KKR & KSR INSTITUTE OF TECHNOLOGY & SCIENCES
(Approved by AICTE, Delhi, Affiliated to JNTU, Kakinada)
Accredited with "A" Grade by NAAC
Department of Electrical and Electronics Engineering

III B.Tech II SEM (R13) :: A/Y(2017-2018)

POWER SYSTEM ANALYSIS

Hand Out

Preamble:

The course is designed to give students the required knowledge for the design and analysis of electrical power grids. Calculation of power flow in a power system network using various techniques, formation of Zbus and its importance are covered in this course. It also deals with short circuit analysis and analysis of power system for steady state and transient stability.

Learning objectives:

- To study the development of impedance diagram (p.u) and formation of Y_{bus}
- To study the Gauss Seidel, Newton Raphson, decoupled and fast decoupled load flow methods.
- To study the concept of the Z_{bus} building algorithm.
- To study short circuit calculation for symmetrical faults
- To study the effect of unsymmetrical faults.
- To study the rotor angle stability analysis of power systems.

Syllabus:

UNIT –I:
Per Unit Representation & Topology
Per Unit Quantities–Single line diagram– Impedance diagram of a power system – Graph theory definition – Formation of element node incidence and bus incidence matrices – Primitive network representation – Formation of Y– bus matrix by singular transformation and direct inspection methods.

UNIT –II:
Power Flow Studies
Necessity of power flow studies – Derivation of static power flow equations – Power flow solution using Gauss-Seidel Method – Newton Raphson Method (Rectangular and polar coordinates form) –Decoupled and Fast Decoupled methods (Algorithmic approach) – Problems on 3–bus system only.

UNIT –III:
Z–Bus formulation
Formation of Z–Bus**:** Partial network– Algorithm for the Modification of Zbus Matrix for addition element for the following cases**:** Addition of element from a new bus to reference– Addition of element from a new bus to an old
bus– Addition of element between an old bus to reference and Addition of element between two old busses (Derivations and Numerical Problems).– Modification of Z–Bus for the changes in network (Problems).

UNIT – IV:
Symmetrical Fault Analysis
3–Phase short circuit currents and reactances of synchronous machine–Short circuit MVA calculations.
UNIT –V:
Symmetrical Components & Fault analysis
Synthesis of unsymmetrical phasor from their symmetrical components– Symmetrical components of unsymmetrical phasor–Phase - shift of symmetrical components in Y–Δ–Power in terms of symmetrical components – Sequence networks – Positive, negative and zero sequence networks– Various types of faults LG– LL– LLG and LLL on unloaded alternator–unsymmetrical faults on power system.
UNIT – VI:
Power System Stability Analysis
Elementary concepts of Steady state– Dynamic and Transient Stabilities– Description of Steady State Stability Power Limit–Transfer Reactance– Synchronizing Power Coefficient –Power Angle Curve and Determination of
Steady State Stability –Derivation of Swing Equation–Determination of Transient Stability by Equal Area Criterion–Application of Equal Area Criterion–Methods to improve steady state and transient stability.

Prerequisite Courses:

S.no	Name of the course	Year/Semester
1	Power Systems-I	II/II
2	Power Systems-II	III/I

COURSE OUTCOMES

C323.1	draw an per unit impedance diagram for a power system network
C323.2	Solve out the load flow solution of a power system network.
C323.3	formulate the Z_{bus} for a power system network
C323.4	Calculate the short circuit MVA in symmetrical faults
C323.5	find out the fault currents for all types of faults
C323.6	analyze the stability of a power system

CO-PO Mapping

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
C323.1	--	2	1	1	--	--	--	--	--	--	--	--
C323.2	--	2	1	--	1	--	--	--	--	--	--	--
C323.3	--	2	1	--	--	--	--	--	--	--	--	--

C323.4	--	1	2	2	--	--	--	--	--	--	--	--
C323.5	--	2	1	1	--	--	--	--	--	--	--	--
C323.6	--	1	2	2	--	--	--	--	--	--	--	--

Lesson Plan:

L /T No.	Topics covered	Teaching Aid	Text Book / Reference Book / Web	Page Numbers
Unit I: Per Unit Representation & Topology				
L-01	Introduction to Power system analysis	GB&PC	T2	1-2
L-02	Per Unit Quantities	GB&PC	T2,R2	325-329,88
L-03	Single line diagram , Impedance diagram of a power system	GB&PC	T2	325-329
T-01	Problems on Per Unit Quantities	GB&PC	T2	325-329
L-04	Graph theory definition	GB&PC	T2	300
L-05	Formation of element node incidence matrices	GB&PC	T2	300-302
L-06	Formation of bus incidence matrices, Primitive network representation	GB&PC	T2 T3	300-302 303-309
T-02	Problems on Graph theory	GB&PC	T2	303-309
L-07	Formation of Y– bus matrix by singular transformation methods.	GB&PC	T2,R2	307-309, 190
L-08	Formation of Y– bus matrix by direct inspection methods	GB&PC	T2,R2	307-309, 190
L-09	Problems	GB&PC	T2	307-309
T-3	Problems on Formation of Y– bus	GB&PC	T2	307-309
Unit II: Power Flow Studies				
L-10	Necessity of power flow studies	GB&PC	T2	575
L-11	Derivation of static power flow equations	GB&PC	T2.R2	575-579,208
L-12	Power flow solution using Gauss-Seidel Method	GB&PC	T2	579-583

	(when PV buses are absent)			
T-04	Numerical problems on GS method	GB&PC	T2	579-583
L-13	Power flow solution using Gauss-Seidel Method (when PV buses are present)	GB&PC	T2	579-583
L-14	Numerical problems	GB&PC	T2	579-583
L-15	Power flow solution using Newton Raphson Method (Rectangular form)	GB&PC	T2,R2	584-586,232
T-05	Numerical problems NR method	GB&PC	T2,R2	586-589,232
L-16	Power flow solution using Newton Raphson Method (polar coordinates form)	GB&PC	T2	586-589
L-17	Problems	GB&PC	T2	601-630
L-18	Problems	GB&PC	T2	601-630
T-06	Numerical problems NR method	GB&PC	T2	586-589
L-19	Decoupled method	GB&PC	T2,R2	595,240
L-20	Fast Decoupled method	GB&PC	T2,R2	595,240
L-21	Summary of power flow studies	GB&PC, **PPT**	T2,W6	601-630
T-07	Numerical problems Decoupled method	GB&PC	T2	601-630
Unit III: Z–Bus formulation				
L-22	Formation of Z–Bus: Partial network, Algorithm for the Modification of Zbus Matrix for addition element for the following cases: Addition of element from a new bus to reference	GB&PC	T3,R3	355-362, 369-280
L-23	Algorithm for the Modification of Zbus Matrix for addition element for the following cases: Addition of element from a new bus to an old bus	GB&PC	T3,R3	355-362, 369-280
L-24	Algorithm for the Modification of Zbus Matrix for addition element for the following cases: Addition of element between an old bus to reference	GB&PC	T3,R3	355-362, 369-280

T-08	Problems on Formation of Z–Bus	GB&PC	T3,R3	355-362, 369-280
L-25	Algorithm for the Modification of Zbus Matrix for addition element for the following cases: Addition of element between two old busses	GB&PC	T3,R3	355-362, 369-280
L-26	Modification of Z–Bus for the changes in network	GB&PC	T3,R3	355-362, 369-280
L-27	Problems	GB&PC	T3,R3	355-362, 369-280
T-09	Problems on Z–Bus	GB&PC	T3,R3	355-362, 369-280
Unit IV: Symmetrical Fault Analysis				
L-28	3–Phase short circuit currents and reactances of synchronous machine	GB&PC	T3	381-384
L-29	Numerical problems	GB&PC	T3	381-384
L-30	Short circuit MVA calculations.	GB&PC	T2	329
T-10	Numerical problems Symmetrical Fault Analysis	GB&PC	T3	381-384
L-31	Numerical problems	GB&PC	T3	381-384
L-32	Numerical problems	GB&PC	T3	381-384
Unit V: Symmetrical Components & Fault analysis				
L-33	Synthesis of unsymmetrical phasor from their symmetrical components	GB&PC	T3,R2	398,400
T-11	Problems on Symmetrical Components	GB&PC	T3	398
L-34	Symmetrical components of unsymmetrical phasor , Phase - shift of symmetrical components in Y–Δ–	GB&PC	T3	398
L-35	Power in terms of symmetrical components	GB&PC	T2	378
L-36	Sequence networks – Positive, negative and zero sequence networks	GB&PC, **PPT**	T2,W1	379
T-12	Problems on fault analysis	GB&PC	T2	382
L-37	LG fault on unloaded alternator, LL fault on unloaded alternator	GB&PC	T3,R2	399,421

L-38	LLG fault on unloaded alternator **,** LLL fault on unloaded alternator	GB&PC	T3,R2	404,425
L-39	unsymmetrical faults on power system	GB&PC	T3,R2	416,432
T-13	Problems on fault analysis	GB&PC	T3	427
Unit VI: Power System Stability Analysis				
L-40	Introduction to Stability , Elementary concepts of Steady state– Dynamic and Transient Stabilities	GB&PC	T3	433
L-41	Description of Steady State Stability Power Limit, Transfer Reactance	GB&PC	T3	433-435
L-42	Synchronizing Power Coefficient	GB&PC	T3	440-444
T-14	Problems	GB&PC	T3	433-435
L-43	Power Angle Curve	GB&PC	T3	440-444
L-44	Determination of Steady State Stability , Derivation of Swing Equation	GB&PC	T3	454
L-45	Determination of Transient Stability by Equal Area Criterion	GB&PC	T3	461,486
T-15	Problems on swing equation	GB&PC	T3	438
L-46	Application of Equal Area Criterion	GB&PC	T3	461
L-47	Methods to improve steady state Stability	GB&PC	T3	454
L-48	Methods to improve transient stability	GB&PC	T3	454
T-16	Problems on Equal Area Criterion	GB&PC	T3	506

GB&CP: Green Glass Board & Piece of chalk, L: lecture, T: Tutorial, W: Web reference

TEXTBOOK:

T1. Power System Analysis by Grainger and Stevenson, Tata McGraw Hill.

T2. Electrical Power Systems by P.S.R.Murthy, B.S.Publications

T3. Modern Power system Analysis – by I.J.Nagrath & D.P.Kothari: Tata Mc Graw–Hill Publishing Company, 3nd edition.

T4. Power System Analysis and Design by J.Duncan Glover, M.S.Sarma, T.J. Overbye – Cengage Learning publications.

REFERENCES:

R1. Power System Analysis – by A.R.Bergen, Prentice Hall, Inc.

R2. Power System Analysis by HadiSaadat – TMH Edition.

R3 Power System Analysis by B.R.Gupta, Wheeler Publications.

WEB REFERENCES:

W1: nptel.ac.in/courses/Webcourse-contents/IIT-KANPUR/power-system/ui/TOC.htm

W2 : www.eeecube.com/2012/01/131601-ee2351-power-system-analysis.html

W4: www.learnerstv.com/Free-Engineering-Video-lectures-ltv230-Page1.htm

W5:https://ocw.mit.edu/courses/electrical-engineering-and-computer-science

W6:http://electrical-engineering-portal.com/

W7:http://resourcehost.blogspot.in/

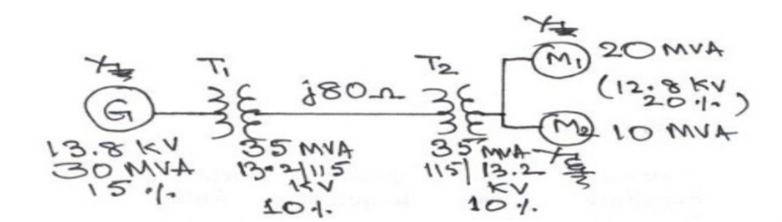
Experiments Related to Course:

S.No	Name of the Experiment	Lab Name	Year/Sem
1	Measurement of sequence impedance of Three phase transformer	Power System Lab	IV/I
2	Measurement of sequence impedance of synchronous machine by fault analysis method	Power System Lab	IV/I
3	Measurement of sequence impedance of synchronous machine by direct method	Power System Lab	IV/I
4	SIMULINK model for evaluating transient stability of single machine connected to infinite bus	Power System Lab	IV/I
5	Load flow solution by using GAUSS-SEIDAL method	Power System Lab	IV/I

Unit wise Important Questions:

Unit I: Per Unit Representation & Topology

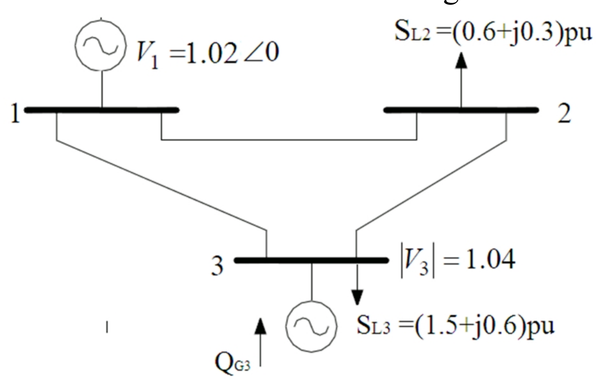
	QUESTIONS	Marks	Related to CO	Level of Learning
1	**a)** What is per unit system? Write the merits and demerits of Per Unit systems?	**5**	**C324.1**	**Knowledge**

<table>
<tr><td></td><td>b) Derive the terms per unit impedance in terms of base MVA, and base KV. Derive the formula for New per Unit Impedance using New per Unit Impedance</td><td>5</td><td>C324.1</td><td>Comprehension</td></tr>
<tr><td>2</td><td>a)Define Single Line Diagram, Impedance Diagram and Reactance Diagram.</td><td>5</td><td>C324.1</td><td>Knowledge</td></tr>
<tr><td></td><td>b)Show that the per unit equivalent impedence of a two winding transformer is the same whether the calculations is made from H.V. side or the L.V. side.</td><td>5</td><td>C324.1</td><td>Comprehension</td></tr>
<tr><td>3</td><td>A 30 MVA, 13.8 KV, 3-phase generator has a sub transient reactance of 15%. The generator supplies 2 motors through a step-up transformer - transmission line – step down transformer arrangement as shown in Fig.1. The motors have rated inputs of 20 MVA and 10 MVA at 12.8KV with 20% sub transient reactance each. The 3-phase transformers are rated at 35MVA, 13.2 KV-Δ /115 KV-Y with 10 % leakage reactance. The line reactance is 80ohms. Draw the equivalent per unit reactance diagram by selecting the generator ratings as base values in the generator circuit.

</td><td>10</td><td>C324.1</td><td>Application</td></tr>
<tr><td>4</td><td>a) Define i)Graph ii)tree iii)branches iv)tree v)tie set vi)cut set</td><td>5</td><td>C324.1</td><td>Knowledge</td></tr>
<tr><td></td><td>b) Explain the procedure to find Y_{bus} using direct inspection method</td><td>5</td><td>C324.1</td><td>Comprehension</td></tr>
<tr><td>5</td><td>Determine Y_{bus} matrix by using singular transformation method for following network
<table>
<tr><td rowspan="2">element</td><td colspan="2">Self impedance</td><td colspan="2">Mutual impedance</td></tr>
<tr><td>Bus code</td><td>impedance</td><td>Bus code</td><td>impedance</td></tr>
<tr><td>1</td><td>1-2(1)</td><td>0.2</td><td>-</td><td>-</td></tr>
<tr><td>2</td><td>1-3</td><td>0.4</td><td>1-2(1)</td><td>0.05</td></tr>
<tr><td>3</td><td>3-4</td><td>0.5</td><td>-</td><td>-</td></tr>
<tr><td>4</td><td>1-2(2)</td><td>0.25</td><td>1-2(1)</td><td>0.1</td></tr>
<tr><td>5</td><td>2-4</td><td>0.2</td><td>-</td><td>-</td></tr>
</table></td><td>10</td><td>C324.1</td><td>Application</td></tr>
</table>

6	Form Y_{bus} for the network by direct inspection method: Element: 5-1, 5-2, 1-2, 2-3, 1-4, 3-6, 4-6 Positive sequence reactance: 0.04, 0.05, 0.04, 0.03, 0.02, 0.07, 0.10	10	C324.1	**Application**

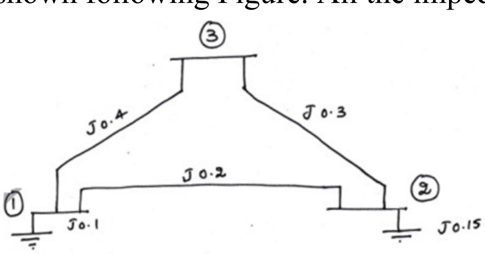
Element	5-1	5-2	1-2	2-3	1-4	3-6	4-6
Positive sequence reactance	0.04	0.05	0.04	0.03	0.02	0.07	0.10

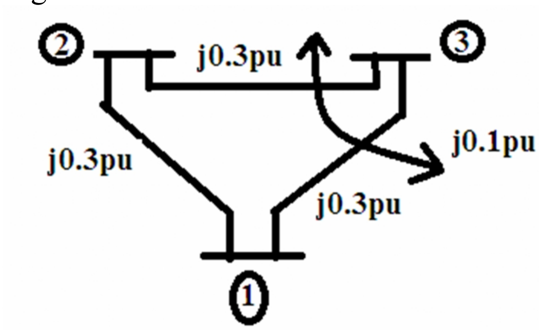
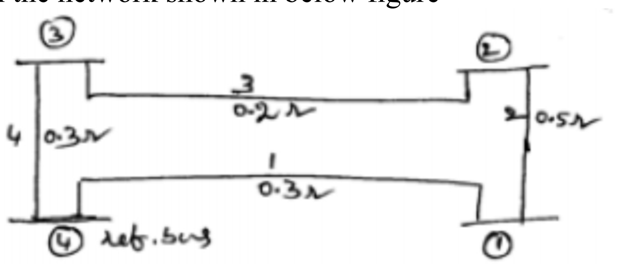
Unit II: **Power Flow Studies**

	QUESTIONS	Marks	Related to CO	Level of Learning
1	a) What is Bus in a power System? Define types of buses	**5**	**C324.2**	**Knowledge**
	b)Derive Static Load Flow Equations of Load Flow Studies in Rectangular and Polar Coordinates?	**5**	**C324.2**	**Comprehension**
2	Derive load flow algorithm using Gauss – Seidel method when PV buses are present and write Algorithm and Flow chart.	**10**	**C324.2**	**Comprehension**
3	Determine Y_{bus} matrix by using singular transformation method for following network 	**10**	**C324.2**	**Application**
4	Explain Newton Raphson method of Load Flow solution in Rectangular Coordinates (Or) Derive the Diagonal and Off-diagonal elements of Jacobean Matrix (Rectangular Coordinates)	**10**	**C324.2**	**Comprehension**
5	Explain Newton Raphson method of Load Flow solution in Polar Coordinates (Or) Derive the Diagonal and Off-diagonal elements of Jacobean Matrix (Rectangular Coordinates)	**10**	**C324.2**	**Comprehension**

6	a)Explain Decoupled load Flow solution method and Fast Decoupled load Flow solution method	**5**	**C324.2**	**Comprehension**
	b) Compare GS ,NR and FDLF methods	**5**	**C324.2**	**Knowledge**

Unit III: **Z–Bus formulation**

<table>
<tr><th></th><th>QUESTIONS</th><th>Marks</th><th>Related to CO</th><th>Level of Learning</th></tr>
<tr><td>1</td><td>a)Explain the step by step procedure for obtaining bus impedance matrix for Type-1 modification (Addition of element from a new bus to reference)</td><td>5</td><td>C324.3</td><td>Comprehension</td></tr>
<tr><td></td><td>b)Explain the step by step procedure for obtaining bus impedance matrix for Type-2 modification (Type-2 modification(Addition of element between an new bus to old bus)</td><td>5</td><td>C324.3</td><td>Comprehension</td></tr>
<tr><td>2</td><td>a)Explain the step by step procedure for obtaining bus impedance matrix for Type-3 Modification (Addition of element from a old bus to an reference)</td><td>5</td><td>C324.3</td><td>Comprehension</td></tr>
<tr><td></td><td>b)Explain the step by step procedure for obtaining bus impedance matrix for Type-4 Modification (Addition of element between two old busses)</td><td>5</td><td>C324.3</td><td>Comprehension</td></tr>
<tr><td>3</td><td>Determine Zbus for the network data given in the following Table using Zbus building Algorithm. Where the impedances shown in per unit.
<table>
<tr><th>Element number</th><th>Bus code
From bus – To bus</th><th>Self impedance</th></tr>
<tr><td>1</td><td>2-3</td><td>0.6 p.u.</td></tr>
<tr><td>2</td><td>1-3</td><td>0.5 p.u.</td></tr>
<tr><td>3</td><td>1-2</td><td>0.4 p.u.</td></tr>
</table></td><td>10</td><td>C324.3</td><td>Application</td></tr>
<tr><td>4</td><td>Determine Zbus for the system whose reactance diagram is shown following Figure. All the impedances are in p.u.

</td><td>10</td><td>C324.3</td><td>Application</td></tr>
</table>

5	A Three bus power system is shown in the following figure. Obtain the bus impedance matrix by using building Algorithm.  	**10**	**C324.3**	**Application**
6	Given the network shown in below figure  Its Z Bus is follows $Z_{Bus} = \begin{bmatrix} 0.23 & 0.11 & 0.07 \\ 0.11 & 0.21 & 0.18 \\ 0.07 & 0.18 & 0.23 \end{bmatrix}$ If the line '2' is removed, determine the Z Bus for the changed network.	**10**	**C324.3**	**Application**

Unit IV: Symmetrical Fault Analysis

	QUESTIONS	Marks	Related to CO	Level of Learning
1	a) Define positive, negative, zero sequence components.	5	C324.4	Knowledge
	b) What is phase operator "a". Derive its properties.	5	C324.4	Knowledge
2	a) Explain sequence impedance network of synchronous generator.	5	C324.4	Knowledge
	b) Explain sequence impedance network of Transformer.	5	C324.4	Knowledge
3	a) What are unsymmetrical faults? Explain in detail.	5	C324.4	Knowledge
	b) Derive fault current for L-G fault.	5	C324.4	Comprehension
4	a) Derive fault current for L-L fault.	5	C324.4	Comprehension
	b) Derive fault current for L-L-G fault.	5	C324.4	Comprehension

5	A. Derive the relation between phase quantities into Symmetrical components	5	C324.4	Comprehension
	B. The line to ground voltage on HV side of step up transformer are 100KV,33KV,38KV on phase A,B,C respectively. The voltage of phase A leads the Phase B by 100^o and lags by 176.56^o . Determine symmetrical components of the Voltages.	5	C324.4	Application
6	A. Explain LG,LL,LLG Faults	5	C324.4	Comprehension
	B. An earth fault occurs on one conductor of 3 conductor cable supplied by 10MVA,3 Phase alternator with neutral earthed. The alternator has Positive , Negative and Zero sequence Impedance of (0.5+j4.7) , (0.2+j0.6) and (j0.43) Ohms respectively. The generator line is excited to give 6.6KV between the lines on Open Circuit.Then Find Fault Current.	5	C324.4	Application

Unit V: **Symmetrical Components & Fault analysis**

	QUESTIONS	Marks	Related to CO	Level of Learning
1	A. What is Fault? Explain the Classification of Faults	5	C324.5	Knowledge
	B Derive the formula for Short Circuit MVA	5	C324.5	Knowledge
2	A transformer rated at 30MVA and having a short circuit reactance of 0.05p.u is connected to the bus bar of a generating station which is supplied through two 33KV feeder cables each having an impedance of (1+j2)Ω.One of the feeders is connected to a generating station using generator capacity of 60MVA connected to its bus bars having a short circuit reactance of 0.1p.u and other feeder to a generator with 80MVA and having a reactance 0.15p.u.Calculate the KVA supplied to the fault in the event of a short circuit occurring between the secondary terminals of the transformer.	10	C324.5	Application

3	Two 3-phase alternators running in parallel each of 5000KVA and having a reactance of 20%, feed directly 11KV substation bus bars. These bus bars feed 33KV through two transformers in parallel each of 5 MVA with 8% reactance. Two overhead transmission lines in parallel are connected to the 33KV bus bars. The line parameters are (3+j5) Ω/phase. If a symmetrical three phase fault occurs at the end of the transmission lines, calculate the fault KVA.	10	C324.5	Application
4	The plant capacity of a three phase generating station consists of two 8 MVA generators of reactance 14.5% each and one 4 MVA generator of reactance 9.5% .These are connected to a common bus bar fro which loads are taken through a number of transformers of 3MVA(step up) each having 4% reactance. Determine the MVA rating of the circuit breakers on i)L.V side ii)H.V side .Reactance are based on the MVA of each equipment	10	C324.5	Application
5	A synchronous generator and motor are rated of 30MVA and 13.2KV and both nave sub transient reactance of 20% and line reactance of 15% on the base of machine ratings. The motor draws 25MW at 0.85pf leading. The terminal voltage is 13KV.When a # phase symmetrical fault occurs at bus terminals, Find sub transient current in generator ,Motor and at Fault Point.	10	C324.5	Application
6	A) Explain in detail symmetrical and Unsymmetrical Faults	5	C324.5	Knowledge
	B)Explain percentage reactance(%X)	5	C324.5	Comprehension

Unit VI: **Power System Stability Analysis**

	QUESTIONS	Marks	Related to CO	Level of Learning
1	A. What is Stability? Explain the types of Stability?	5	C324.6	Knowledge
	B. Derive the expression for Steady state Power	5	C324.6	Knowledge
2	A.Derive swing equation	5	C324.6	Comprehension
	B)Explain swing curve.	5	C324.6	Comprehension

3	A) What is steady state stability? Explain it w.r.t power angle curve	5	C324.6	Knowledge
	B) Expalin the methods to improve steady state stability	5	C324.6	Knowledge
4	A) What is transient stability ? What are the assumptions made to calculate transient stability?	5	C324.6	Knowledge
	b) Expalin the methods to improve Transient stability	5	C324.6	Knowledge
5	A)Explain equal area criterion for the case of load increases.	5	C324.6	Comprehension
	B)Explain equal area criterion for the case of switching operations	5	C324.6	Comprehension
6	Explain equal area criterion for the case of fall with subsequent circuit isolation.	10	C324.6	Comprehension