center of input frequency range. (2M) • C1 can be any value; R1 must have a value between 2 k ohms and 20 K ohms. • Capacitor C2 connected between 7 & +V. • Filter capacitor C2 should be large enough to eliminate variations in the demodulated output voltage in order to stabilize VCO frequency. (2M)
8	**Define capture range and lock range . (3M)** **Explain the process of capturing the lock and also derive for capture range and lock range.(10M)** BTL2 **Answer: page 339 – 342 LIC D. Roy Choudhury** • Lock range(Tracking range): (2M) The lock range - range of frequencies over which PLL system follows changes in input frequency fIN. • Capture range: (1M) Capture range - frequency range in which PLL acquires phase lock. • Always smaller than lock range. (1M) • If divider divides by *M*, it allows the VCO to multiply the reference frequency by *N* / *M*. • In some cases reference frequency constrains by other issues, - then reference divider - useful. (2M) • Frequency multiplication - attains by locking PLL to 'N'th harmonic of signal. (2M) • Let input to phase detector be $xc(t)$ (2M) • Output of voltage- controlled oscillator (VCO) - $xr(t)$ with frequency $\omega r(t)$. (3M)

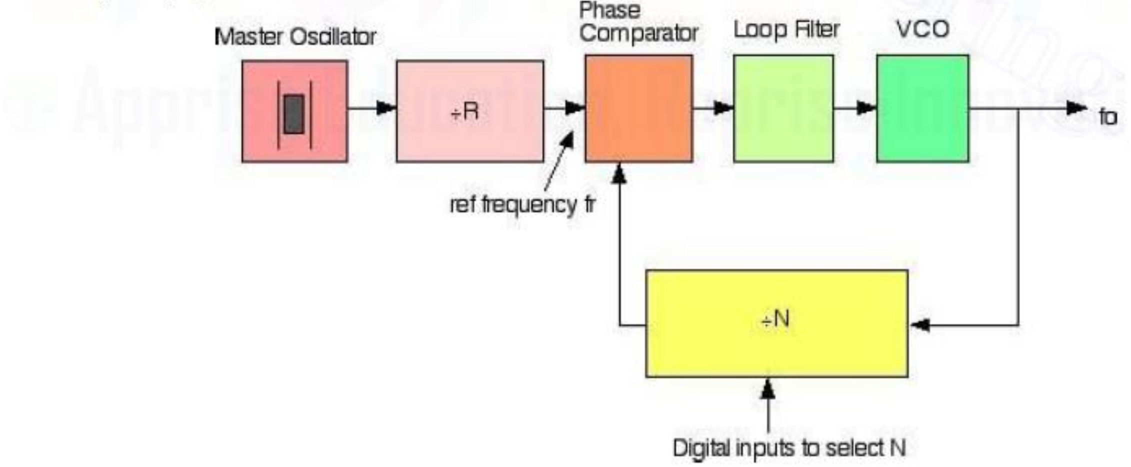
9	**Illustrate the function of 555 timer in Astable mode. (13M) (May/June 2016)** BTL4 **Derive the expression for the pulse width.** Diagram: (7M)  **Fig.5.24 Astable Multivibrator**  **Fig. 5.25 Waveforms of Astable multivibrator** Astable multivibrator, often called a free running multivibrator, is a rectangular wave generating circuit. (2M) Unlike the monostable multivibrator, this circuit does not require an external trigger to change the state of the output, hence the name free running. (2M) However, the time during which the output is either high or low is determined by 2 resistors and capacitors, which are externally connected to the 555 timer. (2M)
	PART *C
1	**Explain with neat block diagrams, how PLL is used as (i) AM Detector (5M) (ii) FM Detector (5M) (iii) Frequency synthesizer (5M) (May/June 2012)** BTL2 **Answer: page 342 – 344 LIC D. Roy Choudhury** AM Detector: (5M)



FM Detector: (5M)

- If PLL locks to a FM signal, VCO tracks instantaneous frequency of input signal.
- Filtered error voltage which controls the VCO, maintains lock with input signal to get demodulated FM output.
- VCO transfer characteristics determine linearity of demodulated output.
- Since, VCO in IC PLL - highly linear, possible to realize highly linear FM demodulators.

Frequency synthesizer: (5M)



- Ability of a frequency synthesizer to generate multiple frequencies is the divider between the output and feedback input.
- This usually in form of a digital counter, with output signal acts as a clock signal.
- The counter preset to some initial count value,
- counts down at each cycle of clock signal.
- When it reaches zero, the counter output changes state and count value reloads.

2 **a) List and define the various performance parameters of a multiplier IC. (5M) (May/June 2012).b) How the multiplier is used as voltage divider? (5M) (May/June 2012). c) How the**

multiplier is used as frequency doubler? (5M) (May/June 2012) BTL2

Answer: page 159 – 164 LIC D. Roy Choudhury

Multiplier IC figure 3.10 (5M)

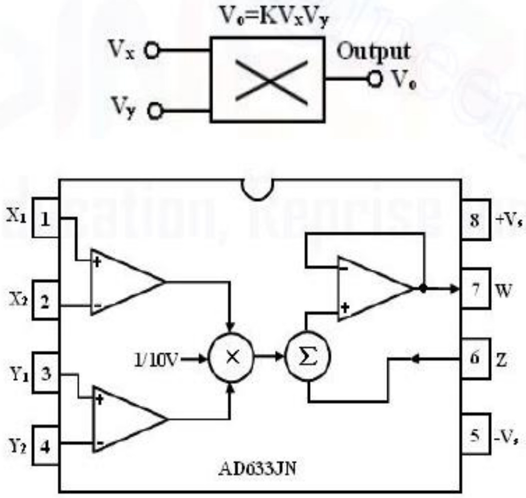


Fig. 3.10 Multiplier IC and its symbol

- Circuit whose output voltage at any instant proportional to product of instantaneous value of two individual input voltages.
- Important applications of these multipliers - multiplication, division, squaring,
- square – rooting of signals, modulation, demodulation.
- Available as integrated circuits consists of op-amps and other circuit elements.
- The Schematic of a typical analog multiplier, namely, AD633 is shown in figure.

Voltage divider figure 3.14 (5M)

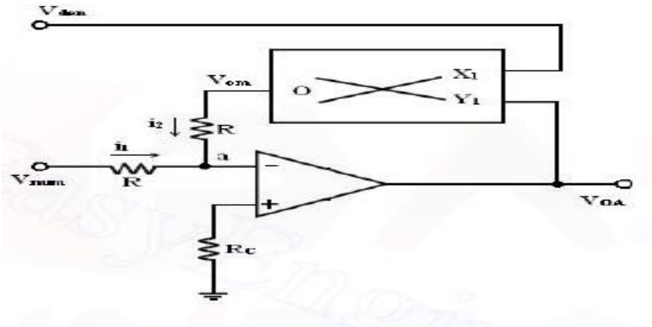


Fig 3.14 divider circuit

- No input signal current flow into nverting input terminal of op-amp, - virtual ground.
- Therefore, at the junction a, i1 +i2 =0,
- current i1 = Vnum / R, where R = input resistance.
- current i2 = Vom /R. With virtual ground existing at a,
- *i*1+*i*2 = Vnum / R + Vom /R = 0

- *KV OA V den = - V num or*
- *voA=- vnum/Kvden*
- where *Vnum* and *Vden* numerator, denominator voltages respectively.

Frequency Doubler figure 3.13 (5M)

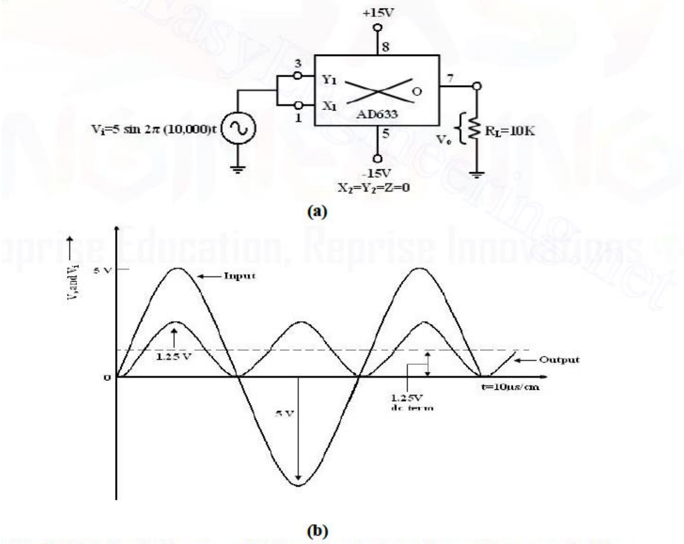


Fig. 3.13 (a) circuit diagram and (b) input –output waveform of frequency doubler

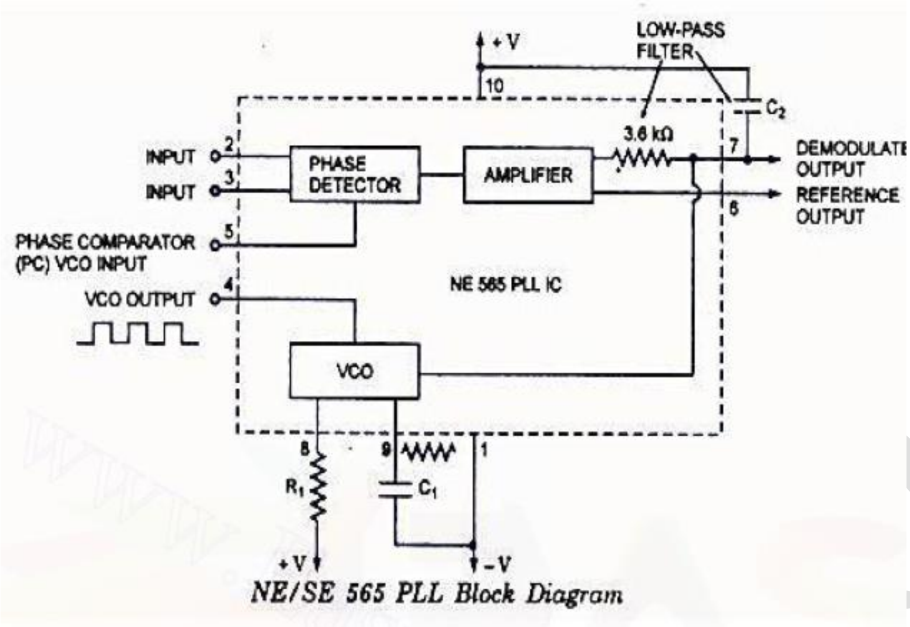
- Squaring circuit connects for frequency doubling operation.
- Sine-wave signal Vi has a peak amplitude of Av, frequency of f Hz.
- Output waveforms ripple with twice input frequency in rectified output of input signal.
- This forms principle of application of analog multiplier as rectifier of ac signals.

3

i)Discuss the principle of operation of NE 565 PLL circuit. (10M)
ii)How can PLL be modeled as a frequency multiplier.(5M) BTL4
Answer: page 337 – 338,342 - 343 LIC D. Roy Choudhury

- Center frequency of PLL - free running frequency of VCO, given by
- fOUT = 1.2/ 4*R*1*C*1 (2M)
- where R1&C1 - an external resistor & capacitor connected to pins 8 & 9.
- VCO free-running frequency fOUT adjusts externally with R1 & C1 (2M)
  C1 can be any value; R1 must have a value between 2 k ohms and 20 K ohms.
- Capacitor C2 connected between 7 & +V.

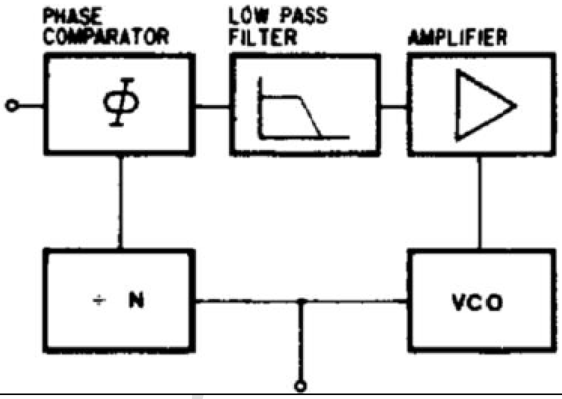
Diagram: (6M)



NE/SE 565 PLL Block Diagram

ii) Frequency multiplier (5M)

- Divide by N network
- Frequency divider insert between the VCO & phase comparator.
- Output of the divider locks to f IN.
- VCO runs at multiple of input frequency.
- Desired amount of multiplication obtains by selecting a proper divide-by-N network,
- where N is an integer.

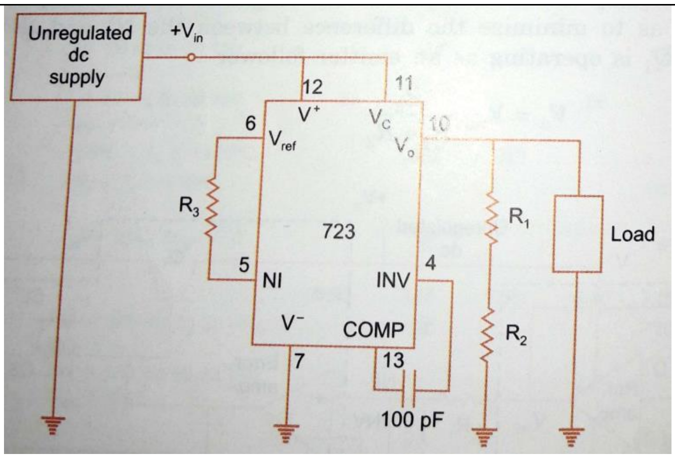
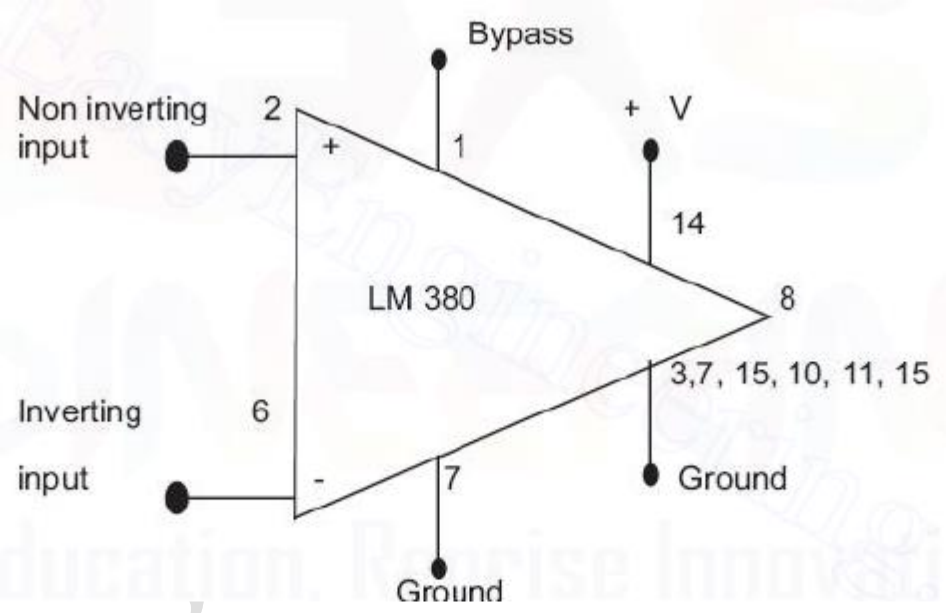


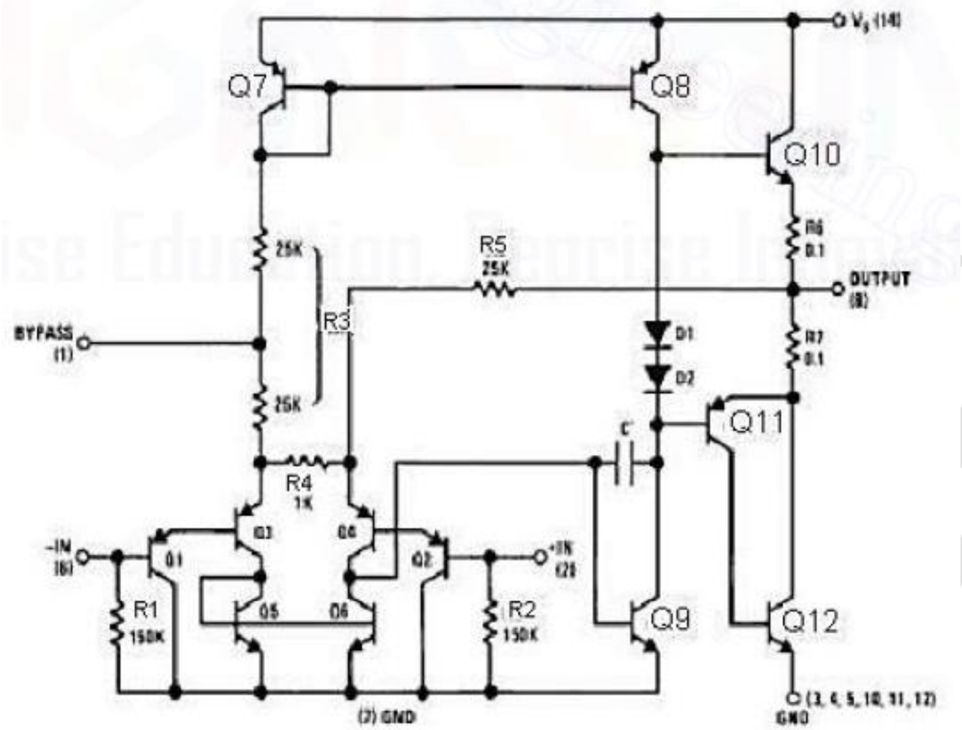
Subject Code:EE8451 **Year/Semester: II /04**
Subject Name: LIC & APPLICATIONS **Subject Handler: D.Joshua**

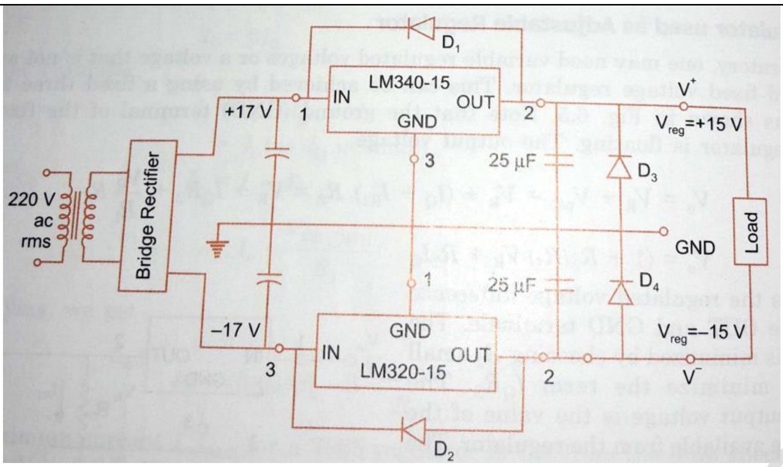
UNIT V – APPLICATION ICs	
AD623 Instrumentation Amplifier and its application as load cell weight measurement - IC voltage regulators –LM78XX, LM79XX; Fixed voltage regulators its application as Linear power supply - LM317, 723 Variability voltage regulators, switching regulator- SMPS - ICL 8038 function generator IC.	
PART * A	
Q.No.	**Questions**
1.	**What are the operating modes of a 555 timer?** BTL1 • Monostable mode • Astable mode
2	**List out the applications of 555 timer.** BTL1 • Oscillator • pulse generator • ramp and square wave generator d. mono-shot multivibrator • burglar alarm • traffic light control.
3	**Define sink current.** BTL1 When the output is low, the load current that flows through cted between Vcc and o/p terminal is called sink current.
4	**Define source current.** BTL1 When the output is high, the load current that flows through the load connected between ground and o/p terminal is called source current.
5	**What is the use of reset pin of 555 timer?** BTL1 This is an interrupt for the timing device when pin 4 is grounded, it stops the working of device and makes it off.
6	**What is the purpose of control voltage pin (5) of 555 timer?** BTL1 This pin is the inverting input terminal of comparator. This is reference level for comparator with which threshold is compared. If reference level is other than 2/3 VCC, then external input is to be given to pin 5. Pulse width modulation is possible due to pin 5.
7	**List out the major blocks in functional diagram of 555 timer.** BTL1 The IC 555 timer combines the following elements. • A relaxation oscillator • RS flip-flop • Two comparators • Discharge transistor
8	**List the types of regulators?** BTL1 • Linear regulator • Switched regulator

9	**Write the expression for pulse width of 555 timer in monostable mode.** BTL1 Pulse width W = 1.1 RC seconds R – resistor in ohms, C – capacitor in farads
10	**Write the expression for total time period of 555 timer in astable mode.** BTL1 T = 0.693 (RA + 2 RB) C seconds Where RA,RB are resistors C is capacitor
11	**What is the frequency of oscillation of free running mode of 555 timer?** BTL1 F = 1.44/ (RA + 2 RB) C Hz Where RA,RB are resistors C is capacitor
12	**List out the applications of 555 timer in astable mode.** BTL1 • missing pulse detector • Linear ramp generator • Frequency divider • Pulse width modulation.
13	**List out the applications of 555 timer in monostable mode.** BTL1 • FSK generator • Pulse-position modulator
14	**Define voltage regulators and give the types.** BTL1 • A voltage regulator is an electronic circuit that provides a stable dc voltage independent of the load current, temperature, and ac line voltage variations. • The classification of voltage regulators: Series / Linear regulators Switching regulators.
15	**What do you mean by linear voltage regulators?** BTL1 Series or linear regulator uses a power transistor connected in series between the unregulated dc input and the load and it conducts in the linear region .The output voltage is controlled by the continuous voltage drop taking place across the series pass transistor.
16	**Define switched voltage regulators.** BTL1 Switching regulators are those which operate the power transistor as a high frequency on/off switch, so that the power transistor does not conduct current continuously. This gives improved efficiency over series regulators.
17	**What are the advantages of adjustable voltage regulators over the fixed voltage regulators?** BTL1 • Improved line and load regulation by a factor of 10 or more. • Because of the improved overload protection, greater load current can be drawn. • Improved reliability.
18	**List out the parameters related to the fixed voltage regulators.** BTL1 • Line regulation • Load regulation • Ripple rejection

	• Output impedance • Maximum power dissipation • Rated output current
19	**Define dropout voltage of a fixed voltage regulator.** BTL1 It is the minimum voltage that must exist between input and output terminals. For most of regulators, it is 2 to 3 volts.
20	**What is an opto-coupler IC? Give examples.** BTL1 • Opto-coupler IC is a combined package of a photo-emitting device and a photosensing device. • Examples for opto-coupler circuit : LED and a photo diode, LED and photo transistor, LED and Darlington. • Examples for opto-coupler IC : MCT 2F , MCT 2E
21	**Mention the advantages of opto-couplers.** BTL1 • Better isolation between the two stages. • Impedance problem between the stages is eliminated. • Wide frequency response.
22	**Why do switching regulators have better efficiency then series regulators? (May/June 2012)** BTL1 In switching regulators, the transistor is operated in cut off region or saturation region. In cut off region, there is no current and hence power dissipation is almost zero. In the saturation region there is negligible voltage drop across it hence the power dissipation is almost zero.
23	**List the important parts of regulated power supply. (April/May2010)** BTL1 • Reference voltage circuit • Error amplifier • Series pass transistor • Feedback network
24	**What are the advantages of a switch mode power supplies? (April/May2010)** BTL1 • Smaller size • Lighter weight (from the elimination of low frequency transformers which have a high weight) • Lower heat generation due to higher efficiency.
25	**What are the disadvantages of linear voltage regulators? (Nov/Dec2011)** BTL1 The input step down transformer is bulky and expensive because of low line frequency. Because of low line frequency, large values of filter capacitors are required to decrease the ripple. Efficiency is reduced due to the continuous power dissipation by the transistor as it operates in the linear region.
	PART * B
1	**Explain high voltage 723 regulator with neat diagrams. (13M)** BTL2 **Answer: page 188 - 193 LIC D.Roy Choudhury** Circuit Diagram: (8M)

	 Output voltage becomes low, voltage at INV terminal goes down. (2M) Output of error amplifier to become more positive (2M) Any increase in load voltage, or changes in input voltage get regulated. (1M)
2	**Demonstrate the functional diagram of LM 380 power amplifier. (13M) (Apr/May 2015) (Apr/May 2017) (Nov/Dec 2016) (May/June 2016)** BTL4 **llustrate the essential characteristics of power amplifier.** **Answer: page 188 - 193 LIC D.Roy Choudhury** Diagram : (6M)  Circuit Diagram: (7M)

	 Features of LM380: • Internally fixed gain of 50 (34dB) • Output is automatically self centering to one half of the supply voltage. • Output is short circuit proof with internal thermal limiting. • Input stage allows the input to be ground referenced or ac • Wide supply voltage range (5 to 22V). • High peak current capability. • High impedance.
3	**Discuss the working of LM340-15 / LM320-15 with neat diagram. (13M) (Nov/Dec 2016)** BTL2 **Answer: page 247 – 248 LIC D.Roy Choudhury** Circuit Diagram: (8M)



Circuit components: (5M)

Transformer, Bridge Rectifier

3 terminal LM320 IC

Combination of diode and capacitor, Load

4

Analyze and explain the operation of switching regulator with neat diagram. (8M)

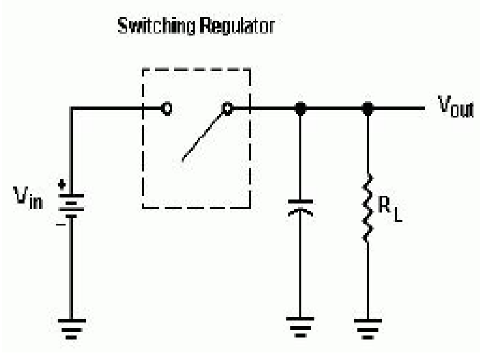
Examine the operation of frequency to voltage converters. (5M) BTL4

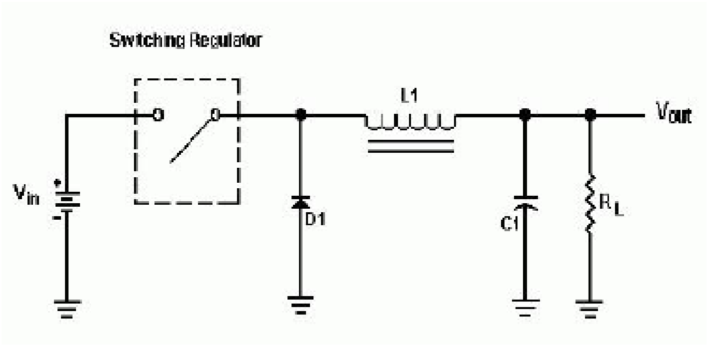
Answer: page 255 – 257 LIC D.Roy Choudhury

Switching regulator: (3M)

- Unregulated dc supply voltage at the input between 9.5V & 40V
- Adjustable regulated output voltage between 2 to 3V.
- Maximum load current of 150 mA (ILmax = 150mA).
- With the additional transistor used, ILmax upto 10A is obtainable.
- Positive or Negative supply operation
- Internal Power dissipation of 800mW.
- Built in short circuit protection.
- Very low temperature drift.
- High ripple rejection.

Diagram: (5M)





Frequency to voltage converters: (5M)

F-V convertor produces an output voltage whose amplitude is a function of input signal

frequency.
V0=kf fi kf is sensitivity of F-V convertor
It is basically a FM discriminator.

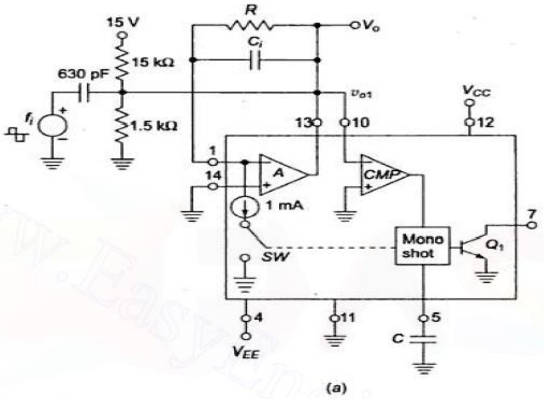


Fig.5.45 Frequency To Voltage Convertor using VFC32 (V-F)

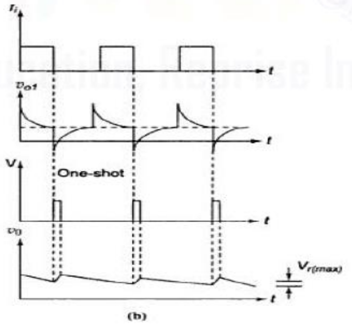
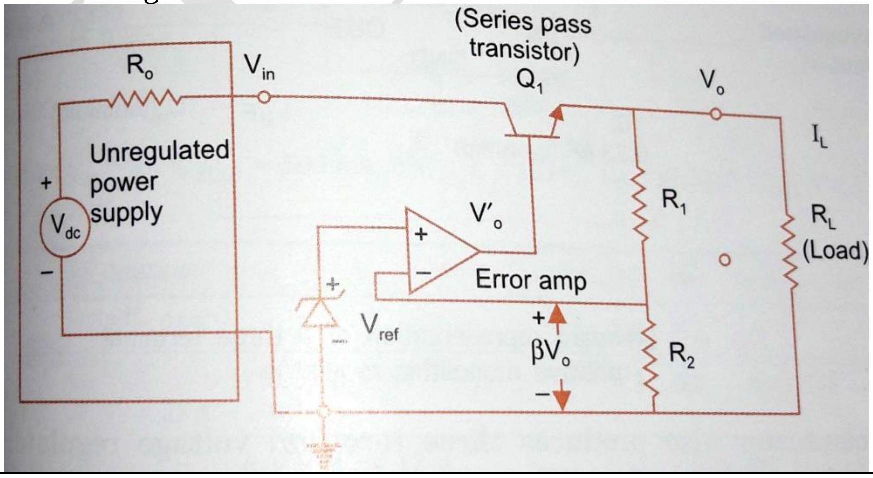


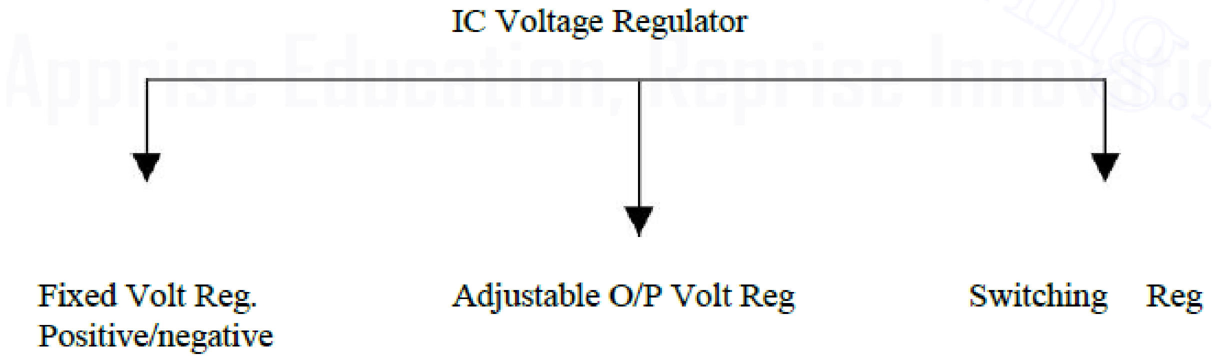
Fig.5.46 F-V Convertor using VF32 and input and output characteristics

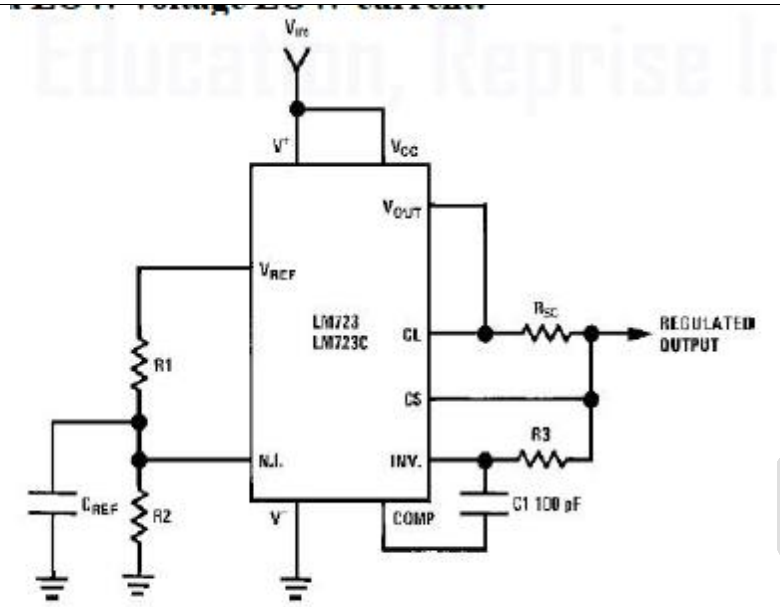
5 **Explain basic series op-amp regulator with relevant diagrams. (13M) (Apr/May 2015)** BTL2

Answer: page 240 – 241 LIC D.Roy Choudhury

Circuit Diagram: (8M)



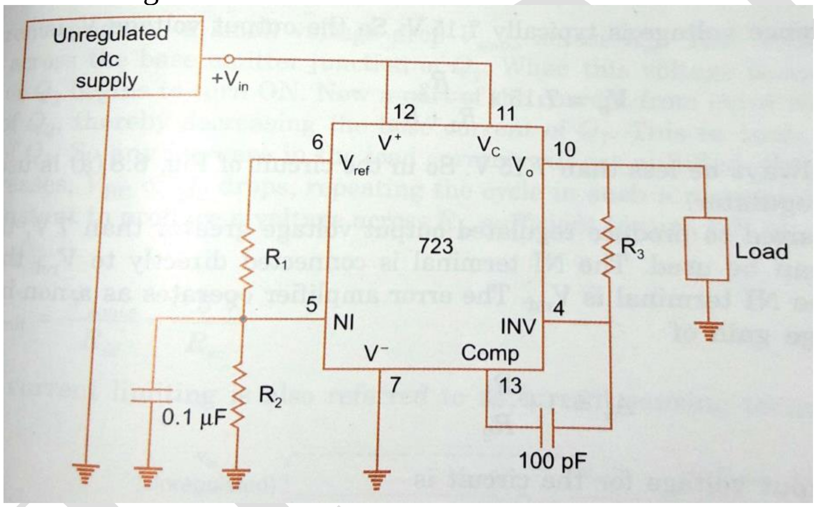
	Important parts: (5M) Reference voltage circuit Error amplifier Series pass transistor Feedback network
6	**(i)Define voltage regulator and explain the working of Linear Voltage regulator with neat circuit diagram using op-amps.(8M) (Nov/Dec 2016)** **(ii)List any two important features of linear voltage regulator IC723. (5M)** BTL1 **Answer: page 241 – 248 LIC D.Roy Choudhury** Factors affecting the output voltage: (3M) • IL (Load Current) • VIN (Input Voltage) • T (Temperature) IC Voltage Regulators: (5M) They are basically series regulators. Important features of IC Regulators: • Programmable output • Facility to boost the voltage/current • Internally provided short circuit current limiting • Thermal shutdown • Floating operation to facilitate higher voltage output  Diagram: (5M)



7 Design a low voltage regulator using IC 723 with relevant diagrams. (13M) BTL4

Answer: page 250 – 251 LIC D.Roy Choudhury

Circuit Diagram: (8M)



Output voltage becomes low, voltage at INV terminal goes down. (2M)

Output of error amplifier to become more positive (2M)

Any increase in load voltage, or changes in input voltage get regulated. (1M)

PART *C

1 **With a neat diagram explain blocks and function of IC723. (15M)** BTL4

Answer: page 248 – 251 LIC D.Roy Choudhury

Features of IC723: (9M)

Unregulated dc supply voltage at the input between 9.5V & 40V

Adjustable regulated output voltage between 2 to 3V.

Maximum load current of 150 mA (ILmax = 150mA).

With the additional transistor used, ILmax upto 10A is obtainable.

<table>
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Positive or Negative supply operation
Internal Power dissipation of 800mW.
Built in short circuit protection.
Very low temperature drift.
High ripple rejection. (6M)
Diagram:

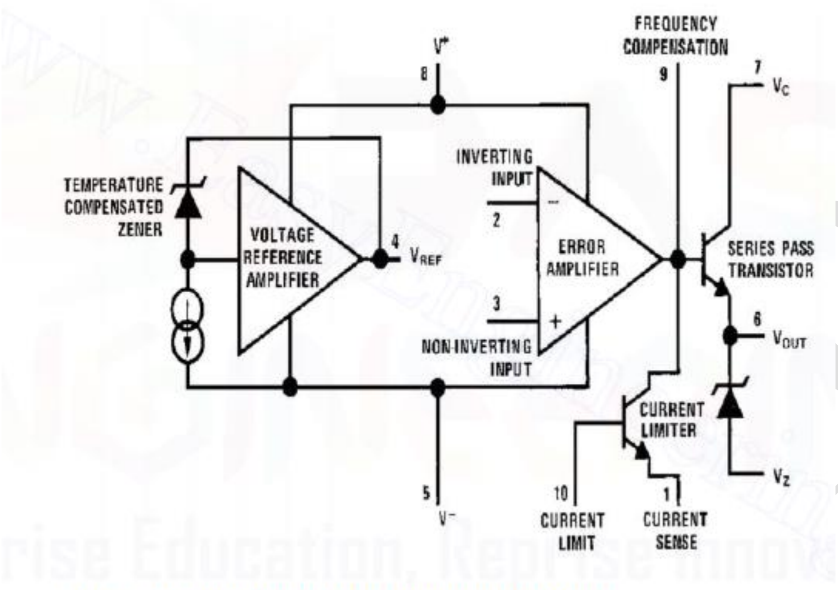

Fig. 5.29 Functional block diagram of IC723
</td>
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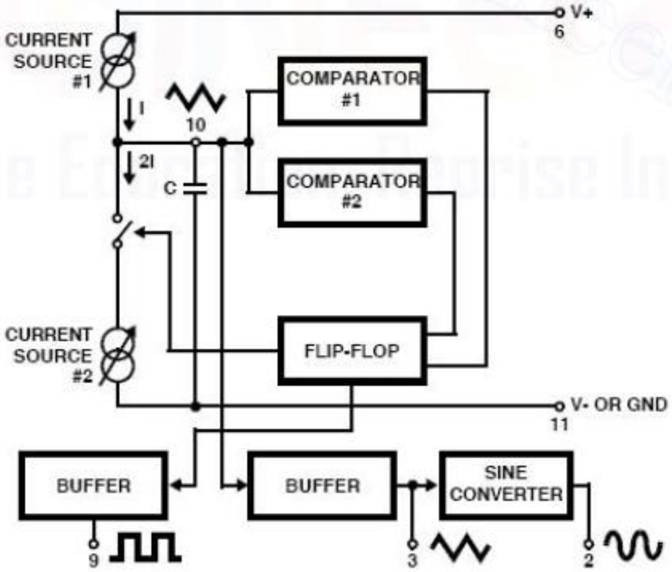
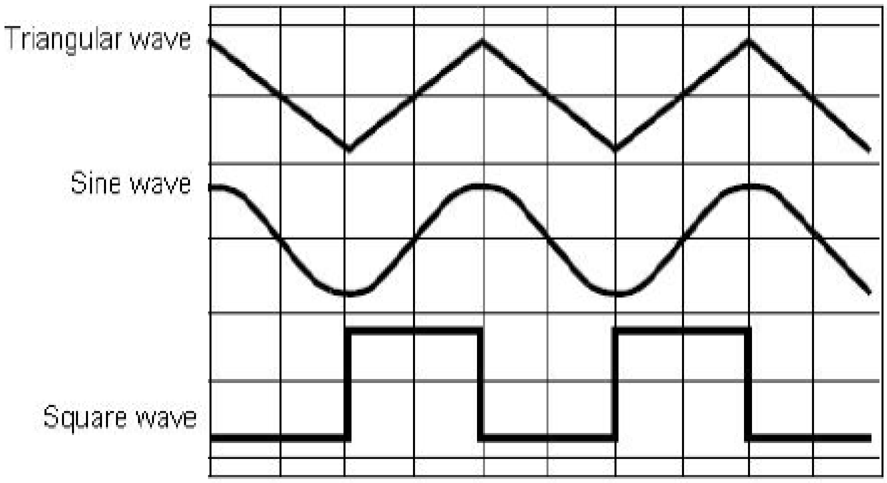
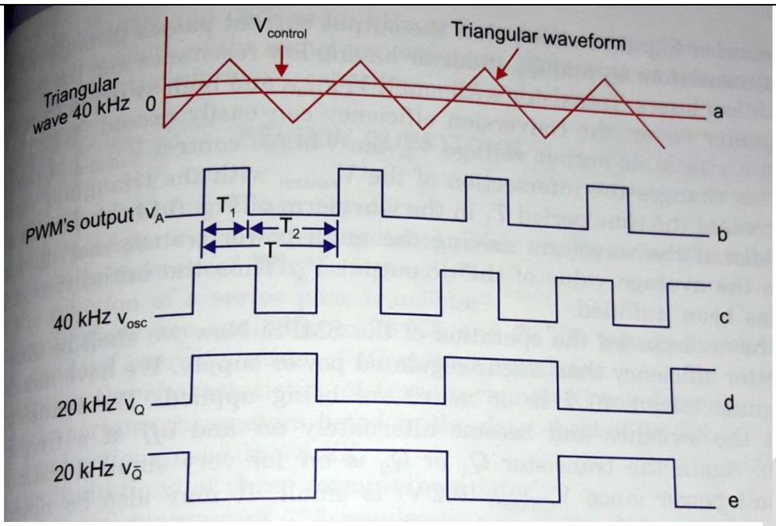
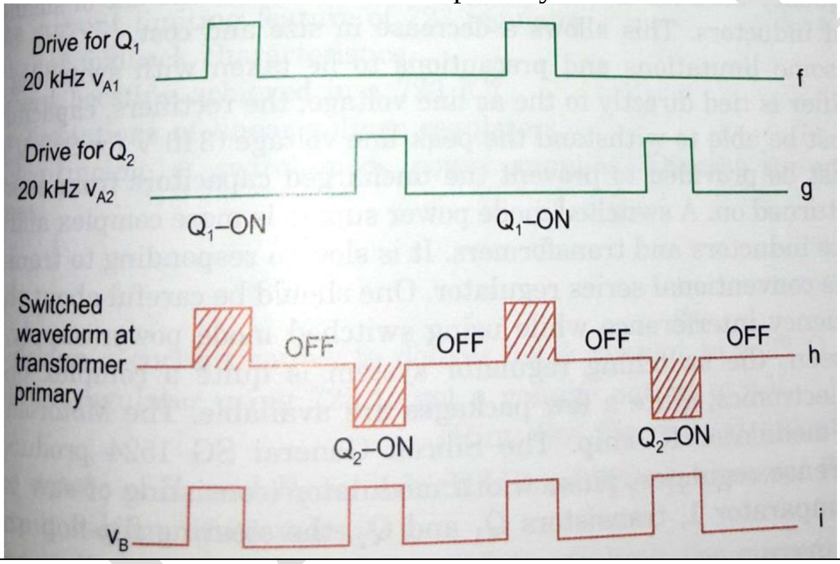
<tr>
<td>2</td>
<td>
Develop the basic principle of function generator? Draw the schematic of ICL 8038 function generator and discuss its feature.(15M) (Apr/May 2015) (Apr/May 2017) (Nov/Dec 2016) (May/June 2016)
Answer: LIC notes , Salivahanan
Diagram: (8M)
</td>
</tr>
</table>

	 Important features of IC 8038: (7M) • All the outputs are simultaneously available. • Frequency range : 0.001Hz to 500kHz • Low distortion in the output wave forms. • Low frequency drifts due to change in temperature. • Easy to use. 
3	**With neat waveforms explain the operation of switched mode power supply. (15M) (Apr/May 2015) (Apr/May 2017) (May/June 2016)** BTL2 **Answer: page 255 – 257 LIC D.Roy Choudhury** Waveform: (7M) Triangular wave, PWM’s output



Output waveform: (8M)
Drive for Q1
Drive for Q2
Switched waveform at transformer primary



IC8451 CONTROL SYSTEMS L T P C 3 0 0 3

OBJECTIVES:

- To understand the use of transfer function models for analysis physical systems and Introduce the control system components.
- To provide adequate knowledge in the time response of systems and steady state error
- Analysis.
- To accord basic knowledge in obtaining the open loop and closed–loop frequency responses of systems.
- To introduce stability analysis and design of compensators

SYLLABUS:

UNIT I SYSTEMS AND REPRESENTATION 9

Basic elements in control systems: – Open and closed loop systems – Electrical analogy of mechanical and thermal systems – Transfer function – AC and DC servomotors – Block diagram reduction techniques – Signal flow graphs.

UNIT II TIME RESPONSE 9

Time response: – Time domain specifications – Types of test input – I and II order system response – Error coefficients – Generalized error series – Steady state error – Root locus construction- Effects of P, PI, PID modes of feedback control –Time response analysis.

UNIT III FREQUENCY RESPONSE 9

Frequency response: – Bode plot – Polar plot – Determination of closed loop response from open loop response - Correlation between frequency domain and time domain specifications

UNIT IV STABILITY AND COMPENSATOR DESIGN 9

Characteristics equation – Routh Hurwitz criterion – Nyquist stability criterion- Performance criteria – Effect of Lag, lead and lag-lead compensation on frequency response-Design of Lag, lead and lag lead compensator using bode plots.

UNIT V STATE VARIABLE ANALYSIS 9

Concept of state variables – State models for linear and time invariant Systems – Solution of state and output equation in controllable canonical form – Concepts of controllability and observability.

TOTAL (L: 45+T:30): 75 PERIODS

OUTCOMES:

Upon completion of the course, the student should be able to:

- Identify the various control system components and their representations.
- Analyze the various time domain parameters.
- Analysis the various frequency response plots and its system.
- Apply the concepts of various system stability criterions.
- Design various transfer functions of digital control system using state variable models.

TEXT BOOK:

1. Nagarath, I.J. and Gopal, M., “Control Systems Engineering”, New Age International Publishers, 2017.
2. Benjamin C. Kuo, “Automatic Control Systems”, Wiley, 2014.

REFERENCES

1. Katsuhiko Ogata, “Modern Control Engineering”, Pearson, 2015.
2. Richard C.Dorf and Bishop, R.H., “Modern Control Systems”, Pearson Education,2009.

3. John J.D., Azzo Constantine, H. and Houpis Sttuart, N Sheldon, “Linear Control System Analysis and Design with MATLAB”, CRC Taylor& Francis Reprint 2009.
4. Rames C.Panda and T. Thyagarajan, “An Introduction to Process Modelling Identification and Control of Engineers”, Narosa Publishing House, 2017.
5. M.Gopal, “Control System: Principle and design”, McGraw Hill Education, 2012.
6. NPTEL Video Lecture Notes on “Control Engineering “by Prof. S. D. Agashe, IIT Bombay.

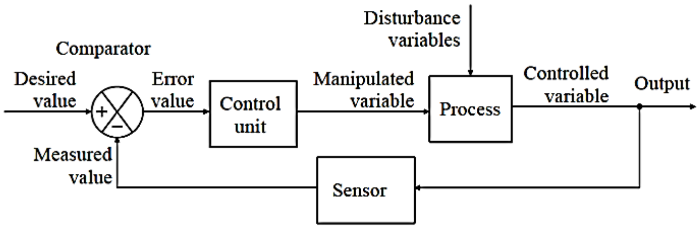
Subject Code: IC8451 **Year/Semester: II/04**
Subject Name: Control Systems **Subject Handler: Mrs. T.Muthukumari**

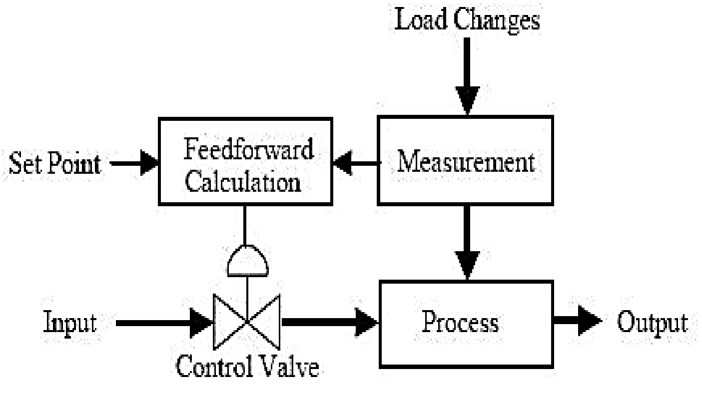
UNIT I - SYSTEMS AND THEIR REPRESENTATION

Basic elements in control systems: – Open and closed loop systems – Electrical analogy of mechanical and thermal systems – Transfer function – AC and DC servomotors – Block diagram reduction techniques – Signal flow graphs.

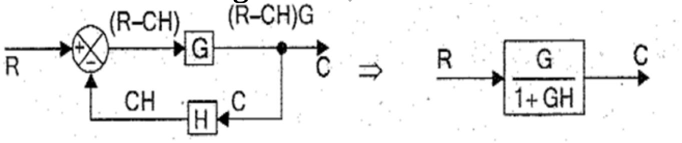
PART * A

Q.No	Questions
1.	**What is a system?** BTL1 When a group of elements or components is connected in sequence to perform a specific function, the group thus formed is called a system.
2.	**What is a control system?** BTL1 A system consists of number of components connected together to perform a specific function. In a system when the output quantity is controlled by varying the input quantity then the system is called control system. The output quantity is called controlled variable Or response and the input quantity is called command signal or excitation. Examples: Control of temperature, liquid level, velocity. Transportation systems, power systems, robotics etc.
3.	**What are the different classifications of control system?** BTL2 • Open loop control system • Closed loop control system
4.	**What are the classifications of electrical system?** BTL2 • Linear and Nonlinear system • Time invariant and Time variant system • Continuous time and Discrete time system • SISO and MIMO system • Lumped and Distributed parameter system • Deterministic and Stochastic system • Static and Dynamic system
5.	**What are the components of control system?** BTL2 The components of control system are plant, feedback path elements, error detector, and controller.

<table>
<tr><td>6.</td><td>Define open loop and closed loop control system. BTL1
The control systems in which the output quantity has no effect upon the input quantity are called open loop control system. This means that the output is not feedback to the input for correction. The control systems in which the output quantity has an effect upon the input quantity in order to maintain the desired output value are called closed loop control system.</td></tr>
<tr><td>7.</td><td>Give practical example of open loop systems. BTL1
The practical examples of open loop control systems are, sprinkler used to water a lawn, automatic toaster, traffic light controller, automatic door opening and closing system.</td></tr>
<tr><td>8.</td><td>Give practical example of closed loop systems. BTL1
The practical examples of closed loop control systems are, human being, home heating system, speed control systems, ship stabilization system, missile launching system, voltage stabilizer, temperature control systems.</td></tr>
<tr><td>9.</td><td>List the advantages of closed loop system. BTL2
Closed loop systems are accurate and reliable.
Changes in output due to external disturbances are corrected automatically.</td></tr>
<tr><td>10.</td><td>List the advantages of open loop system BTL2
The open loop system are simple and economical
The open loop system are easier to construct
Generally the open loop systems are stable</td></tr>
<tr><td>11.</td><td>Differentiate open loop and closed loop System.BTL2
<table>
<tr><th>SL no</th><th>Open loop</th><th>Closed loop</th></tr>
<tr><td>1</td><td>In accurate and unreliable</td><td>Accurate and reliable</td></tr>
<tr><td>2</td><td>Simple and economical</td><td>Complex and costly</td></tr>
<tr><td>3</td><td>Changes in output due to external disturbances are not corrected automatically</td><td>Changes in output due to external disturbances are corrected automatically</td></tr>
<tr><td>4</td><td>They are generally stable</td><td>Great efforts are needed to design a stable system</td></tr>
</table></td></tr>
<tr><td>12.</td><td>What is feedback control system? BTL1
Measure the controlled variable to determine the control strategy
The output of the plant/process is measured with the help of sensor and then given to the controller to take the proper action.
The controller compares the sensor signal with the reference signal and generate the actuating or control signal.
Controller action will be zero until the process variable meets set point.</td></tr>
<tr><td>13.</td><td>Draw the model for feedback control system. BTL2

</td></tr>
<tr><td>14.</td><td>What are the characteristics of negative feedback? BTL2 (April/May -</td></tr>
</table>

	2018,April/May -2017) The characteristics of negative feedback are as follows • Accuracy in tracking steady state value. • Rejection of disturbance signals. • Low sensitivity to parameter variations. • Reduction in gain at the expense of better stability.
15.	**What is effect of positive feedback on stability?** BTL1 The positive feedback increases the error signal and drives the output to instability. The positive feedback is used in minor loops in control systems to amplify certain internal signals or parameters.
16.	**Why negative feedback is preferred in control system?** BTL2 The negative feedback results in better stability in steady state and rejects any disturbance signals. It also has low sensitivity to parameter variations. Hence negative feedback is preferred in closed loop control system.
17.	**What is feedforward control system?** BTL1 • Measures disturbance variable to determine the control strategy. • FFC avoids the slowness of the feedback controller • In FFC, a sensor is used to detect process load changes or disturbances as they enter the system. • Sensors measure the values of the load variables, and a computer calculates the correct control signal for the existing load conditions and process set point. • Here set point is fixed in the feed forward controller**.**
18.	**Draw the model for feedforward control system.** BTL1 
19.	**What is a mathematical model? What are its different types?** BTL1 A mathematical model consists of a collection of equations describing behaviour of the system. There are two types of mathematical modelling • Input /output representations describing relations between the input and output of the system • State model describing the relations between the input ,state variable and output of the system
20.	**What is the need to study mathematical modelling of a system?** BTL2

	A control system is a collection of components to meet a required objective. In order to meet the objective, it is very useful to have a mathematical modeling of the system.
21.	**Define transfer function of the system.** BTL1 The transfer function of a system is defined as the ratio between Laplace transform of the output and Laplace transform of the input when taking initial condition as zero $TF = \frac{C(S)}{R(S)}$
22.	**What are the basic elements used for modelling of electrical system?** BTL2 • Resistor (R) • Inductor (L) • Capacitor(C)
23.	**State whether transfer function technique is applicable to nonlinear system and whether the transfer function is independent of the input of the system.** BTL2 • The transfer function technique is not applicable to nonlinear system • The transfer function of a system is independent of input and depends only on system parameters but the output of a system depends on input.
24.	**What are the basic elements used for modelling of mechanical translational system?** BTL1**(April/May- 2019)** • Mass(M) • Spring (K) • Dashpot(B)
25.	**Write the force balance equation of an ideal mass, dashpot, spring element of an mechanical translational system.** BTL1 a. F = M d2x/dt2 for mass element. b. F = B dx/dt for dashpot element. c. F = kx for spring element.
26.	**What are the basic elements used for modelling of mechanical rotational system?** BTL1 • Mass with moment of inertia J • Dashpot with rotational friction coefficient B • Torsional spring with stiffness K
27.	**Write the torque balance equation of an ideal mass,dashpot and spring element of mechanical rotational system.** BTL1 • F = M d2θ/dt2 for mass element. • F = B dθ/dt for dashpot element. • F = kθ for spring element.
28.	**Name the two types of electrical analogous for mechanical translational system.** BTL1 • Force voltage analogy • Force current analogy
29.	**Write the analogous electrical elements in force voltage analogy for the elements of mechanical translational system.** BTL1 a. Force-voltage e. b. Velocity v-current i. c. Displacement x-charge q.

	d. Frictional coefficient B-Resistance R. e. Mass M- Inductance L. f. Stiffness K-Inverse of capacitance 1/C.
30.	**Write the analogous electrical elements in force current analogy for the elements of mechanical translational system.** BTL1 a. Force-current I. b. Velocity v-voltage v. c. Displacement x-flux φ. d. Frictional coefficient B-conductance 1/R. e. Mass M- capacitance C. f. Stiffness K-Inverse of inductance 1/L.
31.	**What is Block diagram? What are its basic components?** BTL1 A block diagram of a system is a pictorial representation of the functions performed by each components of the system and shows the flow of signals. The basic elements of the block diagram are blocks, branch points, and summing points.
32.	**What is the basis for framing rules of block diagram reduction technique?** BTL1 The rules for block diagram reduction technique are framed such that any modification made on the diagram does not alter the input and output relations.
33.	**What are the basic components of block diagram representations?** BTL2 **(April/May - 2017)** • Block • Branch point • Summing point
34.	**Write the rule for elimination of negative feedback.**BTL1 
35.	**What are the disadvantages of block diagram representation?** BTL2 • It is a tedious method of calculating transfer function. • Overall gain of the system cannot be computed.
36.	**What is a signal flow graph?** BTL1 A signal flow graph is a diagram that represents a set of simultaneous linear algebraic equations. By taking Laplace, transform the time domain differential equations governing s a control system can be transferred to a set of algebraic equations in s domain. The signal flow graph of the system can be constructed using these equations,
37.	**What are the properties of signal flow graph?** BTL2 The basic properties of signal flow graph are • Signal flow graph is applicable to linear systems. • It consists of nodes and branches. A node is a point representing a variable or signal. A branch indicates functional dependence of one signal to other. • A node adds the signals of all incoming branches and transmits this sum to all other branches. • Signals travel along branches only in the marked direction and when it travels it gets multiplied by the gain or transmittance of the branch.

<table>
<tr><td></td><td>

- The algebraic equations must be in the form of cause and effect relationship.

</td></tr>
<tr><td>38.</td><td>

State Mason's Gain formula. BTL1**(April/May -2018)**

$$\text{Overall gain, } T = \frac{1}{\Delta} \sum_{K} P_K \Delta_K$$

Where Pk= Forward path gain of Kth forward path
K =Number of forward paths in the signal flow graph
Δ =1-(sum of individual loop gains)+(Sum of gain products of all possible combinations of two non-touching loop)-(sum of gain products of all possible combination of three non-touching loops)+….
Δk= Δ for that part of the graph which is not touching the Kth forward path.

</td></tr>
<tr><td>39.</td><td>

What is called servo motor? BTL1

- The motors that are used in automatic control systems are called servomotors.
- The motors are used for feedback control system are called servomotor
- It converts electrical signal into angular displacement of the shaft.

</td></tr>
<tr><td>40.</td><td>

What are the features of servomotors? BTL2

- Linear relationship between the speed and electric control signal
- Steady state stability
- Wide range of speed control
- Linearity of mechanical characteristic throughout the entire speed range
- Low mechanical and electrical inertia
- Fast response.

</td></tr>
<tr><td>41.</td><td>

What are the classifications of servomotors? BTL2

Depending on the supply required to run the motor, they are broadly classified as

- DC servo motors
- AC servo motors

</td></tr>
<tr><td>42.</td><td>

What are the applications of DC and AC servomotors? BTL2

- The DC servomotors are generally used for large power applications such as in machine tools and robotics
- The AC servomotors are best suited for low power applications such as X-Y recorders, Disk drives, tape drivers, printers etc.

</td></tr>
<tr><td>43.</td><td>

Compare AC and DC servo motor BTL2

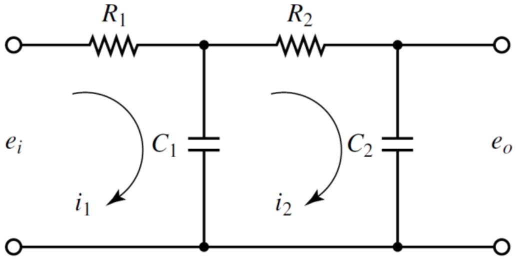
<table>
<tr><th>Sl.No</th><th>DC SERVO MOTOR</th><th>AC SERVO MOTOR</th></tr>
<tr><td>1</td><td>For small size,they deliver high output</td><td>They are designed for low power output</td></tr>
<tr><td>2</td><td>Amplifier is used for DC motor has a drift</td><td>Amplifier have no drift</td></tr>
<tr><td>3</td><td>More efficient</td><td>Efficiency is less as rotor resistance is large</td></tr>
<tr><td>4</td><td>More maintenance is required</td><td>Less maintenance</td></tr>
<tr><td>5</td><td>No slip rings. Hence slip losses are zero</td><td>Slip losses are not zero</td></tr>
</table>

</td></tr>
</table>

6	Brushes produces radio frequency interference	No radio frequency noise	

PART * B

1\. **Obtain the transfer function of the electrical network shown in figure.(13M)** BTL3



Answer: Page 1.23 to 1.24 -A.Nagoor Kani

- **Apply KCL at node 1** (2M)

$$\frac{v_1}{R_1} + C_1\frac{dv_1}{dt} + \frac{v_1 - v_2}{R_2} = \frac{e}{R_1}$$

------------------------(1)

- **Take Laplace transform of the equation(1)** (3M)

$$V_1(s)\left[\frac{1}{R_1} + sC_1 + \frac{1}{R_2}\right] - \frac{V_2(s)}{R_2} = \frac{E(s)}{R_1}$$

- **Apply KCL at node 2** (2M)

$$\frac{v_2 - v_1}{R_2} + C_2\frac{dv_2}{dt} = 0$$

------------------------(2)

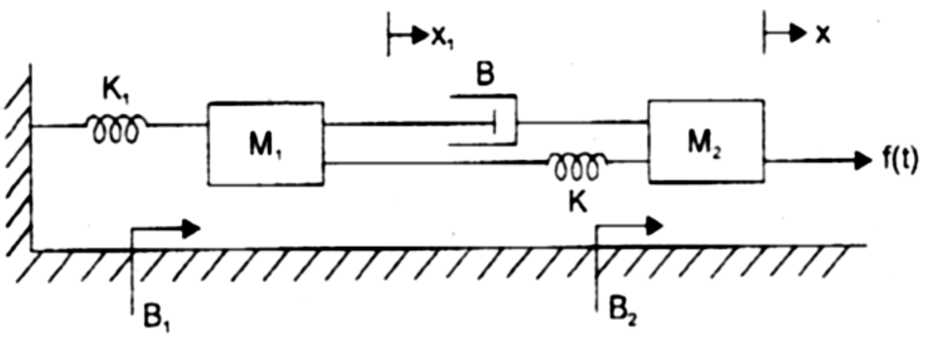
- **Take Laplace transform of the equation(2)** (3M)

$$V_1(s) = \left[1 + sC_2R_2\right].V_2(s)$$

- **Substituting $V_1(s)$ from equation(2) in equation(1) we get** (3M)

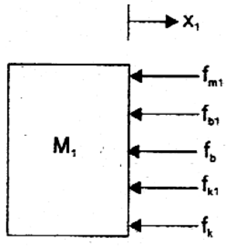
$$\frac{V_2(s)}{E(s)} = \frac{R_2}{\left[(1 + sR_2C_2).(R_1 + R_2 + sC_1R_1R_2) - R_1\right]}$$

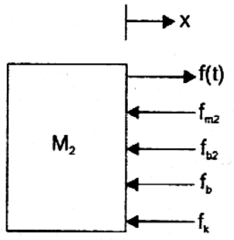
2\. **Write the differential equation governing the mechanical system shown in fig and also determine the transfer function(13M)** BTL3



Answer:Page 1.9 to 1.11- A.Nagoor Kani

- **Draw the free body diagram for mass M$_1$ and M$_2$** **(**2M)





- **Write the force balance equations for M1 and M2** (2M)

$$f_{m1} + f_{b1} + f_b + f_{k1} + f_k = 0$$

$$f_{m2} - f_{b2} + f_b + f_k = f(t)$$

- **Write the differential equations** (2M)
- **Take Laplace transform** (3M)

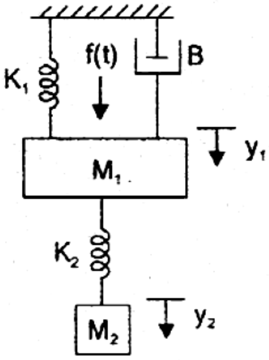
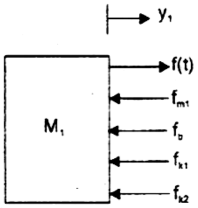
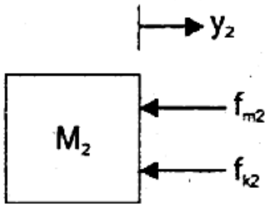
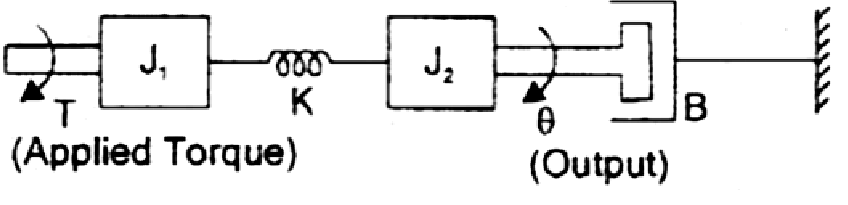
$$X_1(s) = X(s)\ \frac{Bs + K}{M_1 s^2 + (B_1 + B)\,s + (K_1 + K)}$$

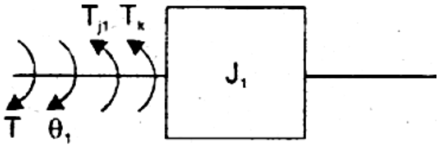
- **Rearrange the equations and find the transfer equation** (4M)

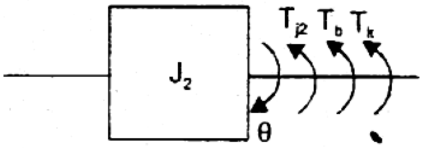
$$X(s)\,[M_2 s^2 + (B_2 + B)s + K] - X(s)\ \frac{(Bs + K)^2}{M_1 s^2 + (B_1 + B)s + (K_1 + K)} = F(s)$$

$$\frac{X(s)}{F(s)} = \frac{M_1 s^2 + (B_1 + B)\,s + (K_1 + K)}{\left[M_1 s^2 + (B_1 + B)\,s + (K_1 + K)\right]\left[M_2 s^2 + (B_2 + B)\,s + K\right] - (Bs + K)^2}$$

3. **Write the differential equation governing the mechanical system shown in fig and also determine the transfer function (13M)** BTL3

	 **Answer: Page 1.11 to 1.12 -A.Nagoor Kani** • **Draw the free body diagram for mass M_1 and M_2** (2M)   • **Write the force balance equations for M1 and M2** (3M) $f_{m2}+f_{k2}=0$ $f_{m1}+f_b+f_{k1}+f_{k2}=f(t)$ • **Write the differential equations** (2M) • **Take Laplace transform** (3M) • **Rearrange the equations and find the transfer equation** (3M) $Y_1(s)[M_1s^2+Bs+(K_1+K_2)]-Y_2(s)K_2=F(s)$ $Y_1(s)=Y_2(s)\ \frac{M_2s^2+K_2}{K_2}$ $\frac{Y_2(s)}{F(s)}=\frac{K_2}{\left[M_1s^2+Bs+(K_1+K_2)\right]\left[M_2s^2+K_2\right]-K_2^2}$
4.	**Write the differential equations governing mechanical rotational system shown in figure and find the transfer function of the system (13M)**BTL3  **Answer: Page 1.19 to 1.20 - A.Nagoor Kani** • **Draw the free body diagram** (2M)





- **Write the torque balance equations for M1 and M2** (3M)

$$T_{j1} + T_k = T$$

$$T_{j2} + T_b + T_k = 0$$

- **Write the differential equations** (2M)

$$J_1 \frac{d^2\theta_1}{dt^2} + K\theta_1 - K\theta = T$$

$$J_2 \frac{d^2\theta}{dt^2} + B\frac{d\theta}{dt} + K(\theta - \theta_1) = 0$$

- **Take Laplace transform** (3M)
- $(J_1 s^2 + K)\,\theta_1(s) - K\,\theta(s) = T(s)$
- $J_2 s^2\theta(s) + B\,s\,\theta(s) + K\theta(s) - K\theta_1(s) = 0$
- **Rearrange the equations and find the transfer equation** (3M)
- $$\therefore \frac{\theta(s)}{T(s)} = \frac{K}{(J_1 s^2 + K)\,(J_2 s^2 + Bs + K) - K^2}$$

5.

Write the differential equations governing the mechanical system shown in figure. Draw the force voltage and force current electrical analogous circuits and verify by writing mesh and node equations.(13M) BTL3 **(April/May -2018)**

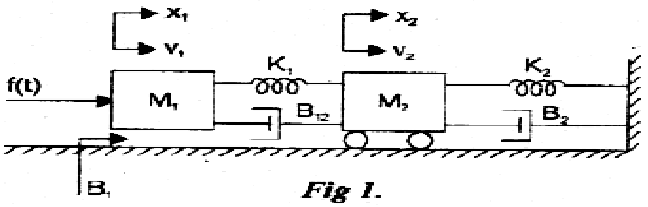
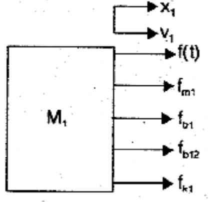
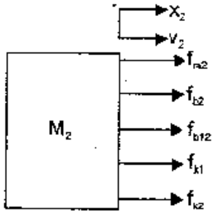


Fig 1.

Answer: Page 1.32 to 1.33 - A.Nagoor Kani

- **Draw the free body diagram** (1M)





- **Write the force balance equations** (1M)

$f_{m1} + f_{b1} + f_{b12} + f_{k1} = f(t)$ $\qquad$ $f_{m2} + f_{b2} + f_{k2} + f_{b12} + f_{k1} = 0$

- **Write the differential equations** (1M)

$$M_1 \frac{d^2x_1}{dt^2} + B_1 \frac{dx_1}{dt} + B_{12} \frac{d}{dt}(x_1 - x_2) + K_1(x_1 - x_2) = f(t)$$

- **Replacing the Displacements by velocity in the differential equations** (1M)

$$M_1 \frac{dv_1}{dt} + B_1 v_1 + B_{12}(v_1 - v_2) + K_1 \int (v_1 - v_2)\, dt = f(t)$$

- **Write the differential equations** (1M)

$$M_2 \frac{d^2x_2}{dt^2} + B_2 \frac{dx_2}{dt} + K_2 x_2 + B_{12} \frac{d}{dt}(x_2 - x_1) + K_1(x_2 - x_1) = 0$$

- **Replacing the Displacements by velocity in the differential equations** (2M)

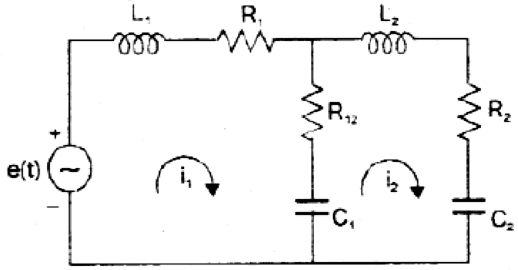
$$M_2 \frac{dv_2}{dt} + B_2 v_2 + K_2 \int v_2\, dt + B_{12}(v_2 - v_1) + K_1 \int (v_2 - v_1)\, dt = 0$$

Force voltage analogy**(3M)**

$f(t) \rightarrow e(t)$	$M_1 \rightarrow L_1$	$B_1 \rightarrow R_1$	$K_1 \rightarrow 1/C_1$
$v_1 \rightarrow i_1$	$M_2 \rightarrow L_2$	$B_2 \rightarrow R_2$	$K_2 \rightarrow 1/C_2$
$v_2 \rightarrow i_2$		$B_{12} \rightarrow R_{12}$	

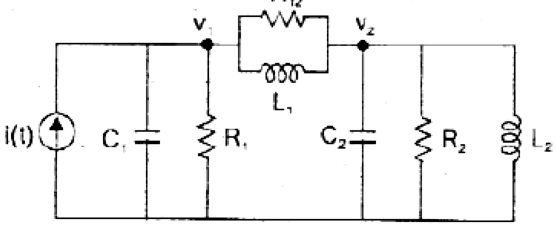
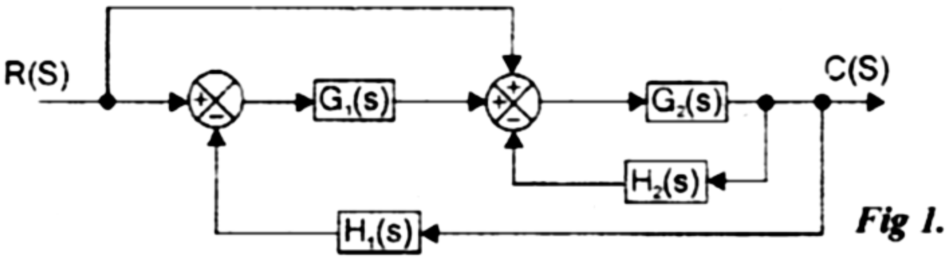
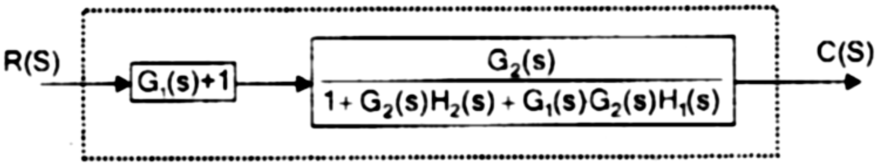
$$L_1 \frac{di_1}{dt} + R_1 i_1 + R_{12}(i_1 - i_2) + \frac{1}{C_1} \int (i_1 - i_2) dt = e(t)$$

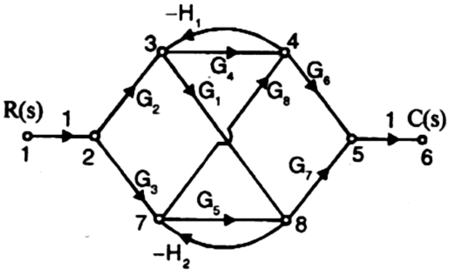
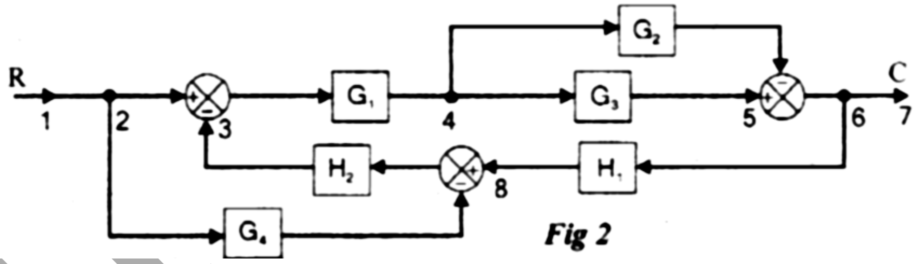
$$L_2 \frac{di_2}{dt} + R_2 i_2 + \frac{1}{C_2} \int i_2\, dt + R_{12}(i_2 - i_1) + \frac{1}{C_1} \int (i_2 - i_1) dt = 0$$

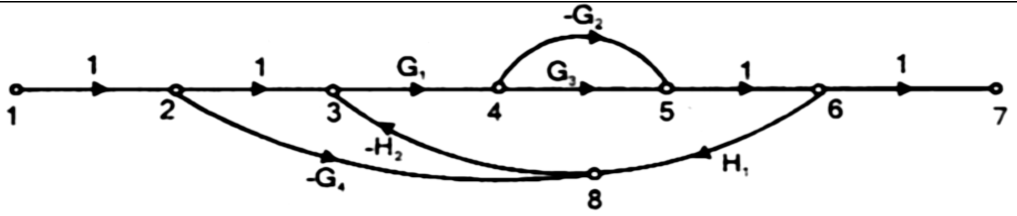


Force current analogy(3M)

$f(t) \rightarrow i(t)$	$M_1 \rightarrow C_1$	$B_1 \rightarrow 1/R_1$	$K_1 \rightarrow 1/L_1$
$v_1 \rightarrow v_1$	$M_2 \rightarrow C_2$	$B_2 \rightarrow 1/R_2$	$K_2 \rightarrow 1/L_2$
$v_2 \rightarrow v_2$	$B_{12} \rightarrow 1/R_{12}$		

	$C_1\frac{dv_1}{dt}+\frac{1}{R_1}v_1+\frac{1}{R_{12}}(v_1-v_2)+\frac{1}{L_1}\int(v_1-v_2)dt=i(t)$ $C_2\frac{dv_2}{dt}+\frac{1}{R_2}v_2+\frac{1}{L_2}\int v_2dt+\frac{1}{R_{12}}(v_2-v_1)+\frac{1}{L_1}\int(v_2-v_1)dt=0$ 
6.	**Using block diagram reduction technique find the closed loop transfer function of the system shown in figure.(13M)** BTL3 **(April/May -2018)**  ***Fig 1.*** **Answer: Page 1.76 to 1.77 - A.Nagoor Kani** • **Step 1:Spilitting the summing point** (1M) • **Step 2:Eliminating the feedback path** (2M) • **Step 3:Moving the summing point after the block** (2M) • **Step 4:Interchanging the summing point and combining the blocks in cascade** • (2M) • **Step 5:Eliminating the feedback path and feed forward path** (1M) • **Step 6:Combining the blocks in cascade** (2M) • **The transfer function of the system is given by**  $\frac{C(s)}{R(s)}=\frac{G_2(s)\left[G_1(s)+1\right]}{1+G_2(s)\,H_2(s)+G_1(s)\,G_2(s)\,H_1(s)}$ (3M)
7.	**Find the overall gain of the system whose signal flow graph shown in figure.12M** BTL3 (13M)

	 **Answer: Page 1.87 to 1.89 - A.Nagoor Kani** **Step 1:Forward path Gains** (2M) **Step 2:Individual Loop gain** (4M) **Step 3:Gain products of two non-touching loops** (4M) **Step 4.Calclualtion of Δ and Δk** (3M) $T = \frac{1}{\Delta}\left(\sum_{K} P_K \Delta_K\right)$ (Number of forward paths is six and so K = 6) $= \frac{1}{\Delta}(P_1\Delta_1 + P_2\Delta_2 + P_3\Delta_3 + P_4\Delta_4 + P_5\Delta_5 + P_6\Delta_6)$ $= \frac{G_2G_4G_6(1+G_5H_2)+G_3G_5G_7(1+G_4H_1)+G_1G_2G_7+G_3G_6G_8 - G_1G_3G_7G_8H_1 - G_1G_2G_6G_8H_2}{1+G_4H_1+G_5H_2-G_1G_8H_1H_2+G_4G_5H_1H_2}$
8.	**Draw a signal flow graph and evaluate the closed loop transfer function of a system whose block diagram is shown in figure.(13M)** BTL3  *Fig 2* **Answer: Page 1.99 to 1.101 - A.Nagoor Kani** • **Draw the signal flow graph for the given block diagram by assigning nodes.** • (3M)



Step 1:Forward path gains (2M)

Step 2:Individual loop gain (2M)

Step 3:Gain products of Two Non-touching loops (2M)

Step 4:Calculation of Δ and Δk (2M)

Step 5:Transfer function: (2M)

$$= \frac{G_1(G_3-G_2)+G_1G_4H_2(G_3-G_2)}{1+G_1H_1H_2(G_3-G_2)} = \frac{G_1(G_3-G_2)(1+G_4H_2)}{1+G_1H_1H_2(G_3-G_2)}$$

9.

Derive the transfer function of AC servomotor in control system.(13M)BTL3

Answer: Page 2.29 - A.Nagoor Kani

Definition of Servomotor :- (2M)

1. Motor used for feedback control systems are called servomotors. It is also called automatic control system.
2. Converts electrical system into angular motion.
3. 2 types: DC servomotor and AC servomotor.

Definition of AC Servomotor :- (3M)

1. Motor which runs at zero speed as its base speed is driven by error signal with AC supply is called servomotor.
2. Used in closed loop servo systems, high-speed instrument servos, and low power applications.
3. Speed control done using armature voltage control and field control.

Operating principle of AC Servomotor (4M)

Salient features include rugged construction, Reliable in operation, Light Weight and No Slip rings.

Transfer function derivation (4M)

Ө(s)/Vc2(s)=Km/s(1+stm)

PART *C

1.

Convert the given block diagram shown in fig. to signal flow graph and determine the closed loop transfer function C(s)/R(s) and verify by block diagram reduction approach. (15M)BTL3

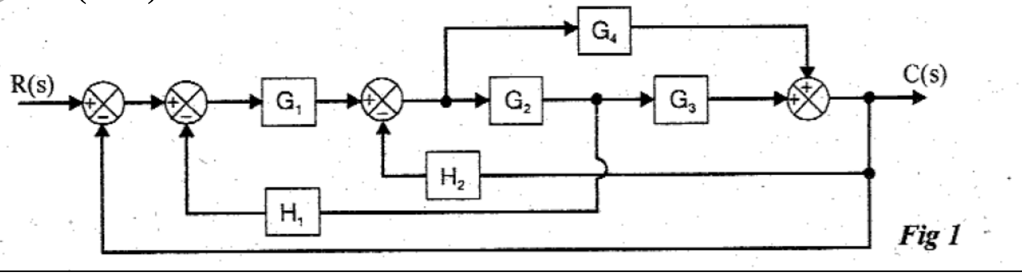
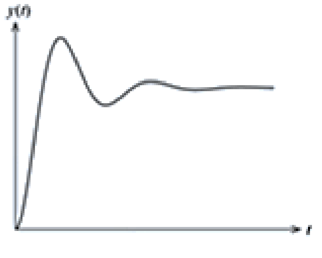
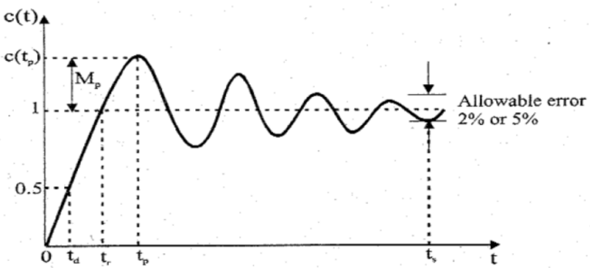


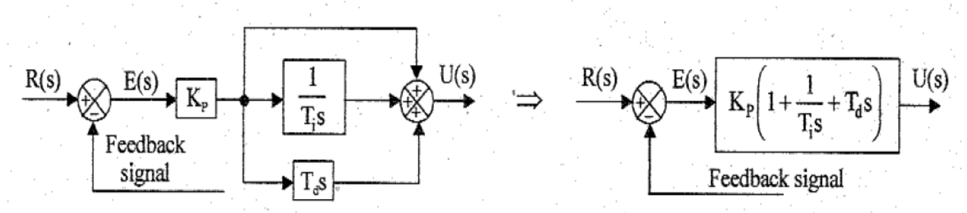
Fig 1

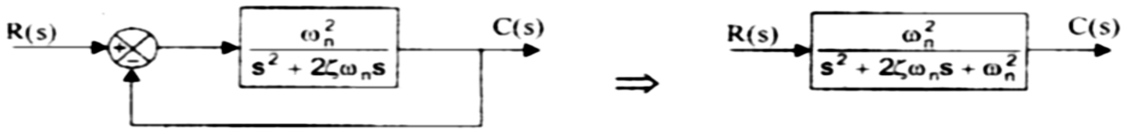
	Answer: Page 1.95 to 1.97 - A.Nagoor Kani • Draw the signal flow graph. • Give the numbering to input, output, summing point and branching point • Find the transfer function using masons gain formula **Step 1:Forward path gains**(2M) **Step 2:Individual loop gain** (2M) **Step 3:Gain products of Two Non-touching loops** (2M) **Step 4:Calculation of Δ and Δk** (2M) **Step 5:Transfer function:** (2M) • Apply block diagram reduction rules to find transfer function • Find transfer function (5M) $T = \frac{G_1G_2G_3 + G_1G_4}{1 + G_1G_2G_3 + G_1G_2H_1 + G_2G_3H_2 + G_1G_4 + G_4H_2}$
2.	**What are the basic elements of mechanical rotational and translational systems? Write its torque balance and force balance equations.(15M)** BTL1 **Answer: Page 1.7 to 1.9 and 1.17-1.19 - A.Nagoor Kani** • **Elements of mechanical system** (2M) 1. Mass(M), Dashpot(B), Spring(K) 2. Moment of inertia (J), Dashpot(F), Spring(K) • **Draw the free body diagram** (2M) • **Apply Newton's second law** (1M) • **Write differential equations** (2M) 1. $F(t)= M\ d^2\theta/dt^2 + B\ d\theta/dt+k\theta$ 2. $T(t)= M\ d^2\theta/dt^2 + B\ d\theta/dt+ k\theta$ • **Force balance equation of translational system** (4M) F = M d^2x/dt2 for mass element. F = B dx/dt for dash pot element. F = kx for spring element. • **Force balance equation of rotational system** (4M) 1. Mechanical Rotational system can be obtained using three basic elements Moment of Inertia (J), Spring (K), Damper (B). 2. F = M d2θ/dt2 for mass element. 3. F = B d θ /dt for dash pot element. 4. F = k θ for spring element. • **Torque-voltage rule:** 1. Angular Velocity v-current i. 2. Angular Displacement x-charge q. 3. Frictional coefficient F-Resistance R. 4. Mass J- Inductance L. 5. Stiffness K-Inverse of capacitance 1/C. • **Torque -current rule:**

	1. Angular Velocity v-voltage v. 2. Angular Displacement x-flux φ. 3. Frictional coefficient F conductance 1/R. 4. Mass J- capacitance C.
	UNIT II – TIME RESPONSE ANALYSIS
	Time response: – Time domain specifications – Types of test input – I and II order system response –Error coefficients – Generalized error series – Steady state error – Root locus construction- Effects of P, PI, PID modes of feedback control –Time response analysis
	PART * A
Q.No	**Questions**
1.	**What is time response analysis?**BTL1 The time response of the system is the output of the closed loop system as a function of time. It is denoted by C(t).The time response can be obtained by solving the differential equation governing the system.
2.	**What is the need for time domain analysis?** BTL2 Most of the control system use time as the independent variable, so it is important to analyze the response given by the system for the applied excitation, which is the function of the time.
3.	**Define transient and steady state response** BTL1 **The transient response** The response of the system when the input changes from one state to another **Steady state response** Response of the system when time t approaches infinity
4.	**What are the standard tests signals employed for time domain studies?**BTL1 • Step signal, Unit step signal • Ramp signal, Unit ramp signal • Parabolic signal, Unit parabolic signal • Impulse signal • Sinusoidal signal
5.	**Define damping ratio** BTL1 The damping ratio is defined as the ratio of actual damping to the critical damping
6.	**Define order of a system** BTL 1 • Order of the differential equation governing the system. • If the system is governed by nth order differential equation then the system is called nth order system.
7.	**Classify the system based on the value of damping?** BTL2**(April/May -2018)** Case(i):Undamped system $\delta=0$ Case(ii):Critically damped system $\delta=1$ Case(iii):Under damped system $0<\delta<1$ Case(iv):Over damped system $\delta>1$
8.	**What will be the nature of the response of the second order system with different types of damping?** BTL2

	• For undamped system the response is oscillatory • For under damped system the response is damped oscillatory • For critically damped system the response is exponential rising • For over damped system the response is exponentially rising but the rise time will be very large
9.	**Sketch the response of a second order under damped system?** BTL2  (0< ζ < 0) underdamped
10.	**What is damped frequency of oscillation?** BTL1 In underdamped system, the response is damped oscillatory. The frequency of damped oscillation is given by $\omega_d = \omega_n\sqrt{1-\delta^2}$
11.	**What is the effect of adding a pole to a second order system?** BTL2 The second order system is generally stable. If a pole is added to it, it becomes third order due to which it becomes less stable in nature. It increases peak overshoot and settling time.
12.	**What is type number of the system?**BTL2 The type number is given by number of poles of loop transfer function at the origin.The type number of the system decides the steady state error.
13.	**What is type 0 and type 1 system?** BTL2 The value of N in the denominator polynomial of loop transfer function decides the type number of the system N- Number of poles at origin. • N = 0, then the system is type 0 system, • N = 1, the system is type 1 system. • N = 2, then the system is type 2 system and so on.
14.	**What is the difference between type and order of the system** BTL2 Type number indicates the number of poles at the origin whereas the order of the system indicates the order of the differential equation governing the dynamics of the system.
15.	**What are static error constants ?** BTL1 The Kp,Kv,Ka are called static error constants**.** **Positional error constant,** $K_p = \underset{s \to 0}{Lt}\ G(s)\,H(s)$ **Velocity error constant,** $K_v = \underset{s \to 0}{Lt}\ s\,G(s)\,H(s)$ **Acceleration error constant,** $K_a = \underset{s \to 0}{Lt}\ s^2G(s)\,H(s)$
16.	**Outline the time domain specifications.** BTL2 The transient response characteristics of a control system to a unit step input is specified in terms of the following specifications

	• Delay time td • Rise time tr • Peak time tp • Maximum overshoot Mp • Settling time ts
17.	**Draw the unit step response curve for the second order system and show the time domain specifications.** BTL2 
18.	**Write the definition for peak overshoot?** BTL1 **(April/May -2017)** Maximum overshoot (M_p) is straight way difference between the magnitude of the highest peak of time response and magnitude of its steady state. Maximum overshoot is expressed in term of percentage of steady-state value of the response.
19.	**Define peak time.** BTL1 The time at which the peak overshoot occurs in the time response of a second order system is called a peak time.
20.	**How would you define rise time?** BTL 1 It is the time required for the response to rise from 10% to 90% of the final value for over damped systems and 0 to 100% of the final value for under damped systems. The rise time is reciprocal of the slope of the response at the instant, the response is equal to 50% of the final value.
21.	**How can the maximum overshoot of a system be decreased without affecting the steady state error?** BTL2 With the use of PD i.e. proportional plus derivative controller, it can be observed that transient response and value of damping ratio increases without affecting steady state error. As damping ratio increases, the maximum overshoot decreases. So, using PD controller it is possible to decrease maximum overshoot without affecting the steady state error.
22.	**Define steady state error.**BTL1**(April/May -2018)** The steady state error is the value of error signal e(t) when t tends to infinity.The steady state error is a measure of system accuracy.These errors arise from the nature of inputs,type of the system and from the non-linearity of the system components.
23.	**What are generalized error coefficients?**BTL1 They are coefficients of generalised error series.The generalised error series is given by $$e_{ss} = \underset{t\to\infty}{Lt}\left[r(t)\,C_0 + \dot{r}(t)\,C_1 + \ddot{r}(t)\,\frac{C_2}{2!} + \dddot{r}(t)\,\frac{C_3}{3!} + \dots + \overset{n.}{r}(t)\,\frac{C_n}{n!} + \dots \right]$$
24.	**State the advantages of generalized error coefficients. BTL 2** • It gives variation of error as a function of time. • It uses any input other than the standard input.

	• As variation of error as a function of time is available, the design of the system becomes easy and optimum
25.	**What is the function of controller?** BTL1 A controller accepts error as its input, manipulates the error according to the requirement of the system, and gives output to the plant or the process to be controlled.
26.	**What did you infer when a proportional controller is introduced in a system?**BTL2 The following aspects of the system behavior are improved by increasing the loop gain • Steady state tracking accuracy • Disturbance signal rejection • Relative stability The drawback of the P controller is, it produces the constant the steady state error.
27.	**Draw the transfer function model for PID control** BTL2 
28.	**Mention the characteristics of PI controller.** BTL2 • The advantages of both P and I controller are combined in PI controller • The proportional action increases the loop gain and makes the system less sensitive to variations of system parameter. • The integral action eliminates or reduces the steady state error
29.	**Why derivative controller is not used in the control system?** BTL2 The derivative controller acts only during transient period when the error varies with time and does not produce any corrective action for a constant error as derivative of a constant error is zero. Hence the derivative controller is never used alone but always used along with some other type of controller.
30.	**What is the effect of PI controller on the system performance?** BTL 2**(April/May-2019)** The PI controller increases the order of the system by one, which results in reducing, the steady state error. But the system becomes less stable than the original system.
31.	**What is root locus?** BTL1 The path taken by a root locus of characteristics equation when open loop gain K is verified from 0 to infinity is called root locus.
32.	**How will you find root locus on real axis?** BTL2 To find the root locus on real axis, choose a test point on real axis. If the total number of poles and zeros on the real axis to the right of this test point is odd number, then the test point lies on the root locus. If it is even then the test point does not lie on the root locus.
33.	**What are asymptotes? How will you find the angle of asymptotes?** BTL1 Asymptotes are straight lines which are parallel to the root locus going to infinity and meet the root locus at infinity. Angle of Asymptotes $= \frac{\pm 180°(2q+1)}{n-m}; q = 0,1,2,....(n-m)$
34.	**What is centroid?How the centroid is calculated?** BTL1

	The meeting point of asymptotes with real axis is called centroid. The centroid is given by **Centroid=** $= \dfrac{\text{Sum of poles-Sum of zeros}}{n-m}$
35.	**How will you find the value of gain K at a point on a root locus?**BTL1 The gain K at a point S=Sa on root locus is given by $= \dfrac{\text{Product of lenth of vector from open loop poles to the point Sa}}{\text{Product of lenth of vector from open loop zeros to the point Sa}}$
36.	**What is breakaway and break-in points? How to determine them?** BTL1 At breakaway points, the root locus breaks from the real axis to enter into the complex plane. At break-in point, the root locus enters the real axis from the complex plane. To find the breakaway or break in points from an equation for K from the characteristics equation and differentiate the equation of K with respect to S.Then find the roots of equation dK/ds=0.The roots of dK/ds are breakaway or break-in points ,provided for this value of gain K should be positive and real.
37.	**How to find the crossing points of root locus in imaginary axis?** BTL1 By Routh Hurwitz criterion
	PART * B
Q.No	**Questions**
1.	**Draw the block diagram of second order system. Classify it.Derive the time response of any one of the damped system for unit step input.(13 M)** BTL2 **(April/May -2017)** **Answer: Page 3.9 to 3.16 - A.Nagoor Kani** - **Block diagram of second order system** (3M)  - **Classification of second order system based on damping ratio** (3M) Case(i):Undamped system δ=0 Case(ii):Critically damped system δ=1 Case(iii):Under damped system 0<δ<1 Case(iv):Over damped system δ>1 - **Derivation of time response** (7M) Consider the unit step signal as an input to the second order system. Laplace transform of the unit step signal is, $R(s) = \frac{1}{s}$ We know the transfer function of the second order closed loop control system is, $\frac{C(s)}{R(s)} = \frac{\omega_n^2}{s^2+2\delta\omega_n s+\omega_n^2}$

Substitute, $\delta = 0$ in the transfer function.

$$\frac{C(s)}{R(s)} = \frac{\omega_n^2}{s^2 + \omega_n^2}$$

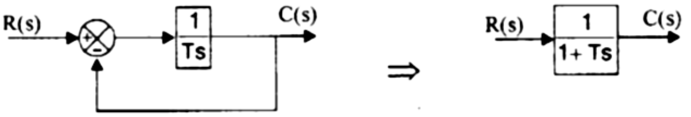
$$\Rightarrow C(s) = \left(\frac{\omega_n^2}{s^2 + \omega_n^2}\right) R(s)$$

2.

Derive the time response of first order system for unit step input and ramp input(13M) BTL2 **(April/May -2018)**

Answer: Page 3.8 to 3.9 - A.Nagoor Kani

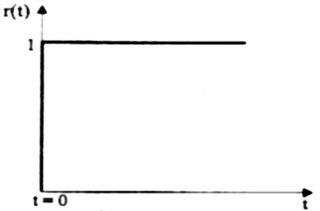
- **Block diagram of first order system** (3M)



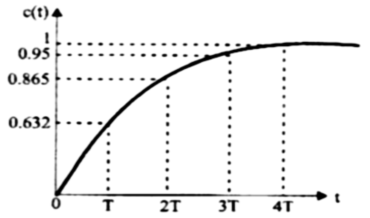
Closed loop for first order system.

- **Derivation of time response for step input and its graph** (5M)

$$c(t) = \mathcal{L}^{-1}\{C(s)\} = \mathcal{L}^{-1}\left\{\frac{1}{s} - \frac{1}{s+\frac{1}{T}}\right\} = 1 - e^{-\frac{t}{T}}$$



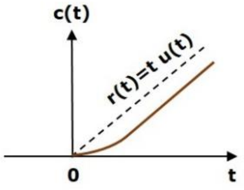
Unit step input.



Response for Unit step input.

- **Derivation of time response for ramp input** (5M)

$$c(t) = t - T(1 - e^{-t/T})$$



3.

With a neat block diagram and derivation explain how PI,PD and PID compensation will improve the time response of a system(13M) BTL1 **(April/May -2018)**

Answer: Page 3.21 to 3.23 - A.Nagoor Kani

Controllers (3M)

A controller is a device introduced in the system to modify the error signal and to produce a control signal.

The controller modifies the transient response of the system.

The following six basic control actions are very common among industrial analog controllers

- Two position or ON-OFF control action
- Proportional control action
- Integral control action
- Proportional plus integral control action
- Proportional plus derivative control action
- Proportional plus integral plus derivative control action.

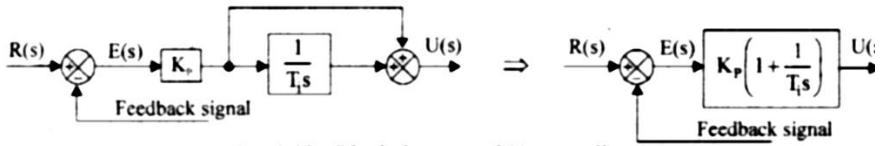
Response with PI controller (3M)

- Output signal consisting of two terms: one proportional to error signal and the other proportional to the integral of error signal

In PI - controller, $u(t) \; \alpha \; \left[e(t) + \int e(t)\,dt\right]$; $\quad \therefore u(t) = K_p\, e(t) + \frac{K_p}{T_i}\int e(t)dt$

$$U(s) = K_p\, E(s) + \frac{K_p}{T_i}\,\frac{E(s)}{s}$$

$$\boxed{\therefore \text{Transfer function of PI - controller, } \frac{U(s)}{E(s)} = K_p\left(1 + \frac{1}{T_i s}\right)}$$



Response with PD controller (3M)

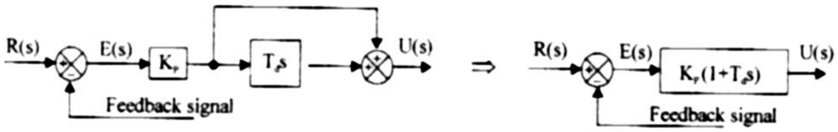
- Output signal consisting of two terms: one proportional to error signal and the other proportional to the derivative of error signal

In PD - controller, $u(t) \; \alpha \; \left[e(t) + \frac{d}{dt}\,e(t)\right]$; $\quad \therefore u(t) = K_p\, e(t) + K_p T_d \frac{d}{dt} e(t)$

where, K_p = Proportional gain

T_d = Derivative time

$$\boxed{\therefore \text{Transfer function of PD - controller, } \frac{U(s)}{E(s)} = K_p(1 + T_d s)}$$



Response with PID controller (4M)

- Output signal consisting of three terms: one proportional to error signal, another one proportional to integral of error signal and the third one proportional to derivative of error signal.

In PID - controller, $u(t) \;\alpha\; \left[e(t) + \int e(t)\,dt + \frac{d}{dt}e(t)\right]$

$$\therefore u(t) = K_p\, e(t) + \frac{K_p}{T_i}\int e(t)dt + K_p T_d \frac{d}{dt}e(t)$$

where, K_p = Proportional gain

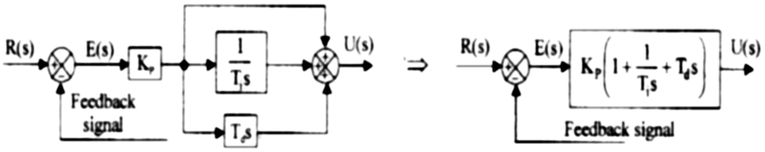
T_i = Integral time

T_d = Derivative time

-

$$U(s) = K_p E(s) + \frac{K_p}{T_i}\ \frac{E(s)}{s} + K_p\ T_d\ s\ E(s)$$

$$\boxed{\therefore \text{ Transfer function of PID - controller, } \frac{U(s)}{E(s)} = K_p\left(1 + \frac{1}{T_i s} + T_d s\right)}$$

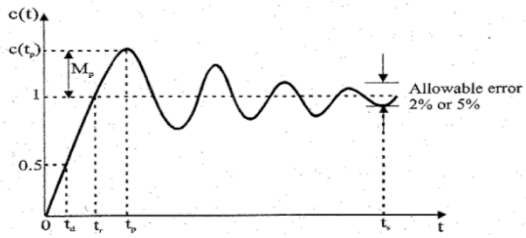


4. **Define the following terms of time domain analysis of a control system 1.Delay time 2.Rise time 3.Over shoot 4.Settling time(13M)** BTL1

Answer: Page 3.16 to 3.21 - A.Nagoor Kani

Time domain specification (2M)

The time response characteristics of the system at under damped condition is drawn below.



The transient response characteristics of a control system to a unit step input is specified in terms of the following specifications

- Delay time
- Rise time
- Peak time
- Maximum overshoot
- Settling time

Delay time (2M)

Delay time (t_d) is the time required to reach at 50% of its final value by a time response signal during its first cycle of oscillation.

Rise time (3M)

Rise time (t_r) is the time required to reach at final value by a under damped time response signal during its first cycle of oscillation. If the signal is over damped, then rise time is counted as the time required by the response to rise from 10% to 90% of its final value.

$$\therefore \text{ Rise Time, } t_r = \frac{\pi - \theta}{\omega_d}$$

where

$$\theta = \tan^{-1}\frac{\sqrt{1-\zeta^2}}{\zeta}$$

$$\therefore \text{Rise time, } t_r = \frac{\pi - \tan^{-1}\frac{\sqrt{1-\zeta^2}}{\zeta}}{\omega_n\sqrt{1-\zeta^2}} \text{ in sec}$$

Peak overshoot (3M)

Maximum overshoot (M_p) is straight way difference between the magnitude of the highest peak of time response and magnitude of its steady state. Maximum overshoot is expressed in term of percentage of steady-state value of the response. As the first peak of response is normally maximum in magnitude, maximum overshoot is simply normalized difference between first peak and steady-state value of a response.

$$\%\text{Peak overshoot, } \%M_p = \frac{c(t_p) - c(\infty)}{c(\infty)} \times 100$$

$$\text{. Percentage Peak Overshoot, } \%M_p = e^{-\frac{\zeta\pi}{\sqrt{1-\zeta^2}}} \times 100$$

Settling time (3M)

Settling time (ts) is the time required for a response to become steady. It is defined as the time required by the response to reach and steady within specified range of 2 % to 5 % of its final value.

$$\boxed{\text{Settling time, } t_s = \frac{1}{\zeta\omega_n} = 4T \quad \text{(for 2\% error)}}$$

$$\boxed{\text{Settling time, } t_s = \frac{3}{\zeta\omega_n} = 3T \quad \text{(for 5\% error)}}$$

$$\boxed{\therefore \text{ Settling time, } t_s = \frac{ln(\%\text{ error})}{\zeta\omega_n} = \frac{ln(\%\text{ error})}{T}}$$

5.

The response of a servomechanism is $c(t) = 1 + 0.2e^{-60t} - 1.2^{e-10t}$ **when subjected to a unit step input. Obtain an expression for closed loop transfer function. Determine the undamped natural frequency and damping ratio. (13M)** BTL3

Answer: Page 3.26 to 3.27 - A.Nagoor Kani

- **Take Laplace transform** (3M)
- **Find closed loop response of the system** (5M)
- **Determine the undamped natural frequency and damping ratio** (5M)

Given that $c(t) = 1 + 0.2e^{-60t} - 1.2^{e-10t}$

On taking Laplace transform of c(t) we get

$$C(s) = \frac{1}{s} + 0.2\frac{1}{(s+60)} - 12\frac{1}{(s+10)} = \frac{(s+60)(s+10) + 0.2\,s(s+10) - 1.2\,s(s+60)}{s(s+60)(s+10)}$$

$$= \frac{s^2 + 70s + 600 + 0.2\,s^2 + 2s - 12s^2 - 72s}{s(s+60)(s+10)} = \frac{600}{s(s+60)(s+10)} = \frac{1}{s}\,\frac{600}{(s+60)(s+10)}$$

Since the input is unit step input R(s)=1/s

$$C(s) = R(s)\,\frac{60}{(s+60)(s+10)} = R(s)\,\frac{600}{s^2 + 70s + 600}$$

The closed loop transfer function of the system is $\frac{C(s)}{R(s)} = \frac{600}{s^2 + 70s + 600}$

The damping ratio and natural frequency of oscillation can be estimated by comparing the system transfer function with standard form of second order transfer function

$$\frac{C(s)}{R(s)} = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2} = \frac{600}{s^2 + 70s + 600}$$

On comparing we get

$$\omega_n^2 = 600$$

$$\therefore\ \omega_n = \sqrt{600} = 24.49 \text{ rad / sec}$$

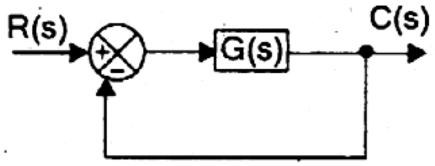
$$2\zeta\omega_n = 70$$

$$\therefore\ \zeta = \frac{70}{2\omega_n} = \frac{70}{2 \times 24.49} = 1.43$$

6.

A unity feed back control system has an open loop transfer function $G(s) = 10/s(s+2)$ .Find the rise time , percentage over shoot, peak time and settling time for a step input of 12 units(13M) BTL3. **(April/May -2018,April/May -2017)**

Answer: Page 3.35 to 3.36 - A.Nagoor Kani



- Find the closed loop transfer function (2M)

$$\therefore\ \frac{C(s)}{R(s)} = \frac{\frac{10}{s(s+2)}}{1 + \frac{10}{s(s+2)}} = \frac{10}{s(s+2) + 10} = \frac{10}{s^2 + 2s + 10}$$

- The standard form of second order transfer function is (1M)

	$\frac{C(s)}{R(s)} = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$ • Compare both the transfer function **(3M)** $\omega_n^2 = 10$; $\therefore\ \omega_n = \sqrt{10} = 3.162 \text{ rad / sec}$ | $2\zeta\omega_n = 2$; $\therefore\ \zeta = \frac{2}{2\omega_n} = \frac{1}{3.162} = 0.316$ $\theta = \tan^{-1}\frac{\sqrt{1-\zeta^2}}{\zeta} = \tan^{-1}\frac{\sqrt{1-0.316^2}}{0.316} = 1249 \text{ rad}$ $\omega_d = \omega_n\sqrt{1-\zeta^2} = 3.162\sqrt{1-0.316^2} = 3 \text{ rad / sec}$ • Find the time domain specifications (7M) Rise time $t_r = \frac{\pi-\theta}{\omega_d} = \frac{\pi - 1249}{3} = 0.63 \text{ sec}$ Percentage overshoot %Mp $= e^{\frac{-\zeta\pi}{\sqrt{1-\zeta^2}}} \times 100 = e^{\frac{-0.316\pi}{\sqrt{1-0.316^2}}} \times 100$ $= 0.3512 \times 100 = 35.12\%$ Peak overshoot $= \frac{35.12}{100} \times 12 \text{ units} = 4.2144 \text{ units}$ Peak time $t_p = \frac{\pi}{\omega_d} = \frac{\pi}{3} = 1047 \text{ sec}$ Time constant $T = \frac{1}{\zeta\omega_n} = \frac{1}{0.316 \times 3.162} = 1 \text{ sec}$ For 5% error, settling time $t_s = 3T = 3 \text{ sec}$ • For 2% error ,settling time $t_s = 4T = 4 \text{ sec}$
7.	**Explain briefly about the steps to be followed to construct a root locus plot of a given transfer function(15M)** BTL2 **Answer: Page 5.67 to 5.71 - A.Nagoor Kani** Step 1: Locate the poles and zeros of G(s)H(s) on the s plane. The root locus branch starts from the open loop poles and terminates at zeros Step 2:Determine the root locus on real axis Step 3:Detemine the asymptotes of root locus branches and meeting point of asymptotes with real axis Step 4: Find the breakaway and break-in points. Step 5:If there is a complex pole then determine the angle of departure from the complex pole ,If there is a complex zero then determine the angle of arrival at the complex zero Step 6: Find the points where the root loci may cross the imaginary axis. Step 7:Take a series of test points in the broad neighborhoods of the region of the S plane and adjusts the test point to satisfy the angle criterion.Sketch the root locus by joining the test point by smooth curve.

	Step 8:The value of gain K at any point on the locus can be determined from the magnitude condition .The value of K at a point S=Sa is given by $= \frac{\text{Product of lenth of vector from open loop poles to the point Sa}}{\text{Product of lenth of vector from open loop zeros to the point Sa}}$
	PART * C
Q.No	**Questions**
1.	**For a unity feedback control system the open loop transfer function** $G(s)=10(s+2)/s^2(s+1)$ **Find , (a)The position, velocity and acceleration error constant.(b)The steady state error when the input is** $R(s)=\frac{3}{s}+\frac{2}{s^2}+\frac{1}{3s^3}$ (15M) BTL3 **Answer: Page 3.45 to 3.48 - A.Nagoor Kani** ➢ Find static error constants(position error constant, Velocity error constant, Acceleration error constant) (8M) $\text{Position error constant, } K_p = \underset{s\to 0}{Lt}\, G(s)H(s) = \underset{s\to 0}{Lt}\, G(s) = \underset{s\to 0}{Lt}\, \frac{10(s+2)}{s^2(s+1)} = \infty$ $\text{Velocity error constant, } K_v = \underset{s\to 0}{Lt}\, s\, G(s)H(s) = \underset{s\to 0}{Lt}\, s\, G(s) = \underset{s\to 0}{Lt}\, s\, \frac{10(s+2)}{s^2(s+1)} = \infty$ $\text{Acceleration error constant, } K_a = \underset{s\to 0}{Lt}\, s^2G(s)H(s) = \underset{s\to 0}{Lt}\, s^2G(s)$ $= \underset{s\to 0}{Lt}\, s^2\, \frac{10(s+2)}{s^2(s+1)} = \frac{10\times 2}{1} = 20$ ➢ Find steady state error (7M) The error signal is $e(t) = r(t)C_0 + \dot{r}(t)C_1 + \ddot{r}(t)\frac{C_2}{2!} + \ldots\ldots + \overset{n}{r}(t)\frac{C_n}{n!} + \ldots.$ $r(t) = \mathcal{L}^{-1}\{R(s)\} = \mathcal{L}^{-1}\left\{\frac{3}{s} - \frac{2}{s^2} + \frac{1}{3s^3}\right\}$ $= 3 - 2t + \frac{1}{3}\frac{t^2}{2!} = 3 - 2t + \frac{t^2}{6}$ $C_0 = \underset{s\to 0}{Lt}\, F(s)\,; \quad C_1 = \underset{s\to 0}{Lt}\, \frac{d}{ds}F(s)\,; \quad C_2 = \underset{s\to 0}{Lt}\, \frac{d^2}{ds^2}F(s)$ C0=0,C1=0 and C2=0.1 then ess=1/60
2.	**For servomechanism with open loop transfer function given below explains what type input signal give rise to a constant steady state error and calculate their values** a) $G(s) = \frac{20(s+2)}{s(s+1)(s+3)}$; b) $G(s) = \frac{10}{(s+2)(s+3)}$; c) $G(s) = \frac{10}{s^2(s+1)(s+2)}$ (15M) **(5M+5M+5M)** BTL3

Answer: Page 3.48 to 3.49 - A.Nagoor Kani

(i) $G(s) = \dfrac{20(s+2)}{s(s+1)(s+3)}$

Let us assume unity feedback system H(s)=1.

The open loop system has a pole at origin. Hence it is a type 1 system. In systems with type number 1,the velocity (ramp) input will give a constant steady state error.

The steady state error with unit velocity input, $e_{ss} = \dfrac{1}{K_v}$

Velocity error constant

$$K_v = \underset{s\to 0}{Lt}\ s\,G(s)\,H(s) = \underset{s\to 0}{Lt}\ s\,G(s)$$

$$= \underset{s\to 0}{Lt}\ s\,\frac{20(s+2)}{s(s+1)(s+3)} = \frac{20\times 2}{1\times 3} = \frac{40}{3}$$

$$e_{ss} = \frac{1}{K_v} = \frac{3}{40} = 0.075$$

(ii) $G(s) = \dfrac{10}{(s+2)(s+3)}$

Let us assume unity feedback system H(s)=1.

The open loop system has no pole at origin. Hence it is a type 0 system. In systems with type number 0,the step input will give a constant steady state error.

The steady state error with unit step input $e_{ss} = \dfrac{1}{1+K_p}$

Position error constant $K_p = \underset{s\to 0}{Lt}\ G(s)H(s) = \underset{s\to 0}{Lt}\ G(s) = \underset{s\to 0}{Lt}\ \dfrac{10}{(s+2)(s+3)} = \dfrac{10}{2\times 3} = \dfrac{5}{3}$

Then e_{ss} =0.375

(iii) $G(s) = \dfrac{10}{s^2(s+1)(s+2)}$

Let us assume unity feedback system H(s)=1

The open loop system has two poles at origin. Hence it is a type 2 system. In systems with type number 2,the acceleration (parabolic) input will give a constant steady state error.

The steady state error with unit acceleration input , $e_{ss} = \dfrac{1}{K_a}$

Acceleration error constant,

$$e_{ss} = \frac{1}{K_a} = \frac{1}{5} = 0.2$$

3. **A unity feedback control system has an open loop transfer function.sketch the root locus** $G(s) = K / s(s^2 + 4s + 13)$ (13M) BTL3 **(April/May -2018)**

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Answer: Page 5.71 to 5.74 - A.Nagoor Kani

Step 1: Locate the poles and zeros of G(s)H(s) on the s plane. The root locus branch starts from the open loop poles and terminates at zeros. (1M)

- The poles are lying at s=0,-2+j3,-2-j3

Step 2:Determine the root locus on real axis (1M)

Step 3:Detemine the asymptotes of root locus branches and meeting point of asymptotes with real axis and find the centroid (2M)

- Angle of asymptotes= $\frac{\pm 180°(2q+1)}{n-m}; q = 0,1,2,....(n-m)$

$(\pm 60, \pm 180)$

- Centroid $= \frac{\text{Sum of poles-Sum of zeros}}{n-m}$ =-1.33

Step 4: Find the breakaway and break-in points. (3M)

- The root locus has neither breakaway nor break in points.

Step 5:If there is a complex pole then determine the angle of departure from the complex pole ,If there is a complex zero then determine the angle of arrival at the complex zero (2M)

- Angle of departure from the complex pole P2=-33.7 º
- Angle of departure from complex pole P3=+33.7º
- Mark the angle of departure at complex poles using protractor.

Step 6: Find the points where the root loci may cross the imaginary axis. (2M)

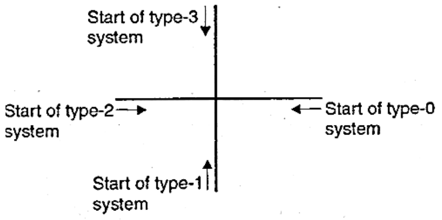
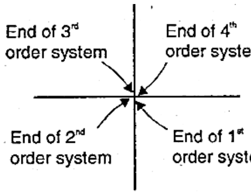
- The crossing point of root locus is .
- The value of K at this crossing point is K=52.

Step 7:Take a series of test points in the broad neighborhoods of the region of the S plane and adjusts the test point to satisfy the angle criterion.Sketch the root locus by joining the test point by smooth curve. (2M)

	UNIT III FREQUENCY RESPONSE ANALYSIS
	Frequency response: – Bode plot – Polar plot – Determination of closed loop response from open loop response - Correlation between frequency domain and time domain specifications
	PART * A
Q.No	**Questions**
1.	**What is frequency response?** BTL1**(April/May -2017)** The frequency and phase function of sinusoidal transfer function of a system are real function of frequency so they are called frequency response.

2.	**What are the advantages of frequency response anlaysis?** BTL2**(April/May -2018)** • The absolute and relative stability of the closed loop system can be estimated from the knowledge of their open loop frequency response • The practical testing of the systems can be easily done with available sinusoidal generators and precise measurements equipments. • The transfer function of the complicated systems can be determined experimentally by frequency response tests. • The effects of noise disturbances and parameter variations are relatively easy to visualize and incorporate corrective measures. • Analysis can be extended to certain non linear system.
3.	**State any four-frequency domain specification.** BTL1 • Resonant Peak • Resonant frequency • Cut-off region • Phase Margin • Gain Margin • Phase cross over frequency • Gain cross over frequency
4.	**Define gain Margin.** BTL1**(April/May -2018)** The gain margin (G.M.) is defined as the margin in gain allowable by which gain can be increased till system reaches on the verge of instability. Mathematically it can be defined as reciprocal of the magnitude of the G(jw)H(jw) measured at phase crossover frequency.
5.	**Define phase margin.** BTL1**(April/May -2018)** The amount of additional phase lags which can be introduced in the system till the system reaches on the verge of instability is called phase margin.
6.	**What is gain crossover frequency and phase crossover frequency?** BTL1 Gain crossover frequency (Wgc): The frequency at which magnitude of G(jw)H(jw) is unity is called gain crossover frequency. Phase crossover frequency (Wpc): The frequency at which phase angle of G(jw)H(jw) is -180 deg. is called phase crossover frequency.
7.	**What is meant by corner frequency in frequency response analysis?** BTL 1 **(April/May -2018)** A frequency up to which the magnitude contribution of a factor is negligible and can be neglected is called its corner frequency. It is the frequency at which low frequency and high frequency asymptotes intersect each other. At the corner frequency, a change in the slope of a magnitude plot occurs. Frequency range and the number of points is chosen automatically.
8.	**How the resonant peak (Mr), resonant frequency (wr), and band width are determined from Nichols chart?** BTL2 The resonant peak is given by the value of µ. Contour which is tangent to G (jw) locus. The resonant frequency is given by the frequency of G (jw) at the tangent point. The bandwidth is given by frequency corresponding to the intersection point of G(jw) and –3dB M-contour.

9.	**What is meant by Cut of frequency**? BTL 1 it is denoted by ωb. the frequency at which the magnitude of the closed loop response is 3 dB down from its zero-frequency value is called cut-off frequency.
10.	**What is meant by resonant peak?** BTL1 Resonant peak (Mr): It is the maximum value of magnitude of the closed loop frequency response.
11.	**What is meant by resonant frequency?** BTL1 Resonant frequency (ωr): The frequency at which resonant peak Mr occurs in closed loop frequency response is called resonant frequency.
12.	**Write a short note on correlation between the time and frequency response?** BTL1 Correlation between time and frequency response of first order or second order systems. The frequency domain specifications can be expressed in terms of the time domain parameters δ and ω_n.For a peak overshoot in time domain there is a corresponding resonant peak in frequency domain. For higher order systems, there is no explicit correlation between time and frequency response. But if there is a pair of dominant complex conjugate poles, then the system can be approximated to second order system and the correlation between time and frequency response can be estimated.
13.	**What are the graphical techniques available for the frequency response analysis?** BTL1 • Bode plot • Polar plot • Nichols plot • M and N circles • Nichols chart
14.	**What are the advantages of Bode plot?** BTL 2 • It shows both low and high frequency characteristics of transfer function in single diagram. • The plots can be easily constructed using some valid approximations. • Relative stability of system can be studied by calculating G.M. and P.M. from the bode plot. • The various other frequency domain specifications like cut-off frequency, bandwidth etc. can be determined. • Data for constructing complicated polar and Nyquist plots can be easily obtained from Bode plot. • Transfer function of system can be obtained from the bode plot.
15.	**What is polar plot?** BTL1 The polar plot of a sinusoidal transfer function G(jω) is a plot of the magnitude of G(jω) versus the phase angle/argument of G(jω) on polar or rectangular coordinates as ω is varied from zero to infinity
16.	**What is minimum phase system?** BTL1 The minimum phase systems are system with minimum phase transfer functions. In minimum phase transfer functions, all poles and zeros will lie on the left half of s plane.
17.	**In minimum phase system,how start and end of polar plots are identified?** BTL2 For minimum phase transfer functions,with only poles ,the type number of the system

	determines the quadrant in which the polar plot starts and the order of the system determines the quadrant in which the polar plot ends.  · *Start of polar plot of all pole minimum phase system.*  *Start of polar plot of all pole minimum phase system.*
18.	**What is the use of Nichol's chart in control system?** BTL2 Nichol's chart used to find closed loop frequency response from open loop frequency response. The frequency domain specifications can be determined from Nichols chart. ➢ The gain of the system can be adjusted to satisfy the given specifications.
19.	**What are the characteristics of phase lead network?** BTL1 Increases system bandwidth which usually correlates to reduce rise and settling times and a susceptibility to high frequency noise. The phase of the forward path transfer function in the vicinity of the zero-gain crossover frequency. This increases the phase margin of the closed loop system and hence the relative stability.
20.	**What is compensation?**BTL1**(April/May- 2019)** The compensation is the design procedure in which the system behaviour is altered to meet the desired specifications, by introducing additional device called compensator.
21.	**What are compensators? What are the different types of compensator?** BTL1 A device inserted into the system for the purpose of satisfying the specifications is called compensator. The different types of compensators are lag, lead and lag lead compensators.
22.	**What is the basis for selection of a compensator for a system?** BTL2 When the system is to be redesigned to meet the required specifications, it is necessary to alter the system by adding an external device to it. The system must provide, • Attenuation in the high frequency range to give a system enough phase margins. • Large bandwidth, short rise time and less settling time.
23.	**What is series compensation?**BTL1 If a compensator is placed in series with the forward path transfer function of the plant is called as series compensation.
24.	**What is parallel compensation?** BTL1 Feedback is taken from some internal element and compensator is introduced in such a feedback path to provide an additional internal feedback loop is called parallel compensation.
25.	**What is series parallel compensation?** BTL1 In some cases, it is necessary to provide both types of compensations series as well as feedback. Such scheme is called series parallel compensation.
26.	**When lag/lead/lag lead compensation is employed?** BTL2**(April/May -2017)** Lag compensation is employed for a stable system for improvement in steady state

	performance Lead compensation is employed for stable /unstable system for improvement in transient state performance Lag lead compensation is employed for stable/unstable system for improvement in both steady state and transient state performance.
27.	**Discuss the effect of adding a pole to open loop transfer function of a system?** BTL2 The addition of a pole to open loop transfer function of a system will reduce the steady state error. The closer the pole to origin lesser will be the steady state error. Thus, the steady state performance of the system is improved. In addition, the addition of pole will increase the order of the system, which in turn makes the system less stable than the original system.
28.	**Discuss the effect of adding a zero to open loop transfer function of a system.** BTL2 The addition of a zero to open loop transfer function of a system will improve the transient response.The addition of zero reduces the rise time.If the zero is introduced close to origin then the peak overshoot will be larger.If the zero is introduced far away from the origin in the left half of the s plane then the effect of zero on the transient response will be negligible.
29.	**What is lag compensation?** BTL1 A compensator having the characteristics of lag network is called lag compensator.The Lag Compensator is an electrical network which produces a sinusoidal output having the phase lag when a sinusoidal input is applied.
30.	**What is lead compensation?** BTL1 A compensators having the characteristics of a lead network is called a lead compensator.If a sinusoidal is applied to the lead network then in steady state the output will have a phase lead with respect to input.
31.	**What is lag lead compensation?** BTL1 Lag-Lead compensator is an electrical network which produces phase lag at one frequency region and phase lead at other frequency region. It is a combination of both the lag and the lead compensators.
	PART * B
Q.No	**Questions**
1.	**Sketch bode plot for the following transfer function and determine the system gain K for the gain cross over frequency to be 5 rad/sec(13M)**BTL3 $G(s) = \frac{Ks^2}{(1+0.2s)(1+0.02s)}$ **Answer: Page 4.22 to 4.24 - A.Nagoor Kani** • The sinusoidal transfer function G(jω) is obtained by replacing S by jω in the given S domain transfer function (1M) • The corner frequencies are 5 and 50 rad/sec (1M) • Find slope and change in slop and tabulate the same (2M) • Find gain for different values of corner frequencies (2M) • Draw the magnitude plot (3M)

- Draw the phase plot for different values of phase angles. (3M)
- Calculate gain K=0.0398 (1M)

2.

The open loop transfer function of a unity feedback system is given by G(s)=1/s(s+1)(1+2s).Sketch the polar plot and determine the gain margin and phase margin(13M)BTL3

Answer: Page 4.44 to 4.46 - A.Nagoor Kani

- The sinusoidal transfer function G(jω) is obtained by replacing S by jω in the given S domain transfer function (1M)
- The corner frequencies are 0.5 and 1 rad/sec (1M)
- Find magnitude and phase at different frequencies (6M)
- Calculate gain and phase margin from the polar plot (5M)

Gain margin is 1.4286

Phase margin is 12°

3.

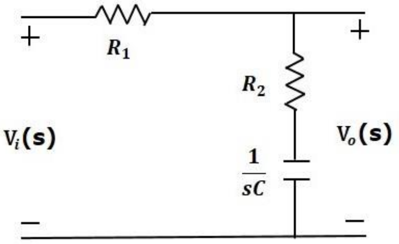
Discuss about lag,Lead,Lag lead compensator.(13M)BTL2

Answer: Page 6.4,6.20,6.53 - A.Nagoor Kani

An external device which is used to alter the behavior of the system so as to achieve given specifications is called compensator. The compensator provides whatever missing in a system so as to achieve required performance.

Lag compensators (4M)

A compensator having the characteristics of lag network is called lag compensator.The Lag Compensator is an electrical network which produces a sinusoidal output having the phase lag when a sinusoidal input is applied. The lag compensator circuit in the ‘s’ domain is shown in the following figure.



The transfer function of the lag compensator

$$\frac{V_o(s)}{V_i(s)} = \frac{1}{\alpha}\left(\frac{s+\frac{1}{\tau}}{s+\frac{1}{\alpha\tau}}\right)$$

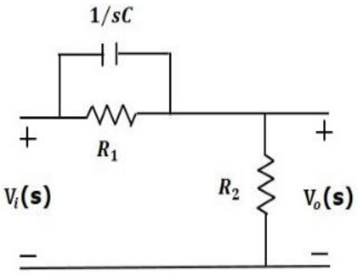
where

$$\tau = R_2C$$

$$\alpha = \frac{R_1+R_2}{R_2}$$

Lead compensators (4M)

A compensators having the characteristics of a lead network is called a lead compensator.If a sinusoidal is applied to the lead network then in steady state the output will have a phase lead with respect to input. The lead compensator circuit in the ‘s’ domain is shown in the following figure.



The transfer function of the lead compensator is

$$\frac{V_o(s)}{V_i(s)} = \beta\left(\frac{s\tau+1}{\beta s\tau+1}\right)$$

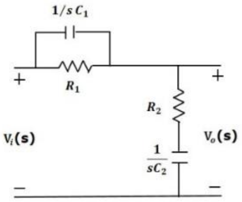
Where,

$$\tau = R_1 C$$

$$\beta = \frac{R_2}{R_1+R_2}$$

Lag Lead compensators (5M)

Lag-Lead compensator is an electrical network which produces phase lag at one frequency region and phase lead at other frequency region. It is a combination of both the lag and the lead compensators. The lag-lead compensator circuit in the ‘s’ domain is shown in the following figure.



The transfer function of this network is the product of transfer function of the lag and lead network.

$$\frac{V_o(s)}{V_i(s)} = \beta\left(\frac{s\tau_1+1}{\beta s\tau_1+1}\right)\frac{1}{\alpha}\left(\frac{s+\frac{1}{\tau_2}}{s+\frac{1}{\alpha\tau_2}}\right)$$

We know $\alpha\beta = 1.$

$$\Rightarrow \frac{V_o(s)}{V_i(s)} = \left(\frac{s+\frac{1}{\tau_1}}{s+\frac{1}{\beta\tau_1}}\right)\left(\frac{s+\frac{1}{\tau_2}}{s+\frac{1}{\alpha\tau_2}}\right)$$

Where,

$$\tau_1 = R_1 C_1$$

$$\tau_2 = R_2 C_2$$

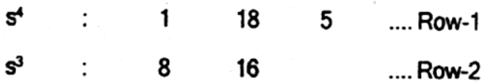
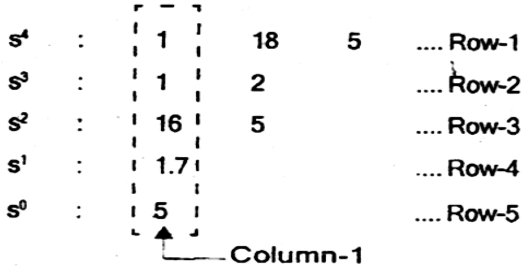
4.	**Write the procedure for lag compensator design using bode plot.(13M)B**TL1 **(April/May -2017)** **Answer: Page 6.9 to 6.11 - A.Nagoor Kani** The following steps may be followed to design a lag compensator using bode plot and to be connected in series with the transfer function of uncompensated system Step 1:Choose the value of K of uncompensated system to meet the steady state requirements Step 2:Sketch the bode plot for the uncompensated system Step 3: Determine the phase margin of the uncompensated system from the bode plot. If the margin does not satisfy the requirement then lag compensation is required. Step 4: Choose a suitable value for the phase margin of the uncompensated system. $\gamma_n = \gamma_d + \xi$ Step 5:Determine the new gain cross over frequency **ω_{gcn}** Step 6: Determine the parameter β of the compensator. Find db gain at new gain cross over frequency Step 7: Determine the transfer function of the lag compensator. Step 8:Determine the open loop transfer function of the compensated system Step 9: Determine the actual phase margin of the compensated system. If the actual phase margin is satisfies the given specification then the design is accepted. Otherwise the procedure from step 4 to 9 by taking ξ=5° more than previous design.
5.	**Consider the following system, G(s)=K/S(1+2S).Design a lag compensator so that the phase margin (PM) is at least 40° and steady state error to a unit step input is** ≤ 0.2 **(13M)**BTL3 **Answer: Page 6.11 to 6.15 - A.Nagoor Kani** Step 1:Choose the value of K of uncompensated system to meet the steady state requirements **K=5** Step 2:Sketch the bode plot for the uncompensated system (2M) Step 3:Determine the phase margin of the uncompensated system from the bode plot. If the margin does not satisfy the requirement then lag compensation is required**.** (2M) **Phase margin =18°** Step 4:Choose a suitable value for the phase margin of the uncompensated system**.** (1M) $\gamma_n = \gamma_d + \xi$ **=45°** Step 5:Determine the new gain cross over frequency **ω_{gcn}** (2M) **=0.5 rad/sec** Step 6: Determine the parameter β of the compensator. Find db gain at new gain cross over frequency**(1M)** **β =10** Step 7: Determine the transfer function of the lag compensator**.** (2M) **G(s)=10(1+20S)/(1+200S)** Step 8:Determine the open loop transfer function of the compensated system (2M) **G(S)=5(1+20S)/S(1+200S)(1+2S)** Step 9:Determine the actual phase margin of the compensated system**.** (2M)

	Phase margin =18° The actual phase margin of the compensated system satisfies the requirement. Hence, the design is acceptable.
6.	**Write the procedure for lead compensator design using bode plot.(13 M)** BTL1 **Answer: Page 6.32 to 6.333 - A.Nagoor Kani** The following steps may be followed to design a lead compensator using bode plot and to be connected in series with the transfer function of uncompensated system Step 1:Choose the value of K of uncompensated system to meet the steady state requirements Step 2:Sketch the bode plot for the uncompensated system Step 3: Determine the phase margin of the uncompensated system from the bode plot. If the margin does not satisfy the requirement then lag compensation is required. Step 4: Choose a suitable value for the phase margin of the uncompensated system. $\gamma_n = \gamma_d - \gamma + \xi$ Step 5: Determine the transfer function of the lead compensator. Step 6:Determine the open loop transfer function of the compensated system Step7:Verify the design
7.	**Write the procedure for lag lead compensator design using bode plot(13M)BTL1** **Answer: Page 6.55 to 6.57 - A.Nagoor Kani** The following steps may be followed to design a lag compensator using bode plot and to be connected in series with the transfer function of uncompensated system Step 1:Choose the value of K of uncompensated system to meet the steady state requirements Step 2:Sketch the bode plot for the uncompensated system Step 3: Determine the phase margin of the uncompensated system from the bode plot. If the margin does not satisfy the requirement then lag compensation is required. Step 4: Choose a suitable value for the phase margin of the uncompensated system. $\gamma_n = \gamma_d + \xi$ Step 5:Determine the new gain cross over frequency ω_{gcn} Step 6: Determine the parameter β of the lag compensator. Find db gain at new gain cross over frequency Step 7: Determine the transfer function of the lag compensator. Step 8: Determine the transfer function of the lead compensator. Step 9: Determine the transfer function of the lag lead compensator Step 10:Determine the open loop transfer function of the compensated system Step 11: Draw the bode plot of the compensated system and verify whether the specifications are satisfied or not. If the specifications are not satisfied then choose another choice of α such that α<1/β and repeat steps 8 to 11.
	PART * C
Q.No	**Questions**

1.	**Sketch the bode plot for the following transfer function and determine phase margin and gain margin(15M)**BTL3. **(April/May -2018)** $$G(s) = \frac{75\,(1+0.2s)}{s\left(s^2+16s+100\right)}$$ **Answer: Page 4.25 to 4.28 - A.Nagoor Kani** • The sinusoidal transfer function G(jω) is obtained by replacing S by jω in the given S domain transfer function (1M) • The corner frequencies are 5 and 10 rad/sec (2M) • Find slope and change in slop and tabulate the same (1M) • Find gain for different values of corner frequencies (2M) • Draw the magnitude plot (3M) • Draw the phase plot for different values of phase angles. (3M) • Find phase margin and gain margin from the bode plot (3M) Phase margin=92° Gain margin=Infinity
2.	**The open loop transfer function of a unity feedback system is given by the following. Sketch the polar plot and determine the phase margin (15M)** BTL3. **(April/May -2018)** $$G(s) = \frac{(1+0.2s)(1+0.025s)}{s^3(1+0.005s)(1+0.001s)}$$ **Answer: Page 4.50 to 4.52 - A.Nagoor Kani** • The sinusoidal transfer function G(jω) is obtained by replacing S by jω in the given S domain transfer function (1M) • Find magnitude and phase at different frequencies (8M) • Calculate gain and phase margin from the polar plot (6M) Phase margin is -77°
3.	**Consider the following system with transfer function Design a lag lead compensator C(s) such that the phase margin of the compensated system is at 35 degree .and the velocity error constant Kv is 80 (15M)** BTL3. **(April/May -2018)** **G(S)=K/s(s+3)(s+6)** **Answer: Page 6.59 to 6.65 - A.Nagoor Kani** Step 1:Choose the value of K of uncompensated system to meet the steady state requirements (1M) **K=1440** Step 2:Sketch the bode plot for the uncompensated system (2M) Step 3: Determine the phase margin of the uncompensated system from the bode plot. If the margin does not satisfy the requirement then lag compensation is required. (1M) **Phase margin =-46°(from the bode plot)**

	Step 4: Choose a suitable value for the phase margin of the uncompensated system. (1M) $\gamma_n = \gamma_d + \xi$ **Phase margin =40°** Step 5:Determine the new gain cross over frequency ω_{gcn} (1M) **=4 rad/sec** Step 6: Determine the parameter β of the lag compensator. Find db gain at new gain cross over frequency (1M) **=14** Step 7: Determine the transfer function of the lag compensator. (2M) **$G_1(s)$=14(1+2.5s)/(1+35s)** Step 8: Determine the transfer function of the lead compensator**.** (2M) **$G_2(s)$=0.07(1+0.22s)/(1+0.0154s)** Step 9: Determine the transfer function of the lag lead compensator (2M) **$G_c(s)$=(1+2.5s)(1+0.22s)/(1+35s)(1+0.0154s)** Step 10:Determine the open loop transfer function of the compensated system (1M) **$G_c(s)$=80(1+2.5s)(1+0.22s)/s(1+35s)(1+0.0154s)(1+0.33s)(1+0.167s)** Step 11: Draw the bode plot of the compensated system and verify whether the specifications are satisfied or not**.** (1M) **Phase margin=36°** The phase margin of the compensated system is satisfactory. Hence the design is acceptable.
	UNIT IV CONCEPTS OF STABILITY ANALYSIS
	Characteristics equation – Routh Hurwitz criterion – Nyquist stability criterion-Performance criteria –Effect of Lag, lead and lag-lead compensation on frequency response-Design of Lag, lead and lag lead compensator using bode plots.
	PART * A
Q.No	**Questions**
1.	**Define BIBO stability** BTL1 A linear relaxed system is said to have BIBO stability if every bounded input results in a bounded output
2.	**How the roots of the characteristics equation are related to stability?** BTL2 It the roots of the characteristics equation has real part then the impulse response of the system is not bounded .Hence the system will be unstable. If the roots has negative real part then the impulse response is bounded .Hence the system will be stable.
3.	**What is the necessary condition for stability**BTL1 The necessary condition for stability is that all the coefficient of the characteristics polynomial be positive.
4.	**What is Routh stability criterion?** BTL1 The necessary and sufficient condition for stability is that all of the elements in the first column of the routh array be positive. If this condition is not met the system is unstable and the number of sign changes in the elements of the first column of the routh array corresponds to the number of roots of the characteristics equation in the right half of S plane

5.	**What is auxiliary polynomial?** BTL1 In the construction of Routh array a row of all zero indicates the existence of an even polynomial as a factor of the given characteristics equation. In an even polynomial, the exponents of s are even integers are zero only. This even polynomial factor is called auxiliary polynomial. The coefficient of auxiliary polynomial is given by the elements of the row just above the row of all zeros.
6.	**What is dominant pole?**BTL1**(April/May -2018)** The dominant pole is a pair of complex conjugate pole which decides transient response of the system. In higher order systems the dominant poles are very close to the origin and all other poles of the system are widely separated and so they have less effect on transient response of the system.
7.	**What is the relation between stability and coefficient of characteristics polynomial?** BTL2 If the coefficients of the characteristics polynomial are negative or zero, then some of the roots lies on right half of s plane. Hence the system is unstable, If the coefficients of characteristics polynomial are positive and if no efficient is zero then there is a possibility of the system to be stable provided all the roots of are lying on left half of S plane.
8.	**What is the nature of impulse response when the roots of characteristics equation are lying on imaginary axis?** BTL1 If the roots of characteristics equation lie on imaginary axis the nature of the impulse response is oscillatory.
9.	**What is the principle of argument?** BTL1 The principle of argument states that let F(s) ne an analytic function and if an arbitrary, closed contour in the clockwise direction is chosen in the s plane so that F(s) is analytic at every point of the contour. Then the corresponding F(S) plane contour mapped in the F(s) plane will encircle the origin times in the anticlockwise direction where N is the difference between the number of poles ,P and zeros Z of F(s) that are enclosed by the chosen closed contour in the S plane.
10.	**What is Nyquist stability criterion?**BTL1 **(April/May -2017)** Consider an open-loop transfer function GOL(s) that is proper and has no unstable pole-zero cancellations. Let N be the number of times that the Nyquist plot for GOL(s) encircles the -1 point in the clockwise direction. Also let P denote the number of poles of GOL(s) that lie to the right of the imaginary axis. Then, Z = N + P where Z is the number of roots of the characteristic equation that lie to the right of the imaginary axis (that is, its number of “zeros”). The closed-loop system is stable if and only if Z = 0
11.	**Write some important properties of Nyquist stability criterion.**BTL2 1. It provides a necessary and sufficient condition for closed-loop stability based on the open-loop transfer function. 2. The reason the -1 point is so important can be deduced from the characteristic equation, $1 + G_{OL}(s) = 0$. This equation can also be written as $G_{OL}(s) = -1$, which implies that $AR_{OL} = 1$, as noted earlier. The -1 point is referred to as the *critical point*. 3. Most process control problems are open-loop stable. For these situations, $P = 0$ and thus $Z = N$. Consequently, the closed-loop system is unstable if the Nyquist plot for

	$G_{OL}(s)$ encircles the -1 point, one or more times.
12.	**What are the advantages of Nyquist stability criterion over that of Routh's criterion** BTL2 • Routh criterion does not give the sufficient information about relative stability of the system • It does not help much in design problems in which the designer is required to achieve the desired performance by varying one or more system parameters. • Nyquist stability criterion gives information about both absolute stability and relative stability • Nyquist plot of open loop transfer function can be easily obtained.From this plot closed loop stability can be determined.
13.	**What will be the stability of the system when the roots of the characteristics equation are lying on imaginary axis?**BTL2 Marginally stable or limitedly stable.
	PART * B
Q.No	**Questions**
1.	**Construct the Routh array and determine the stability of the system whose characteristics equation is** $s^4+8s^3+18s^2+16s+5=0$ **. Also determine the number of roots lying on right half of S plane, left half of S plane and on imaginary axis**.(13M) **Repeated question** BTL 3 **(April/May -2018)** **Answer: Page 5.13 - A.Nagoor Kani** The characteristics equation is $s^4+8s^3+18s^2+16s+5=0$ The given characteristics equation is of 4th order hence it has 4 roots s^4 : 1 18 5 .... Row-1 s^3 : 8 16 .... Row-2 The elements of S3 row can be divided by 8 to simplify the computations. s^4 : 1 18 5 .... Row-1 s^3 : 1 2 .... Row-2 s^2 : 16 5 .... Row-3 s^1 : 1.7 .... Row-4 s^0 : 5 .... Row-5 Column-1 The elements of the first column of Routh array, all the elements are positive and there is no sign change. All the roots are lying on left half of S plane and system is stable.
2.	**Construct the Routh array and determine the stability of the system whose**

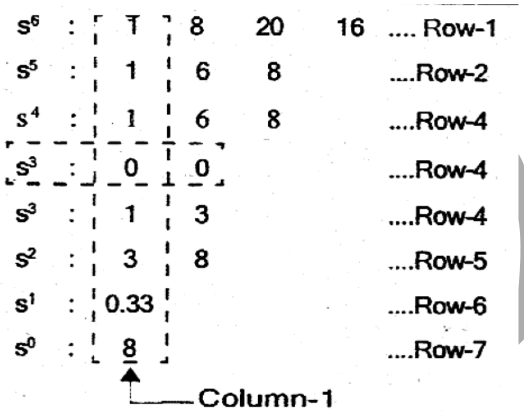
characteristics equation is $s^6+2s^5+8s^4+12s^3+20s^2+16s+16=0$ **. Also determine the number of roots lying on right half of S plane, left half of S plane and on imaginaryaxis.** (13M) BTL3

Answer: Page 5.13 to 5.14 - A.Nagoor Kani

The characteristics equation is $s^6+2s^5+8s^4+12s^3+20s^2+16s+16=0$
The given characteristics equation is of 6th order hence it has 6 roots.

s^6	:	1	8	20	16	.... Row-1
s^5	:	2	12	16		.... Row-2

The elements of S5 row can be divided by 2 to simplify the computations.



s^6	:	1	8	20	16	.... Row-1
s^5	:	1	6	8		....Row-2
s^4	:	1	6	8		....Row-4
s^3	:	0	0			....Row-4
s^3	:	1	3			....Row-4
s^2	:	3	8			....Row-5
s^1	:	0.33				....Row-6
s^0	:	8				....Row-7

On examining the 1st column of Routh array it is observed that there is no sign change. The rows with all zeros indicate the possibility of roots on imaginary axis. Hence, the system is limitedly or marginally stable.

The auxiliary polynomial is

$s^4+6s^2+8=0$

Let, $s^2=x$

$\therefore x^2+6x+8=0$

The roots of quadratic are, $x=\dfrac{-6\pm\sqrt{6^2-4\times 8}}{2}$

$=-3\pm 1=-2$ or -4

The roots of auxiliary polynomial is,

$s=\pm\sqrt{x}\ =\pm\sqrt{-2}$ and $\pm\sqrt{-4}$

$=+j\sqrt{2},-j\sqrt{2},+j2$ and $-j2$

Four roots are lying on the imaginary axis and two roots are lying on the left half of s plane.

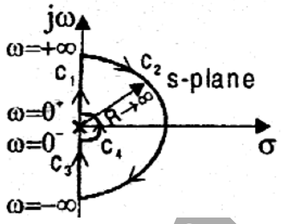
3.

Draw the Nyquist plot for the system whose open loop transfer function is given below. $G(s)H(s) = K/s(s+2)(s+10)$ **. Determine the range of K for which the closed loop system is stable.(13M)** BTL3

Answer: Page 5.36 to 5.39 - A.Nagoor Kani

$$G(s)H(s) = \frac{K}{s\,(s+2)\,(s+10)} = \frac{K}{s \times 2\left(\frac{s}{2}+1\right) \times 10\left(\frac{s}{10}+1\right)} = \frac{0.05K}{s\,(1+0.5s)\,(1+0.1s)}$$

Nyquist contour (2M)



The Nyquist contour has four sections C_1, C_2,C_3 and C_4.The mapping of each sections is performed separately and the overall Nyquist plot is obtained by combining the individual sections.

Mapping of Section C1: (2M)

In section C1, ω varies from 0 to +infinity.

Let s=j ω

$$\therefore G(j\omega)H(j\omega) = \frac{0.05K}{j\omega\,(1+j0.5\omega)\,(1+j0.1\omega)}$$

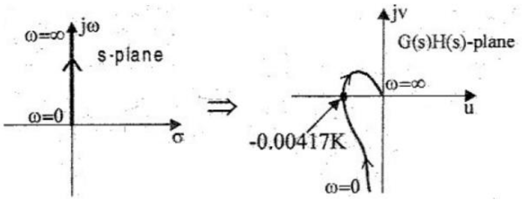
$$= \frac{0.05K}{j\omega\,(1+j0.6\omega-0.05\omega^2)} = \frac{0.05K}{-0.6\omega^2 + j\omega\,(1-0.05\omega^2)}$$

When the locus of G(j ω)H(j ω) crosses real axis the imaginary term will be zero and the corresponding frequency is the phase cross over frequency ωpc.

$$\therefore \text{At } \omega = \omega_{pc}, \quad \omega_{pc}(1-0.05\omega_{pc}^2) = 0 \quad \Rightarrow \quad 1-0.05\omega_{pc}^2 = 0 \quad \Rightarrow \quad \omega_{pc} = \sqrt{\frac{1}{0.05}} = 4.472 \text{ rad/sec}$$

$$\text{At } \omega = \omega_{pc} = 4.472 \text{ rad/sec}, \qquad G(j\omega)H(j\omega) = \frac{0.05K}{-0.6\omega^2} = -\frac{0.05K}{0.6 \times (4.472)^2} = -0.00417K$$

The open loop is Type 1 and third order system. Hence the polar plot of G(j ω)H(j ω) starts at -90° axis at infinity crosses real axis at -0.00417 K and ends at origin in second quadrant.



Mapping of Section C2: (2M)

The mapping of section C2 from S plane to G(s)H(s) plane is obtained by letting $s = \underset{R\to\infty}{Lt} R\,e^{j\theta}$ in G(s)H(s) and varying θ from +π/2 to –π/2.Since $s\to R\,e^{j\theta}$ and $R\to\infty$, the G(s)H(s) can be approximated. [i.e., (1+sT) ≈ sT].

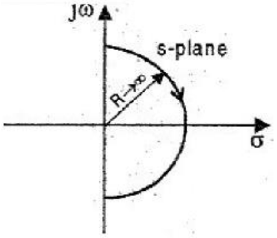
$$G(s)\,H(s) = \frac{0.05K}{s\,(1+0.5s)\,(1+0.1s)} \approx \frac{0.05K}{s\times 0.5s\times 0.1s} = \frac{K}{s^3}$$

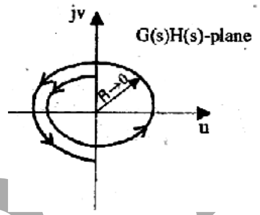
Let, $s = \underset{R\to\infty}{Lt} Re^{j\theta}$.

$$\therefore\ G(s)H(s)\Big|_{s=\underset{R\to\infty}{Lt}Re^{j\theta}} = \frac{K}{s^3}\Big|_{s=\underset{R\to\infty}{Lt}Re^{j\theta}} = \frac{K}{\underset{R\to\infty}{Lt}(Re^{j\theta})^3} = 0e^{-j3\theta}$$

When $\theta = \frac{\pi}{2}$, $G(s)H(s) = 0e^{-j3\frac{\pi}{2}}$

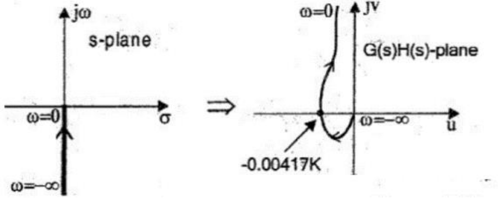
When $\theta = -\frac{\pi}{2}$, $G(s)H(s) = 0e^{+j3\frac{\pi}{2}}$





Mapping of section C3: (2M)

In section C3, ω varies from –infinity to 0.The mapping of section C3 is given by the locus of G(jω)H(jω) as ω is varied from –infinity to 0.



Mapping of section C4 (3M)

The mapping of section C4 from S plane to G(s)H(s) plane is obtained by letting $s = \underset{R\to 0}{Lt} R\,e^{j\theta}$ in obtained by letting $s = \underset{R\to 0}{Lt} R\,e^{j\theta}$

[i.e., (1+sT) ≈ 1].

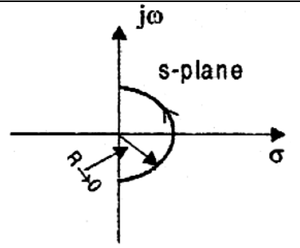
$$G(s)H(s) = \frac{0.05K}{s\,(1+0.5s)\,(1+0.1s)} \approx \frac{0.05K}{s\times 1\times 1} = \frac{0.05K}{s}$$

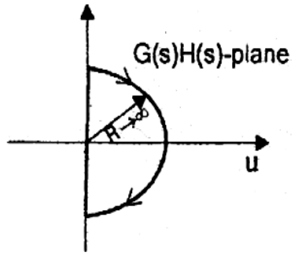
Let $s = \underset{R\to 0}{Lt} Re^{j\theta}$.

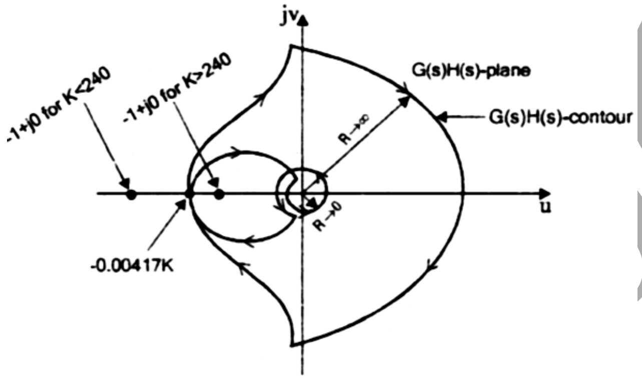
$$\therefore\ G(s)H(s)\Big|_{s=\underset{R\to 0}{Lt}Re^{j\theta}} = \frac{0.05K}{s}\Big|_{s=\underset{R\to 0}{Lt}Re^{j\theta}} = \frac{0.05K}{\underset{R\to 0}{Lt}(Re^{j\theta})} = \infty e^{-j\theta}$$

When $\theta = -\frac{\pi}{2}$, $G(s)H(s) = \infty e^{+j\frac{\pi}{2}}$

When $\theta = \frac{\pi}{2}$, $G(s)H(s) = \infty e^{-j\frac{\pi}{2}}$







Limiting value of K is 240 (2M)

PART * C

Q.No **Questions**

1.

State Nyquist stability criterion and explain the three situations while examining the stability of the linear control system(15M) BTL2

Answer: Page 5.30 to 5.5.33 - A.Nagoor Kani

Nyquist stability criterion: (5M)

- The Nyquist stability criterion is similar to the Bode criterion in that it determines closed-loop stability from the open-loop frequency response characteristics.
- The Nyquist stability criterion is based on two concepts from complex variable theory, *contour mapping* and the *Principle of the Argument*.
- Nyquist Stability Criterion. Consider an open-loop transfer function GOL(s) that is proper and has no unstable pole-zero cancellations. Let N be the number of times that the Nyquist plot for GOL(s) encircles the -1 point in the clockwise direction. Also let P denote the number of poles of GOL(s) that lie to the right of the imaginary axis. Then, Z = N + P where Z is the number of roots of the characteristic equation that lie to the right of the imaginary axis (that is, its number of "zeros"). The closed-loop system is stable if and only if Z = 0.

Examining the stability of the linear control system: (10M)

No encirclement of -1+j0 point:

This implies that the system is stable if there are no poles of G(s)H(s) in the right half of S plane. If there are poles on right half of S plane then the system is unstable

Anticlockwise encirclement of -1+j0 point:

In this case the system is stable if the number of anticlockwise is same as the number of poles of G(S)H(S) in the right half of S plane. If the number of anticlockwise encirclement is not equal to number of poles on right half of S plane then the system is unstable.

Clockwise encirclement of the -1+j0 point:

In this case the system is always unstable. Also in this case if no poles of G(s)H(s) in right half of S plane ,then the number of clockwise encirclement is equal to number of poles of closed loop system on right half of S plane.

2.

Define stability .With an example explain the steps to be followed for Routh Hurwitz criterion(15M) BTL1

Answer: Page 5.1 to 5.9 - A.Nagoor Kani

Stability (3M)

- The term STABILITY refers to the stable working condition of a control system
- The response or output is predictable ,finite and stable for a given input (for any changes in system parameters)
- A system is STABLE if its output is bounded for any bounded input
- If a system output is stable for all variations of its parameters, then the system is called ABSOLUTELY STABLE system
- If a system output is stable for a limited range of variations of its parameters then the system is called CODITIONALLY STABLE system.

Routh Hurwitz criterion (6M)

- The Routh stability criterion is based on ordering the coefficients of the characteristics equation into a schedule called the Routh array.
- The Routh stability can be stated as follows"The necessary and sufficient condition for stability is that all of the elements in the first column of the routh array be positive.If this condition is not met the system is unstable and the number of sign changes in the elements of the first column of the routh array corresponds to the number of roots of the characteristics equation in the right half of S plane."

Construction of Routh array (6M)

- Let the characteristics polynomial

$$a_0s^n + a_1s^{n-1} + a_2s^{n-2} + a_3s^{n-3} + \dots a_{n-1}s^1 + a_ns^0$$

- The coefficients of the polynomial are arranged in two rows as below

$$\begin{array}{lcllll} s^n & : & a_0 & a_2 & a_4 & a_6 \dots\dots \\ s^{n-1} & : & a_1 & a_3 & a_5 & a_7 \dots\dots \end{array}$$

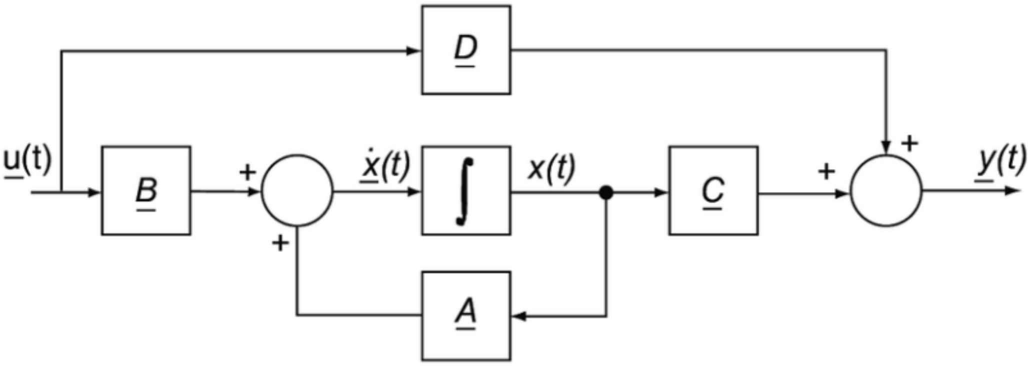
- When n is even ,S^n row is formed by the coefficients of even order terms and row is formed by coefficients of odd order terms
- When n is odd , S^n row is formed by the coefficients of odd order terms and row is formed by coefficients of even order terms

The other rows of Routh array upto S^0 can be formed by the following procedure.

	s^{n-x} : $x_0 \quad x_1 \quad x_2 \quad x_3 \quad x_4 \quad x_5.....$ s^{n-x-1} : $y_0 \quad y_1 \quad y_2 \quad y_3 \quad y_4 \quad y_5.....$ s^{n-x-2} : $z_0 \quad z_1 \quad z_2 \quad z_3 \quad z_4 .....$ • The elements of S^{n-x-2} row are given by $z_0 = \frac{(-1)\begin{vmatrix} x_0 & x_1 \\ y_0 & y_1 \end{vmatrix}}{y_0} = \frac{y_0x_1 - y_1x_0}{y_0}$ $\quad z_2 = \frac{(-1)\begin{vmatrix} x_0 & x_3 \\ y_0 & y_3 \end{vmatrix}}{y_0} = \frac{y_0x_3 - y_3x_0}{y_0}$ $z_1 = \frac{(-1)\begin{vmatrix} x_0 & x_2 \\ y_0 & y_2 \end{vmatrix}}{y_0} = \frac{y_0x_2 - y_2x_0}{y_0}$ $\quad z_3 = \frac{(-1)\begin{vmatrix} x_0 & x_4 \\ y_0 & y_4 \end{vmatrix}}{y_0} = \frac{y_0x_4 - y_4x_0}{y_0}$ • All the elements of any row can be multiplied or divided by a positive constant to simplify the computational work In the construction of routh array one may come across the following three cases • Case (i) Normal Routh array (Non-zero elements in the first column of routh array) • Case (ii) A row of all zeros • Case(iii) First elements of a row is zero but same or other elements are not zero
	UNIT V CONTROL SYSTEM ANALYSIS USING STATE VARIABLE METHODS
	Concept of state variables – State models for linear and time invariant Systems – Solution of state and output equation in controllable canonical form – Concepts of controllability and observability
	PART * A
Q.No	**Questions**
1.	**What are the advantages of state space analysis?** BTL2**(April/May -2018,April/May-2019)** • State space analysis is applicable to any type of systems. They can be used for modeling and analysis of linear & nonlinear system, time variant & time invariant systems and multiple input and multiple output systems • The state space analysis can be performed with initial conditions. • The variables used to represent the system can be any variables in the system • Using this analysis, the internal states of the system at any instant can be predicted.
2.	**What are the drawbacks of transfer function analysis?** BTL2 • Transfer function is defined under zero initial conditions. • Transfer function is applicable to linear time invariant systems. • Transfer function analysis is restricted to single input and single output systems. • The transfer function modeling is a terminal approach where we can find only the output and not the state of the other variables inside the system.
3.	**What is state and state variable?B**TL1 State: It is a group of variables, which summarizes the history of the system in order to predict the future values (outputs). State Variable: The number of the state variables required is equal to the number of the storage elements present in the system.

4.	**What is state vector? BTL1** It is a vector, which contains the state variables as elements.
5.	**Write the state model for nth order system** BTL1 The most general state-space representation of a linear system with m inputs, p outputs and n state variables are written in the following form: $\dot{X}$= AX + BU Y = CX + DU Where X= state vector of order n X_1. U = input vector of order n X_1. A=System matrix of order n X_n. B=Input matrix of order n X_m C =output matrix of order p X_n D = transmission matrix of order p X_m.
6.	**What is state space?** BTL1 The set of all possible values which the state vector x(t) can have at time t forms the state space of the system
7.	**Define observability of the system.**BTL1**(April/May -2018)** A control system is said to be observable if it is able to determine the initial states of the control system by observing the outputs in finite duration of time. We can check the observability of a control system by using Kaman's test.
8.	**What is state transition matrix and how it is related to state of the system?** BTL1 The matrix exponential e^{AT} is called state transition matrix.In the expanded form $e^{AT} = 1 + At + \frac{1}{2!}A^2t^2 + \frac{1}{3!}A^3t^3 + ... + \frac{1}{i!}A^it^i$
9.	**List the main properties of state transition matrix** BTL2 1. $\Phi(0) = I$ 2. $\Phi^{-1}(t) = \Phi(-t)$ 3. $x(0) = \Phi(-t)x(t)$ 4. $\Phi(t_2 - t_1)\Phi(t_1 - t_0) = \Phi(t_2 - t_0)$ 5. $\Phi(t)^k = \Phi(kt)$
10.	**What are phase variables?** BTL1 The phase variables are defined as the state variables which are obtained from one of the system variables and its derivatives.
11.	**What is observability?** BTL1 A system is said to be completely observable if every state X(t) can be completely identified by measurements of the output Y(t) over a finite time interval.
12.	**What is the necessary condition to be satisfied for design using state feedback?** BTL1 The state feedback design requires arbitrary pole placements to achieve the desire performance. The necessary and enough condition to be satisfied for arbitrary pole placement is that the system is completely state controllable.
13.	**What is the need for controllability test?** BTL2**(April/May -2017)** The controllability test is necessary to find the usefulness of a state variable. If the state variables are controllable then by controlling (i.e. varying) the state variables the desired outputs of the system are achieved.

14.	**What is the need for observability test?** BTL2 The observability test is necessary to find whether the state variables are measurable or not. If the state variables are measurable then the state of the system can be determined by practical measurements of the state variables.
15.	**State the condition for controllability by Gilbert's method.** BTL2 Case (i) when the Eigen values are distinct Consider the canonical form of state model shown below which is obtained by using the transformation X=MZ. $\dot{X}= \Lambda Z + U$ Y=Z + DU Where, Λ = M-1AM; = CM, = M-1B and M = Modal matrix. In this case the necessary and enough condition for complete controllability is that, the matrix must have no row with all zeros. If any row of the matrix is zero, then the corresponding state variable is uncontrollable. Case (ii) when Eigen values have multiplicity In this case the state modal can be converted to Jordan canonical form shown below: Z= JZ + U Y=Z + DU Where, J = M-1AM In this case the system is completely controllable, if the elements of any row of that correspond to the last row of each Jordan block are not all zero.
16.	**State the condition for observability by Gilbert's method**. BTL2 Consider the transformed canonical or Jordan canonical form of the state model shown below: which is obtained by using the transformation, X =MZ Z= ΛZ + U Y=Z + DU (Or) Z= JZ + U Y=Z + DU where =CM and M=modal matrix. The necessary and enough condition for complete observability is that none of the columns of the matrix be zero. If any of the column has all zeros, then the corresponding state variable is not observable.
17.	**State the duality between controllability and observability**. BTL2 The concept of controllability and observability are dual concepts and it is proposed by Kalman as principle of duality. The principle of duality states that a system is completely state controllable if and only if its dual system is completely state controllable if and only if its dual system is observable or vice versa.
18.	**What is state diagram? Draw the block diagram representation of state model.** BTL1**(April/May -2017)** The pictorial representation of the state model of the system is called state diagram. The state diagram of the system can be either in block diagram or in signal flow graph form.

	
19.	**What are the basic elements used to construct the state diagram.** BTL2 The basic elements used to construct the state diagram are scalar, adder, and Integrator.
20.	**Sketch the basic elements used to construct the block diagram of a state model.** BTL2 The basic elements used to construct the state diagram are scalar, adder, and Integrator.
21.	**What are phase variable?1** The phase variables defined as those particular state variables, which are obtained from one of the system variables and its derivatives. Usually the variables used are the system output and the remaining state variables are then derivatives of the output.
22.	**What are the advantages of state space modeling using phase variable?** BTL2 • The state variable can be utilized for the purpose of feedback • The implementation of design with state variable feedback becomes straight forward • The solution of state equation gives time variation of variables, which have direct relevance to the physical system.
23.	**What are the disadvantages in choosing phase variable for state space modelling?** BTL2 The disadvantage in choosing phase variable is that the phase variables are not physical variables of the system and therefore are not available for measurement and control purposes
24.	**What is the advantage and the disadvantage in canonical form of state model?** BTL2 The advantages of canonical form are that the state equations are independent of each other. The disadvantage is that the canonical variables are not physical variables and so they are not available for measurement and control.
25.	**What is the solution of homogeneous state equation?** BTL1 The solution of homogeneous state equation is $X(t)=e^{At}X_0$
26.	**What is Jordan canonical form?** BTL1 When the eigen values have multiplicity the system matrix cannot be dragonized .But the transformation X=MZ will transform the system matrix to a form called Jordan martrix Where $J=M^{-1}AM$.The transformed state model in this case is called Jordan canonical form.
	PART * B
Q.No	**Questions**
1.	**Construct the state model for a system characterized by the differential equation $d^3y/dt^3+6d^2y/dt^2+11dy/dt+6y+u=0$.Give the block diagram representation of the state model. (13M)**BTL3 **(April/May -2018)**

	Answer: Page 7.26 - A.Nagoor Kani - **Convert differential equations in to dot variables** (2M) $x_1 = y$ $x_2 = \frac{dy}{dt} = \dot{x_1}$ $x_2 = \frac{d^2y}{dt^2} = \dot{x_2}$ - **Apply the state variables to dot variables** (2M) 1.$\dot{x}_1 = x_2$ 2.$\dot{x}_2 = x_3$ 3. $\dot{x_3} = -6x_1 - 11x_2 - 6x_3 - u$ - **Rearrange the equation and derive state model** (3M) - **Draw the block diagram for state equation and output equation** **(6M)**
2.	**Obtain the state model of the system whose open loop transfer function is given as, Y(s)/U(s)=10/s^3+4s^2+2s+1.(13M)**BTL3 **Answer: Page 7.29 to 7.30 - A.Nagoor Kani** - Use inspection, cascade, signal flow graph method (1M) - Take inverse Laplace transform & Convert differential equations in to dot variables - (2M) - Apply the state variables to dot variables (2M) - Rearrange the equation and derive state model (3M) - Draw the block diagram for state equation and output equation (5M)
3.	**A feedback system has a closed loop transfer function Y(s)/U(s) = 10(s+4)/s(s+1) (s+3), construct block diagram representation of each state model. (13M)**BTL3 **Answer: Page 7.33 to 7.36 - A.Nagoor Kani** - Use inspection, cascade, signal flow graph method (1M) - Take inverse Laplace transform & Convert differential equations into dot variables - (2M) - Apply the state variables to dot variables (2M) - Rearrange the equation and derive state model (3M) - Draw the block diagram for state equation and output equation (5M).
4.	**Determine the canonical state model of the system, whose transfer function is T(s) = 2(s+5)/(s+1) (s+3) (s+4). (13M)**BTL3 **Answer: Page 7.36 to 7.37 - A.Nagoor Kani** - Use inspection, cascade, signal flow graph method (1M) - Take inverse Laplace transform & Convert differential equations in to dot variables (2M) - Apply the state variables to dot variables (2M)

	• Rearrange the equation and derive state model (3M) • Draw the block diagram for state equation and output equation (5M)
5.	**Compute state transition matrix A = 0 -1** **(13M)** BTL3 **(April/May -2017)** **-2 -3** **Answer: Page 7.42 to 7.44 - A.Nagoor Kani** • Find eigen values by using |SI -A |=0 (4M) • Find inverse matrix of |SI -A | (4M) • Use partial fraction method to find A, B, C (2M) • Find inverse Laplace of φ(s) to get φ(t) (3M)
6.	**Test the controllability and observability by using any one method of the given state space representation model. (13M)**BTL3 **(April/May -2017)** $\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\\ \dot{x}_3\end{bmatrix}=\begin{bmatrix}0&0&1\\ -2&-3&0\\ 0&2&-3\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ x_3\end{bmatrix}+\begin{bmatrix}0\\ 2\\ 0\end{bmatrix}u\ ;\ y=[1\ 0\ 0]\begin{bmatrix}x_1\\ x_2\\ x_3\end{bmatrix}$ **Answer: Page 7.61 to 7.65- A.Nagoor Kani** • From the state model identify A, B, C Matrix (2M) • Use Gilberts method or Kalman’s method (2M) • In Gilberts method Find Ḃ and C. The value of Ḃ does not contain zero value then the system is completely controllable. The value of C does not contain zero value then the system is completely observable. (5M) • In Kalman’s method Find Qo and Qc. The value of Qo does not contain zero value then the system is completely controllable. The value of Qo does not contain zero value then the system is completely observable. (4M)
	PART * C
Q.No	**Questions**
1.	**Test the controllability of the following state model by using both the methods. (15M)** BTL3

	$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\\ \dot{x}_3\end{bmatrix}=\begin{bmatrix}0&0&1\\ -2&-3&0\\ 0&+2&-3\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ x_3\end{bmatrix}+\begin{bmatrix}0\\ 2\\ 0\end{bmatrix}u;\ y=\begin{bmatrix}1&0&0\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ x_3\end{bmatrix}.$ **Answer: Page 7.57 to 7.61- A.Nagoor Kani** • From the state model identify A, B, C Matrix (2M) • Use Gilberts method or Kalman's method (2M) • In Gilberts method Find Ḃ and C. The value of Ḃ does not contain zero value then the system is completely controllable. The value of C does not contain zero value then the system is completely observable. (6M) • In Kalman's method Find Qo and Qc. The value of Qo does not contain zero value then the system is completely controllable. The value of Qo does not contain zero value then the system is completely observable. (5M) • The system is completely observable.
2.	**Verify the system is completely controllable and observable.(15M)** BTL3 $[\dot{x}(t)]=\begin{bmatrix}0&0&1\\ -2&-3&0\\ 0&2&-3\end{bmatrix}\begin{bmatrix}x_1(t)\\ x_2(t)\\ x_3(t)\end{bmatrix}+\begin{bmatrix}0\\ 2\\ 0\end{bmatrix}u(t);\ y(t)=\begin{bmatrix}1&0&0\end{bmatrix}\begin{bmatrix}x_1(t)\\ x_2(t)\\ x_3(t)\end{bmatrix}.$ **Answer: Page 7.57 to 7.61- A.Nagoor Kani** • From the state model identify A, B, C Matrix (2M) • Use Gilberts method or Kalman's method (2M) • In Gilberts method Find Ḃ and C. The value of Ḃ does not contain zero value then the system is completely controllable. The value of C does not contain zero value then the system is completely observable. (6M) • In Kalman's method Find Qo and Qc. The value of Qo does not contain zero value then the system is completely controllable. The value of Qo does not contain zero value then the system is completely observable. (5M)