GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

Course Tittle: ____

Following documents are available in Course File.

S.No.	Points	Yes	No
1	Institute and Department Vision and Mission Statements	✓	
2	PEO & PO Mapping	✓	
3	Academic Calendar	✓	
4	Subject Allocation Sheet	✓	
5	Class Time Table, Individual Timetable (Single Sheet)	✓	
6	Syllabus Copy	✓	
7	Course Handout	✓	
8	CO-PO Mapping	✓	
9	CO-Cognitive Level Mapping	✓	
10	Lecture Notes	✓	
11	Tutorial Sheets With Solution	✓	
12	Soft Copy of Notes/Ppt/Slides	✓	
13	Sessional Question Paper and Scheme of Evaluation	✓	
14	Best, Average and Weak Answer Scripts for Each Sessional Exam. (Photocopies)	✓	
15	Assignment Questions and Solutions	✓	
16	Previous University Question Papers	✓	
17	Result Analysis		
18	Feedback From Students	✓	
19	Course Exit Survey		
20	CO Attainment for All Mids.	✓	
21	Remedial Action.		

Course Instructor / Course Coordinator

(Name)

Course Instructor / Course Coordinator

(Signature)

VISION AND MISSION

Vision of the Institute

To be among the best of the institutions for engineers and technologists with attitudes, skills and knowledge and to become an epicentre of creative solutions.

Mission of the Institute

To achieve and impart quality education with an emphasis on practical skills and social relevance.

Vision of the Department

To impart technical knowledge and skills required to succeed in life, career and help society to achieve self sufficiency.

Mission of the Department

To become an internationally leading department for higher learning.
To build upon the culture and values of universal science and contemporary education.
To be a center of research and education generating knowledge and technologies which lay groundwork in shaping the future in the fields of electrical and electronics engineering.
To develop partnership with industrial, R&D and government agencies and actively participate in conferences, technical and community activities.

PEO'S AND PO'S MAPPINGS

Programme Educational Objectives (PEOs)	Programme Outcomes (POs)											
	1	2	3	4	5	6	7	8	9	10	11	12
1	M	M	-	-	H	-	-	H	H	-	H	H
2	-	-	M	M	H	H	H	-	-	-	-	H
3	-	-	-	-	H	H	M	M	M	M	H	H
4	-	-	-	M	M	H	M	H	H	-	M	H

ACADEMIC CALENDER

REVISED ACADEMIC CALENDAR
Academic Year 2018-19
III B.Tech-II Semester

S.No	EVENT	PERIOD	DURATION
1	1st Spell of Instructions	10-12-2018 to 06-02-2019	8 Weeks 3 Days
2	1st Mid-term Examinations	07-02-2019 to 09-02-2019	3 Days
3	2nd Spell of Instructions	11-02-2019 to 03-04-2019	7 Weeks 5Days
4	2nd Mid-term Examinations	04-04-2019 to 06-04-2019	3 Days
5	Preparation	08-04-2019 to 17-04-2019	9 Days
6	**End Semester Examinations (Theory/ Practicals) Regular**	**18-04-2019 to 08-05-2019**	**2 Weeks 5Days**
7	**Supplementary and Summer Vacation**	**09-05-2019-to 22-06-2019**	**2 Weeks**
8	Commencement of Second Semester , AY	24-06-19	

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

2018-19 II sem Subject Allocation sheet

GRIET/EEE/05B/G/18-19 **30.10.18**

II YEAR(GR17)	Section-A	Section-B
Managerial Economics and Financial Analysis		
Power Generation and Distrubution	SN	SN
AC Machines	VVSM	VVSM
Control Systems	Dr DGP	MS
Princeples of Digital Electronics	PRK	PRK
AC Machines Lab	PPK/DSR	PPK/DSR
Control Systems Lab	MS/PSVD	MS/PSVD
Analog and Digital Electronics Lab	RAK/DKK	RAK/DKK
Value Education and Ethics		
Gender Sensitization Lab	MS/PSVD	MS/PSVD
III YEAR (GR15)		
Computer Methods in Power systems	VVRR/MP	VVRR/MP
Switch Gear & Protection	PSVD	Dr JSD
Management Science		
Utilization of Electrical Energy	MRE	MRE
Non Conventional Sources of Energy		
Neural and Fuzzy Systems		
Sensors&Transducers	UVL	UVL
Power Systems Lab	GSR/YSV	GSR/YSV
Advanced English Communications Skills Lab		
Industry Oriented Mini Project Lab	PPK/AVK/Dr JP	MP/Dr JP
IV YEAR (GR15)		
Programmable Logic Controllers	PK	
Flexible AC Transmission Systems	Dr TSK	
EHV AC Transmission		
Power System Automation		
Modern Power Electronics	AVK	
DSP Based Electromechanical Systems		
Advaced Control Systems		
Programmable Logic Controllers-Lab	VVSM	PK
Main Projects	RAK/Dr SVJK	PK/VVRR
M.Tech PE		
Modeling and Analysis of Electrical Machines	Dr BPB	

Department of Electrical & Electronics Engineering

Digital control of power Electronics and Drive Systems	Dr DGP	
FACTS and Custom power Devices	Dr TSK	
Smart Grids	VVRR	
Audit Course -2	YSV/UVL	
Power Quality Lab	Dr BPB	
Digital Signal Processing Lab	AVK	
MINI Projects	Dr JP/GSR	
M.Tech PS		
Digital Protection of Power System	Dr JSD	
Power System Dynamics -II	Dr SVJK	
FACTS and Custom power Devices	Dr TSK	
Smart Grids	VVRR	
Audit Course -2	YSV/UVL	
Power Quality Lab	Dr BPB	
Power System Protection Lab	VUR	
MINI Projects	Dr JP/GSR	
Other Dept.		
BEE (I YEAR) CSE (6)	MNSR,MK,MVK,	
BEE Lab	MNSR,MK,MVK,YSV,VUR,PS,UVL, MRE,GBR	
EET (II YEAR) Mech (2)	KS	KS
EET LAB (II TEAR) Mech (2)	KS,DKK,PPK,	

HOD,EEE

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

III _YEAR

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

GRIET/PRIN/06/G/01/18-19 — Wef : 10 Dec 2018

BTech - EEE - A — III year - II Semester

DAY/ HOUR	9:00 - 9:45	9:45 - 10:30	10:30 - 11:15	11:15- 12:00	12:00- 12:30	12:30 - 1:20	1:20 - 2:10	2:10 -3:00
MONDAY	SGP		CMPS		B	S&T		UEE
TUESDAY	SGP		S&T		R	UEE		CMPS
WEDNESDAY	MS		UEE		E	SGP		S&T
THURSDAY	IOMP Lab(A1) / AECS Lab(A2)				A	CMPS		S&T
FRIDAY	PS Lab(A2) /AECS Lab(A1)				K	MS		UEE
SATURDAY	IOMP Lab(A2) / PS Lab (A1)					CMPS		SGP

Room No	
Theory	4501
Lab	4504/4407/
Class Incharge:	M Rekha

Subject Code	Subject Name	Faculty Code	Faculty name	Almanac	
CMPS	Computer Methods in Power systems	VVRR/MP	V Vijaya Rama Raju/M Prashanth	1st Spell of Instructions	10-12-2018 to 06-02-2019
SGP	Switch Gear & Protection	PSVD	P Srividya Devi	1st Mid-term Examinations	07-02-2019 to 09-02-2019
MS	Management Science	Dr MSRS	Dr M S R Sesha giri	2nd Spell of Instructions	11-02-2019 to 03-04-2019
UEE	Utilization of Electrical Energy	MRE	M Rekha	2nd Mid-term Examinations	04-04-2019 to 06-04-2019
S&T	Sensors&Transducers	UVL	U Vijaya Lakshmi	Preparation	08-04-2019 to 17-04-2019
PS Lab	Power Systems Lab	GSR/YSV	G Sandhya Rani/Y Satyavani	End Semester Examinations (Theory/ Practicals) Regular	18-04-2019 to 08-05-2019
AECS Lab	Advanced English Communications Skills Lab	ES	E Sailaja		
IOMP Lab	Industry Oriented Mini Project Lab	AVK/PPK /Dr JP	A Vinay Kumar/P Praveen Kumar/ Dr J Praveen	Supplementary and Summer Vacation	09-05-2019-to 22-06-2019
				Commencement of Second Semester , AY	24-06-19

HOD — Co-ordinator — DAA

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

III _ YEAR

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

GRIET/PRIN/06/G/01/18-19 — Wef : 10 Dec 2018

BTech - EEE - B — III year - II Semester

DAY/ HOUR	9:00 - 9:45	9:45 - 10:30	10:30 - 11:15	11:15- 12:00	12:00- 12:30	12:30 - 1:20	1:20 - 2:10	2:10 -3:00
MONDAY	PS Lab(B1) /AECS Lab(B2)				BREAK	UEE	CMPS	
TUESDAY	PS Lab(B2) /IOMP Lab(B1)					CMPS	S&T	
WEDNESDAY	IOMP Lab(B2) / AECS Lab(B1)					SGP	CMPS	
THURSDAY	SGP		UEE			S&T	MS	
FRIDAY	UEE		CMPS			S&T	SGP	
SATURDAY	MS		SGP			UEE	S&T	

Room No	
Theory	4404
Lab	4504/4407/
Class Incharge:	M Rekha

Subject Code	Subject Name	Faculty Code	Faculty name
CMPS	Computer Methods in Power systems	VVRR/MP	V Vijaya Rama Raju/M Prashanth
SGP	Switch Gear & Protection	DrJSD	Dr J Sridevi
MS	Management Science	Dr MSRS	Dr M S R Sesha giri
UEE	Utilization of Electrical Energy	MRE	M Rekha
S&T	Sensors&Transducers	UVL	U Vijaya Lakshmi
PS Lab	Power Systems Lab	GSR/YSV	G Sandhya Rani/Y Satyavani
AECS Lab	Advanced English Communications Skills Lab	ES	E Sailaja
IOMP Lab	Industry Oriented Mini Project Lab	MP/Dr JP	M Prashanth/ Dr J Praveen

Almanac	
1st Spell of Instructions	10-12-2018 to 06-02-2019
1st Mid-term Examinations	07-02-2019 to 09-02-2019
2nd Spell of Instructions	11-02-2019 to 03-04-2019
2nd Mid-term Examinations	04-04-2019 to 06-04-2019
Preparation	08-04-2019 to 17-04-2019
End Semester Examinations (Theory/ Practicals) Regular	18-04-2019 to 08-05-2019
Supplementary and Summer Vacation	09-05-2019-to 22-06-2019
Commencement of Second Semester , AY	24-06-19

HoD — Co-ordinator — DAA

III B.Tech (EEE) II Semester

COMPUTER METHODS IN POWER SYSTEMS

Course Code:GR15A3021 **L T P C III Year II Sem 2 1 0 3**

UNIT I Power flow Studies-1: Per-Unit System of Representation. Per-Unit equivalent reactance network of a three phase Power System, Numerical Problems. Ybus formation by Direct Transformation Method, Numerical Problems. Necessity of Power Flow Studies – Data for Power Flow Studies – Derivation of Static load flow equations – Load flow solutions using Gauss Seidel Method: Acceleration Factor, Load flow solution with and without P-V buses, Algorithm and Flowchart. Numerical Load flow Solution for Simple Power Systems (Max. 3-Buses): Determination of Bus Voltages, Injected Active and Reactive Powers (Sample One Iteration only) and finding Line Flows/Losses for the given Bus Voltages.

UNIT II Power flow Studies-2: Newton Raphson Method in Rectangular and Polar Co-Ordinates Form, Load Flow Solution with and without PV Busses- Derivation of Jacobian Elements, Algorithm and Flowchart. Decoupled and Fast Decoupled Methods.- Comparison of Different Methods – DC load Flow.

UNIT III Formation of Zbus: Partial network, Algorithm for the Modification of Zbus Matrix for addition of an element for the following cases: Addition of an element from a new bus and 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 buses (Derivations and Numerical Problems)-Modification of Zbus for the changes in network (Problems).

Short Circuit Analysis: Symmetrical fault Analysis: Short Circuit Current and MVA Calculations, Fault levels, Application of Series Reactors, Numerical Problems.

Symmetrical Component Theory: Symmetrical Component Transformation, Positive, Negative and Zero sequence components: Voltages, Currents and Impedances.

Sequence Networks: Positive, Negative and Zero sequence Networks, Numerical Problems. Unsymmetrical Fault Analysis: LG, LL, LLG faults with and without fault impedance, Numerical Problems.

UNIT IV Steady State 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 and Methods to improve steady state stability.

UNIT V Power System Transient State Stability Analysis: Derivation of Swing Equation. Determination of Transient Stability by Equal Area Criterion, Application of Equal Area Criterion, Critical Clearing Angle Calculation - Solution of Swing Equation: Point-by-Point Method and Modified Euler's method. Multi machine stability. Methods to improve Stability.

TEXT BOOKS: 1.Electric Power Systems by C. L. Wadhwa, New Age International.

2. Modern Power System Analysis by I.J.Nagrath & D.P.Kothari, Tata McGraw-Hill.

REFERENCES: 1. Power System Analysis by Grainger and Stevenson, Tata McGraw Hill.

2. Power System Analysis by Hadi Saadat, TMH Edition.

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

CO'S AND PO'S MAPPINGS

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ……..…**Electrical**……..… Year: ……**III**……….. Section: A& B

Course/Subject: …**Computer Methods in Power System**…Course Code.. GR15A3021..

Name of the Faculty:**V.Vijaya Rama Raju/M.Prashanth**..........……………Dept.:**EEE**………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

GR15A3021	**Computer Methods in Power System**	1. Able to understand the necessity of per unit system representation of power system components.	H	H	M	M	-	H	M	-	H	-	H	H
		2. Able to calculate the power flows and line losses in the power system under steady state.	-	M	H	H	-	-	M	M	H	M	H	H
		3. Able to design Power System in terms of Positive, Negative & Zero sequence components for fault analysis.	H	H	H	M	-	M	H	-	H	-	H	H
		4. Able to distinguish the difference between steady state and transient stability.	M	H	H	-	M	H	-	M	H	H	M	H
		5. Able to apply various numerical techniques to solve power system problems.	H	M	M	H	-	-	H	H	M	M	-	H

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

COURSE OBJECTIVES

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ……..…**Electrical**……..… Year: ……**III**……….. Section: A& B

Course/Subject: …**Computer Methods in Power System**…Course Code.. GR15A3021..

Name of the Faculty:**V.Vijaya Rama Raju/M.Prashanth**..........……………Dept.:**EEE**………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

The objective of this course is to provide the student:

S.No.	Course Objectives
1.	Represent power system elements using per unit system.
2.	Perform steady-state analysis for a balanced three-phase power system.
3.	Understand the necessity of load flows in a power system.
4.	To analyze the system subjected to various types of faults.
5.	To examine the state of the system subjected to different types of disturbances.

COURSE OUTCOMES

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ……..…**Electrical**……..… Year: ……**III**……….. Section: A& B

Course/Subject: …**Computer Methods in Power System**…Course Code.. GR15A3021..

Name of the Faculty:**V.Vijaya Rama Raju/M.Prashanth**..........……………Dept.:**EEE**………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

The expected outcomes of the Course/Subject are:

S.No	Outcomes
1.	Able to understand the necessity of per unit system representation of power system components.
2.	Able to calculate the power flows and line losses in the power system under steady state.
3.	Able to design Power System in terms of Positive, Negative & Zero sequence components for fault analysis.
4.	Able to distinguish the difference between steady state and transient stability.
5.	Able to apply various numerical techniques to solve power system problems.

Signature of HOD | Signature of faculty

Date: | Date:

Note: Please refer to Bloom's Taxonomy, to know the illustrative verbs that can be used to state the outcomes.

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

GUIDELINES TO STUDY THE COURSE/SUBJECT

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ……..…**Electrical**……..… Year: ……**III**……….. Section: A& B

Course/Subject: …**Computer Methods in Power System**…Course Code.. GR15A3021..

Name of the Faculty:**V.Vijaya Rama Raju/M.Prashanth**..........……………Dept.:**EEE**………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

Guidelines to study the Course/ Subject:Electrical Measurements & Instrumentation

<u>Course Design and Delivery System (CDD):</u>

- The Course syllabus is written into number of learning objectives and outcomes.
- Every student will be given an assessment plan, criteria for assessment, scheme of evaluation and grading method.
- The Learning Process will be carried out through assessments of Knowledge, Skills and Attitude by various methods and the students will be given guidance to refer to the text books, reference books, journals, etc.

The faculty be able to –

- Understand the principles of Learning
- Understand the psychology of students
- Develop instructional objectives for a given topic
- Prepare course, unit and lesson plans
- Understand different methods of teaching and learning
- Use appropriate teaching and learning aids
- Plan and deliver lectures effectively
- Provide feedback to students using various methods of Assessments and tools of Evaluation
- Act as a guide, advisor, counselor, facilitator, motivator and not just as a teacher alone

Signature of HOD | Signature of faculty

Date: | Date:

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering
COURSE SCHEDULE

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ……..….**Electrical**……..…. Year: ……**III**……….. Section: A& B

Course/Subject: …**Computer Methods in Power System**…Course Code.. GR15A3021..

Name of the Faculty:**V.Vijaya Rama Raju/M.Prashanth**..........……………Dept.:**EEE**………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

The Schedule for the whole Course / Subject is:

S. No.	Description	Total No. Of Periods
1.	Power flow Studies-1(YBus,GS Method)	24
2.	Power flow Studies-2(NR, Decoupled and Fast Decoupled methods)	14
3.	Short Circuit Analysis, Sequence Networks and Unsymmetrical Fault Analysis	22
4.	Steady State Stability Analysis	8
5.	Power System Transient State Stability Analysis	10

Total No. of Instructional periods available for the course: .………….. 78 Hours / Periods

SCHEDULE OF INSTRUCTIONS

COURSE PLAN

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ……..…**Electrical**……..…. Year: ……**III**……….. Section: A& B

Course/Subject: …**Computer Methods in Power System**…Course Code.. GR15A3021..

Name of the Faculty:**V.Vijaya Rama Raju/M.Prashanth**..........……………Dept.:**EEE**………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

S.No	Reference Text Books	Author
T1	Computer Techniques and models in Power Systems	K. Uma Rao

Unit No.	Lesson No.	No. of Periods	Topics / Sub-Topics	Objectives & Outcomes Nos.	References (Text Book, Journal…) Page Nos.: ____to ____
1.	1	2	Per-Unit equivalent reactance network of a 3-phase power system and some numerical problems	1,2,3&1,2	16 to 19
	2	2	Formation of Y_{BUS} using Direct Method	1&2	59,60
	3	2	Formation of Y_{BUS} using Singular Transformation method	1&2	38,39
	4	2	Numerical Problems	1,3,4&2	40,42 to 45
	5	2	Introduction to the Power Flow Studies	1,2&1,2	236,237
	6	2	Derivation of the Static Load flow Equations	1,2,3&2	237 to 239
	7	2	Gauss Seidal method for getting Load Flow solutions	1,2,3,4&2	246 to 250
	8	2	Derivation of acceleration Factor	1,2,3,4&2	250
	9	2	Load flow solution with and without PV buses	1,2,3,4&2	247 to 249

	10	2	Algorithms and Flow charts for the Load flow solutions	1,2,3,4&2	247,248
	11	2	Numerical Load flow solution for simple power system of maximum 3 buses	1,2,3,4&2	250 to 252
	12	2	Numerical problems on determination of Bus Voltages, Injected active and reactive powers and line flows/losses for the given bus voltages for one iteration only	1,2,3,4&2	250 to 258
2.	13	2	Introduction to Newton Raphson method in rectangular and polar co-ordinates form	1,2,3,4&2	258 to 269
	14	2	Load flow solution with or without PV buses	1,2,3,4&2	258 to 269
	15	2	Derivation of Jacobian Elements	1,2,3,5&2	258 to 269
	16	2	Algorithm and Flow chart for obtaining Load flow solution using NR method and few problems	1,2,3&2	265,269
	17	2	Decoupled and fast Decoupled Methods	1,2,3&2	270 to 272
	18	2	Comparison of different Methods	1,2,3&2	287 to 289
	19	2	DC Load Flow and some Numerical problems	1,2,5&2,5	272 to 282
3.	20	2	Formation of Z_{BUS} Matrix	1,2,5&1,2	36,37,70,71
	21	2	Modification of Z_{BUS} Matrix for different cases	1,2,3&2	71 to 78
	22	2	Problems on modification of Z_{BUS} Matrix	1,2,3&2	78 to 87
	23	2	Introduction to symmetrical fault analysis and also fault levels	1,2,3&1,2,3	131 to 142
	24	2	Short circuit current and MVA calculations. Few numerical problems	1,2,3&1,2,3	118,119,143 to 151
	25	2	Application of Series Reactors	1,4,5&2,3	

	26	2	Introduction to Symmetrical Component Theory, Symmetrical component transformation	1,3,4&1,2,3	154 to 161
	27	2	Positive, Negative and Zero sequence components : voltages, currents and Impedances	1,2,3,4,5&1,2,3	173 to 175, 179 to 181
	28	2	Problems on Positive, Negative and Zero sequence networks	1,3,4,5&1,2,3	181 to 188
	29	2	Introduction to Unsymmetrical fault analysis and its different types	1,3,4&1,2,3	200 to 209
	30	2	Numerical problems on different unsymmetrical faults with and without fault Impedance	1,3,4&1,2,3	210 to 225
4.	31	2	Introduction to power system steady state stability analysis, concepts of steady state, dynamic and transient stabilities	1,2,5&2,4	351 to 354
	32	2	Description of Steady state stability power limit, transfer reactance	1,2,4&2,4	369 to 372
	33	2	Description of synchronizing power coefficient and power angle curve	1,2,3&2,4	363 to 367
	34	2	Determination of Steady state stability and methods to improve Steady state stability	1,2,4&2,4	369 to 372
5.	35	2	Introduction to power system Transient state stability analysis, derivation of Swing equation	1,2,4&2,5	356 to 361

	36	2	Equal Area Criterion, its applications, Critical clearing angle calculation, few Problems	1,2,4,5&2,5	378 to 382
	37	2	Point-by-Point method	1,2,4,5&2,4	390 to 392
	38	2	Modified Euler's method	1,2,5&4,5	
	39	2	Methods to improve stability	1,2,4,5&2,4,5	413

Signature of HOD

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

SCHEDULE OF INSTRUCTIONS

UNIT PLAN

Academic **Y**ear : 2018-2019

Semester : II UNIT NO.: ………**1**………….

Name of the Program: B.Tech ……..…**Electrical**……..…. Year: ……**III**……….. Section: A&B

Course/Subject: **Computer Methods in Power System**…Course Code: .. GR15A3021..

Name of the Faculty: …… **V.Vijaya Rama Raju/M.Prashanth** ……………….Dept.: …**EEE**………
Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

S.No	Reference Text Books	Author
T1	Computer Techniques and models in Power Systems	K. Uma Rao

Lesson No.	No. of Periods	Topics / Sub - Topics	Objectives	Outcomes	References (Text Book, Journal…) Page Nos.: ____to ____
1	2	Per-Unit equivalent reactance network of a 3-phase power system and some numerical problems	1,2,3	1,2	16 to 19
2	2	Formation of Y_{BUS} using Direct Method	1	2	59,60
3	2	Formation of Y_{BUS} using Singular Transformation method	1	2	38,39
4	2	Numerical Problems	1,3,4	2	40,42 to 45
5	2	Introduction to the Power Flow Studies	1,2	1,2	236,237
6	2	Derivation of the Static Load flow Equations	1,2,3	2	237 to 239
7	2	Gauss Seidal method for getting Load Flow solutions	1,2,3,4	2	246 to 250
8	2	Derivation of acceleration Factor	1,2,3,4	2	250
9	2	Load flow solution with and without PV buses	1,2,3,4	2	247 to 249
10	2	Algorithms and Flow charts for the Load flow solutions	1,2,3,4	2	247,248

11	2	Numerical Load flow solution for simple power system of maximum 3 buses	1,2,3,4	2	250 to 252
12	2	Numerical problems on determination of Bus Voltages, Injected active and reactive powers and line flows/losses for the given bus voltages for one iteration only	1,2,3,4	2	250 to 258

Signature of HOD   Signature of faculty

Date: Date:

Note:
1. ENSURE THAT ALL TOPICS SPECIFIED IN THE COURSE ARE MENTIONED.
2. ADDITIONAL TOPICS COVERED, IF ANY, MAY ALSO BE SPECIFIED IN BOLD
3. MENTION THE CORRESPONDING COURSE OBJECTIVE AND OUT COME NUMBERS AGAINST EACH TOPIC.

SCHEDULE OF INSTRUCTIONS

UNIT PLAN

Academic **Y**ear : 2018-2019

Semester : II UNIT NO.: ………**2**…………

Name of the Program: B.Tech ……..…**Electrical**……..… Year: ……**III**……….. Section: A&B

Course/Subject: **Computer Methods in Power System**…Course Code: .. GR15A3021..

Name of the Faculty: …… **V.Vijaya Rama Raju/M.Prashanth** ……………….Dept.: …**EEE**………
Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

S.No	Reference Text Books	Author
T1	Computer Techniques and models in Power Systems	K. Uma Rao

Lesson No.	No. of Periods	Topics / Sub - Topics	Objectives	Outcomes	References (Text Book, Journal…) Page Nos.: ____to ____
1	2	Introduction to Newton Raphson method in rectangular and polar co-ordinates form	1,2,3,4	2	258 to 269
2	2	Load flow solution with or without PV buses	1,2,3,4	2	258 to 269
3	2	Derivation of Jacobian Elements	1,2,3,5	2	258 to 269
4	2	Algorithm and Flow chart for obtaining Load flow solution using NR method and few problems	1,2,3	2	265,269
5	2	Decoupled and fast Decoupled Methods	1,2,3	2	270 to 272
6	2	Comparison of different Methods	1,2,3	2	287 to 289
7	2	DC Load Flow and some Numerical problems	1,2,5	2,5	272 to 282

Signature of HOD Signature of faculty

Date: Date:

Note: 1. ENSURE THAT ALL TOPICS SPECIFIED IN THE COURSE ARE MENTIONED.
2. ADDITIONAL TOPICS COVERED, IF ANY, MAY ALSO BE SPECIFIED IN BOLD
3. MENTION THE CORRESPONDING COURSE OBJECTIVE AND OUT COME NUMBERS AGAINST EACH TOPIC.

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

SCHEDULE OF INSTRUCTIONS

UNIT PLAN

Academic **Y**ear : 2018-2019

Semester : II UNIT NO.: ………**3**…………

Name of the Program: B.Tech ……..…**Electrical**……..… Year: ……**III**……….. Section: A&B

Course/Subject: **Computer Methods in Power System**…Course Code: .. GR15A3021..

Name of the Faculty: …… **V.Vijaya Rama Raju/M.Prashanth** ……………….Dept.: …**EEE**………
Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

S.No	Reference Text Books	Author
T1	Computer Techniques and models in Power Systems	K. Uma Rao

Lesson No.	No. of Periods	Topics / Sub - Topics	Objectives	Outcomes	References (Text Book, Journal…) Page Nos.: ____to ____
1	2	Formation of Z_{BUS} Matrix	1,2,5	1,2	36,37,70,71
2	2	Modification of Z_{BUS} Matrix for different cases	1,2,3	2	71 to 78
3	2	Problems on modification of Z_{BUS} Matrix	1,2,3	2	78 to 87
4	2	Introduction to symmetrical fault analysis and also fault levels	1,2,3	1,2,3	131 to 142
5	2	Short circuit current and MVA calculations. Few numerical problems	1,2,3	1,2,3	118,119,143 to 151
6	2	Application of Series Reactors	1,4,5	2,3	
7	2	Introduction to Symmetrical Component Theory, Symmetrical component transformation	1,3,4	1,2,3	154 to 161
8	2	Positive, Negative and Zero sequence components : voltages, currents and Impedances	1,2,3,4,5	1,2,3	173 to 175, 179 to 181

9	2	Problems on Positive, Negative and Zero sequence networks	1,3,4,5	1,2,3	181 to 188
10	2	Introduction to Unsymmetrical fault analysis and its different types	1,3,4	1,2,3	200 to 209
11	2	Numerical problems on different unsymmetrical faults with and without fault Impedance	1,3,4	1,2,3	210 to 225

Signature of HOD

Date:

Signature of faculty

Date:

Note: 1. ENSURE THAT ALL TOPICS SPECIFIED IN THE COURSE ARE MENTIONED.
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3. MENTION THE CORRESPONDING COURSE OBJECTIVE AND OUT COME NUMBERS AGAINST EACH TOPIC.

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

SCHEDULE OF INSTRUCTIONS

UNIT PLAN

Academic **Y**ear : 2018-2019

Semester : II UNIT NO.: ………**4**…………

Name of the Program: B.Tech ……..…**Electrical**……..… Year: ……**III**……….. Section: A&B

Course/Subject: **Computer Methods in Power System**…Course Code: .. GR15A3021..

Name of the Faculty: …… **V.Vijaya Rama Raju/M.Prashanth** ……………….Dept.: …**EEE**………
Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

S.No	Reference Text Books	Author
T1	Computer Techniques and models in Power Systems	K. Uma Rao

Lesson No.	No. of Periods	Topics / Sub - Topics	Objectives	Outcomes	References (Text Book, Journal…) Page Nos.: ____to ____
1	2	Introduction to power system steady state stability analysis, concepts of steady state, dynamic and transient stabilities	1,2,5	2,4	351 to 354
2	2	Description of Steady state stability power limit, transfer reactance	1,2,4	2,4	369 to 372
3	2	Description of synchronizing power coefficient and power angle curve	1,2,3	2,4	363 to 367
4	2	Determination of Steady state stability and methods to improve Steady state stability	1,2,4	2,4	369 to 372

Signature of HOD Signature of faculty

Date: Date:

Note: 1. ENSURE THAT ALL TOPICS SPECIFIED IN THE COURSE ARE MENTIONED.
2. ADDITIONAL TOPICS COVERED, IF ANY, MAY ALSO BE SPECIFIED IN BOLD
3. MENTION THE CORRESPONDING COURSE OBJECTIVE AND OUT COME NUMBERS AGAINST EACH TOPIC.

SCHEDULE OF INSTRUCTIONS

UNIT PLAN

Academic **Y**ear : 2018-2019

Semester : II UNIT NO.: ………**5**…………

Name of the Program: B.Tech ……..…**Electrical**……..… Year: ……**III**……….. Section: A&B

Course/Subject: **Computer Methods in Power System**…Course Code: .. GR15A3021..

Name of the Faculty: …… **V.Vijaya Rama Raju/M.Prashanth** ……………….Dept.: …**EEE**………
Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

S.No	Reference Text Books	Author
T1	Computer Techniques and models in Power Systems	K. Uma Rao

Lesson No.	No. of Periods	Topics / Sub - Topics	Objectives	Outcomes	References (Text Book, Journal…) Page Nos.: ____to ____
1	2	Introduction to power system Transient state stability analysis, derivation of Swing equation	1,2,4	2,5	356 to 361
2	2	Equal Area Criterion, its applications, Critical clearing angle calculation, few Problems	1,2,4,5	2,5	378 to 382
3	2	Point-by-Point method	1,2,4,5	2,5	390 to 392
4	2	Modified Euler's method	1,2,5	4,5	
5	2	Methods to improve stability	1,2,4,5	2,4,5	413

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Date: Date:

Note: 1. ENSURE THAT ALL TOPICS SPECIFIED IN THE COURSE ARE MENTIONED.
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3. MENTION THE CORRESPONDING COURSE OBJECTIVE AND OUT COME NUMBERS AGAINST EACH TOPIC.

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ………………..**Electrical**…Year: ………**III**.………....Section: A&B

Course/Subject: ……………**Computer Methods in power System**……………..……………..

Name of the Faculty: **V.Vijaya Rama Raju/M.Prashanth** …………………Dept.:…**EEE**…………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

Lesson No: …………………….1&2…………….Duration of Lesson: ……... 90min……………….

Lesson Title: Per-Unit equivalent reactance network of a 3-phase power system and some numerical problems

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Understand the p.u reactance daigram

TEACHING AIDS : OHP PROJECTOR, WHITEBOARD, MARKER, DUSTER.
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Derive p.u reactance diagram.
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: Explain the p.u. system of analyzing power system problems. Discuss the advantages of this method over the absolute method of analysis. (Obj;- 1,2,3 Out;-1,2)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering
LESSON PLAN

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ………………..**Electrical**…Year: ………**III**.………....Section: A&B

Course/Subject: ……………**Computer Methods in power System**……………..……………..

Name of the Faculty: **V.Vijaya Rama Raju/M.Prashanth** …………………Dept.:…**EEE**…………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

Lesson No: ……………………..3&4…………….Duration of Lesson: ……... 90min……………….

Lesson Title: Formation of Y_{BUS} using Direct Method

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Determine the Ybus using Direct Method.

TEACHING AIDS : OHP PROJECTOR, WHITEBOARD, MARKER, DUSTER

TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Form the Ybus by using Direct Method.
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: Advantage of Direct Method for Formation of Ybus (Obj;- 1 Out;-2)

Signature of faculty

LESSON PLAN

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ………………..**Electrical**…Year: ………**III**..………....Section: A&B

Course/Subject: ……………**Computer Methods in power System**……………..……………..

Name of the Faculty: **V.Vijaya Rama Raju/M.Prashanth** …………………Dept.:…**EEE**…………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

Lesson No: …………………….5&6…………….Duration of Lesson: ……... 90min……………….

Lesson Title: Formation of Y_{BUS} using Singular Transformation method

INSTITUTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Determine the Ybus using Singular transformation method

TEACHING AIDS : OHP PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Form the Ybus by using Singular transformation method
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: Derive Ybus by using Singular transformation method (Obj;- 1 Out;-2)

Signature of faculty

LESSON PLAN

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ………………..**Electrical**…Year: ………**III**..………....Section: A&B

Course/Subject: ……………**Computer Methods in power System**……………..……………..

Name of the Faculty: **V.Vijaya Rama Raju/M.Prashanth** …………………Dept.:…**EEE**…………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

Lesson No: …………………….7&8…………….Duration of Lesson: ……... 90min……………….

Lesson Title: Numerical Problems on Ybus formation

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Form the Ybus and compare both the methods

TEACHING AIDS : OHP PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Numerical problems on Ybus Formation
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: What are the advantages of Ybus(Obj;- 1,3,4 Out;-2)

Signature of faculty

LESSON PLAN

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ………………..**Electrical**…Year: ………**III**..………....Section: A&B

Course/Subject: ……………**Computer Methods in power System**……………..……………..

Name of the Faculty: **V.Vijaya Rama Raju/M.Prashanth** …………………Dept.:…**EEE**…………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

Lesson No: …………………….9&10…………….Duration of Lesson: ……... 90min……………….

Lesson Title: Introduction to the Power Flow Studies

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Know different types of buses
2. Know the planning , design and operation a power system

TEACHING AIDS : OHP PROJECTOR, WHITEBOARD, MARKER, DUSTER

TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Power Flow Studies and its equations.
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: Q1. (a) What is the load flow study and explain the need for load flow solution.
(b) What are the assumptions in SLFE(static load ow equations) and derive the approximate load flow equations (Obj;- 1,2Out;-1,2)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ………………..**Electrical**…Year: ………**III**.………....Section: A&B

Course/Subject: ……………**Computer Methods in power System**……………..……………..

Name of the Faculty: **V.Vijaya Rama Raju/M.Prashanth** …………………Dept.:…**EEE**…………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

Lesson No: ……………………..11&12…………….Duration of Lesson: ……... 90min……………….
Lesson Title: Derivation of the Static Load flow Equations

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Know different types of buses
2. Know the Static Load flow Equations

TEACHING AIDS : OHP PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Classification of buses, Derivation of the Static Load flow Equations.
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: 1) What are the assumptions in SLFE(static load ow equations) and derive the approximate load flow equations (Obj;- 1,2,3 Out;-2)

Signature of faculty

GOKARAJU RANGARAJU
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Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ………………..**Electrical**…Year: ………**III**..………...Section: A&B

Course/Subject: ……………**Computer Methods in power System**……………..……………..

Name of the Faculty: **V.Vijaya Rama Raju/M.Prashanth** …………………Dept.:…**EEE**…………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

Lesson No: …………………….12&13…………….Duration of Lesson: ……... 90min……………….
Lesson Title: Gauss Seidal method for getting Load Flow solutions

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Know the Gauss Seidal method

TEACHING AIDS : OHP PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Explain Gauss Seidal method.
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: 1) Explain the load flow solution using G-S method. (Obj;- 1,2,3,4Out;-2)

Signature of faculty

LESSON PLAN

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ………………..**Electrical**…Year: ………**III**..………....Section: A&B

Course/Subject: ……………**Computer Methods in power System**……………..……………..

Name of the Faculty: **V.Vijaya Rama Raju/M.Prashanth** …………………Dept.:…**EEE**…………

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Lesson No: …………………….15&16…………….Duration of Lesson: ……... 90min……………….
Lesson Title: Derivation of acceleration factor

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Know the calculation of acceleration factor for GS method
2. Know the different values of acceleration factor for various conditions

TEACHING AIDS : OHP PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- First 5 minutes for Attendance.
- Next 10 minutes for Revision of Previous Topic that Covered.
- Next 60 minutes for the Class (acceleration factor)
- Last 15 minutes for doubts.

Assignment / Questions: 1) Explain the load flow solution using G-S method assuming different acceleration factors (Obj;- 1,2,3,4 Out;-2)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ………………..**Electrical**…Year: ………**III**.………....Section: A&B

Course/Subject: ……………**Computer Methods in power System**……………..……………..

Name of the Faculty: **V.Vijaya Rama Raju/M.Prashanth** …………………Dept.:…**EEE**…………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

Lesson No: ……………………..17&18…………….Duration of Lesson: ……... 90min……………….

Lesson Title: Load flow solution with and without PV buses

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Know the Load flow solution for different cases
2. Know the GS method

TEACHING AIDS : OHP PROJECTOR, WHITEBOARD, MARKER, DUSTER

TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Load flow solution with and without PV buses
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions:1) Explain the load flow solution using G-S method with and without PV buses (Obj;- 1,2,3,4 Out;-2)

Signature of faculty

LESSON PLAN

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ………………..**Electrical**…Year: ………**III**..………....Section: A&B

Course/Subject: ……………**Computer Methods in power System**……………..……………..

Name of the Faculty: **V.Vijaya Rama Raju/M.Prashanth** …………………Dept.:…**EEE**…………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

Lesson No: …………………….19&20…………….Duration of Lesson: ……... 90min……………….
Lesson Title: Algorithms and Flow charts for the Load flow solutions

.
INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1 .Derive the Load flow solutions.

TEACHING AIDS :OHP PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Load flow solutions.
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: Derscribe the algorithms and Flow charts for the Load flow solutions (Obj;- 1,2,3,4 Out;-2)

Signature of faculty

GOKARAJU RANGARAJU
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Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ………………..**Electrical**…Year: ………**III**.………....Section: A&B

Course/Subject: ……………**Computer Methods in power System**……………..……………..

Name of the Faculty: **V.Vijaya Rama Raju/M.Prashanth** …………………Dept.:…**EEE**…………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

Lesson No: …………………….21&22…………….Duration of Lesson: ……... 90min……………….
Lesson Title: Numerical Load flow solution for simple power system of maximum 3 buses
.

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Solve the Load flow solution for simple power system

TEACHING AIDS : OHP PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Numerical Load flow solution for simple power system
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: Consider a simple 3 bus power system and solve the Load flow solution.(Obj;-1,2,3,4Out;-2)

Signature of faculty

LESSON PLAN

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ………………..**Electrical**…Year: ………**III**..………....Section: A&B

Course/Subject: ……………**Computer Methods in power System**……………..……………..

Name of the Faculty: **V.Vijaya Rama Raju/M.Prashanth** …………………Dept.:…**EEE**…………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

Lesson No: …………………….23&24…………….Duration of Lesson: ……... 90min……………….

Lesson Title: Numerical problems on determination of Bus Voltages, Injected active and reactive powers and line flows/losses for the given bus voltages for one iteration only.

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Solve problems on determination of Bus Voltages, Injected active and reactive powers
2. Solve problems on line flows/losses for the given bus voltages for one iteration only

TEACHING AIDS : OHP PROJECTOR, WHITEBOARD, MARKER, DUSTER

TEACHING POINTS :

- First 5 minutes for Attendance.
- Next 10 minutes for Revision of Previous Topic that Covered.
- Next 60 minutes for the Class (Numerical problems)
- Last 15 minutes for doubts.

Assignment / Questions: Find the voltages at the end of first iteration by using G-S method.(Obj;- 1,2,3,4Out;-2)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ………………..**Electrical**…Year: ………**III**..………....Section: A&B

Course/Subject: ……………**Computer Methods in power System**……………..……………..

Name of the Faculty: **V.Vijaya Rama Raju/M.Prashanth** …………………Dept.:…**EEE**…………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

Lesson No: …………………….25&26…………….Duration of Lesson: ……... 90min……………….
Lesson Title: Introduction to Newton Raphson method in rectangular and polar co-ordinates form.

<u>INSTRUCTIONAL/LESSON OBJECTIVES:</u>

On completion of this lesson the student shall be able to:

1. Know Newton Raphson method in rectangular co-ordinates form
2. Know Newton Raphson method in polar co-ordinates form

TEACHING AIDS : LCD PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Newton Raphson method in rectangular and polar co-ordinates form.
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: Develop load flow equations suitable for solution by N-R method using rectangular coordinates when only PQ buses are present (Obj;- 1,2,3,4Out;-2)

Signature of faculty

LESSON PLAN

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ………………..**Electrical**…Year: ………**III**..………...Section: A&B

Course/Subject: ……………**Computer Methods in power System**……………..……………..

Name of the Faculty: **V.Vijaya Rama Raju/M.Prashanth** …………………Dept.:…**EEE**…………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

Lesson No: …………………….27&28…………….Duration of Lesson: ……... 90min……………….
Lesson Title: Load flow solution with or without PV buses.

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Derive the Load flow solution with or without PV buses

.

TEACHING AIDS : LCD PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Determination of Load flow solution
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: Develop load flow equations suitable for solution by N-R method using rectangular coordinates when only PQ buses are present (Obj;- 1,2,3,4Out;-2)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ………………..**Electrical**…Year: ………**III**..………....Section: A&B

Course/Subject: ……………**Computer Methods in power System**……………..……………..

Name of the Faculty: **V.Vijaya Rama Raju/M.Prashanth** …………………Dept.:…**EEE**…………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

Lesson No: …………………….29&30…………….Duration of Lesson: ……... 90min……………….
Lesson Title: Derivation of Jacobian elements.

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Compute the Jacobian elements

TEACHING AIDS : LCD PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Deriving Jacobian elements.
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: Derive the necessary expressions for the off diagonal and diagonal elements of the sub matrices J1 ,J2 , J3 and J4 for carrying out a load flow study on power system by using N-R method in polar form.(Obj;- 1,2,3,4Out;-2)

Signature of faculty

GOKARAJU RANGARAJU
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Department of Electrical & Electronics Engineering

LESSON PLAN

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ………………..**Electrical**…Year: ………**III**.………....Section: A&B

Course/Subject: ……………**Computer Methods in power System**……………..……………..

Name of the Faculty: **V.Vijaya Rama Raju/M.Prashanth** …………………Dept.:…**EEE**…………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

Lesson No: …………………….31&32…………….Duration of Lesson: ……... 90min……………….

Lesson Title: Algorithm and Flow chart for obtaining Load flow solution using NR method and few problems.

.

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Know the Algorithm and Flow chart for obtaining Load flow solution using NR method
2. Solve problems on NR method

TEACHING AIDS : LCD PROJECTOR, WHITEBOARD, MARKER, DUSTER

TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: NR Method and few problems
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: Write the algorithm for N-R method using rectangular coordinates when PV buses are absent (Obj;- 1,2,3,4 Out;-2)

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LESSON PLAN

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ………………..**Electrical**…Year: ………**III**..………....Section: A&B

Course/Subject: ……………**Computer Methods in power System**……………..……………..

Name of the Faculty: **V.Vijaya Rama Raju/M.Prashanth** …………………Dept.:…**EEE**…………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

Lesson No: ……………………..33&34…………….Duration of Lesson: ……... 90min……………….
Lesson Title: Decoupled and fast Decoupled methods.

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Know the Decoupled and fast Decoupled methods

TEACHING AIDS : LCD PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Decoupled and fast Decoupled methods
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: 1.Write the algorithm for FDLF method
2.What are the assumptions in FDLF method?(Obj;- 1,2,3,4 Out;-2,5)

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Course/Subject: ……………**Computer Methods in power System**……………..……………..

Name of the Faculty: **V.Vijaya Rama Raju/M.Prashanth** …………………Dept.:…**EEE**…………

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Lesson No: …………………….35&36…………….Duration of Lesson: ……... 90min……………….
Lesson Title: Comparison of different methods.

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Know which method is better one
2. Know the various conditions in each method

TEACHING AIDS : LCD PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Comparison of different Load flow solution methods.
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions:.1. Compare the different methods of load flow techniques.
2.Compare G-S method and N-R methods.(Obj;- 1,2,3,4 Out;-2,5)

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Name of the Faculty: **V.Vijaya Rama Raju/M.Prashanth** …………………Dept.:…**EEE**…………

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Lesson No: …………………….37&38…………….Duration of Lesson: ……... 90min……………….
Lesson Title: DC Load Flow and some Numerical problems.

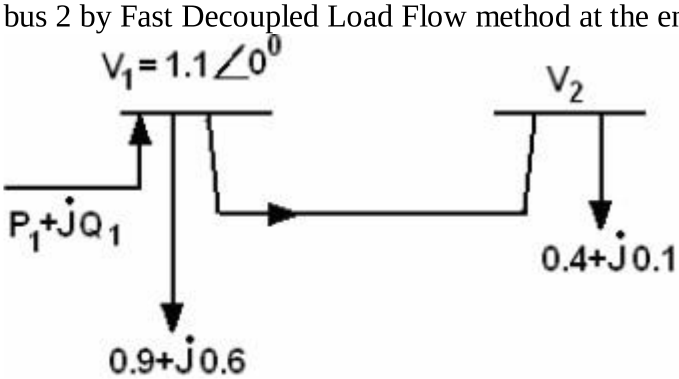
INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Solve all the numerical problems related to different load flow methods
TEACHING AIDS : LCD PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: some Numerical problems
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions:1. A 2 bus system is as shown in the following figure. Determine the voltage at bus 2 by Fast Decoupled Load Flow method at the end of first iteration.(Obj;- 1,2,3,4Out;-2,5)



$$Y_{BUS} = \begin{bmatrix} 1.4\angle -60^0 & 1.7\angle 110^0 \\ 1.7\angle 110^0 & 1.4\angle -60^0 \end{bmatrix}$$

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Lesson No: ……………………..39&40…………….Duration of Lesson: ……... 90min……………….
Lesson Title: Formation of Z_{BUS} Matrix.

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1.Form Z_{BUS} Matrix from a network

TEACHING AIDS : LCD PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Formation of Z_{BUS} Matrix from a network.
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: Assume a simple 3-bus system and obtain Z_{BUS}.(Obj;- 1,2 Out;-1,2)

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Name of the Faculty: **V.Vijaya Rama Raju/M.Prashanth** …………………Dept.:…**EEE**…………

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Lesson No: …………………….41&42…………….Duration of Lesson: ……... 90min……………….

Lesson Title: Modification of Z_{BUS} Matrix for different cases.

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Modify the Z_{BUS} for any changes in the network.

TEACHING AIDS : LCD PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Modification of Z_{BUS} Matrix for different cases
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: 1.Derive the formulae for the Z_{BUS} using building algorithm for the addition of link with mutual coupling to other elements.(Obj;- 1,2,3 Out;-1,2)

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Lesson No: …………………….43&44……………Duration of Lesson: ……... 90min……………….
Lesson Title: Problems on modification of Z_{BUS} Matrix.

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Modify the Z_{BUS} for any changes in the network

TEACHING AIDS : LCD PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Modify the Z_{BUS} for any changes in the network
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: Derive the formulae for the Z_{BUS} using building algorithm for the addition of a new bus with mutual coupling to other elements (Obj;- 1,2,3 Out;-2)

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Course/Subject: ……………**Computer Methods in power System**…………….……………..

Name of the Faculty: **V.Vijaya Rama Raju/M.Prashanth** …………………Dept.:…**EEE**…………

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Lesson No: …………………….45&46…………….Duration of Lesson: ……... 90min……………….
Lesson Title: Introduction to symmetrical fault analysis and also fault levels.

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Know the symmetrical fault analysis
2. Know the different fault levels

TEACHING AIDS : LCD PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: symmetrical fault analysis.
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: 1) A 65-MVA star-connected 16 kV synchronous generator is connected to 20kV/120kV, 75 MVA _/Y transformer. The sub-transient reactance of the machine is 0.32p.u. and the reactance of transformer is 0.1 p. u. When the machine is unloaded, a 3-phase fault takes place on the HT side of the transformer. Determine the sub transient symmetrical fault current on both sides of the transformer. (Obj;- 1,2,3 Out;-1,2,3)

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Lesson No: …………………….47&48…………….Duration of Lesson: ……... 90min……………….
Lesson Title: Application of Series Reactors.

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Know about series reactors and their applications

TEACHING AIDS : LCD PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Series Reactors.
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: What is a series reactor and what are its applications (Obj;- 1,4Out;-2,3)

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Lesson No: …………………….49&50…………….Duration of Lesson: ……... 90min……………….
Lesson Title: Introduction to Symmetrical Component Theory, Symmetrical component transformation.

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Know about Symmetrical Components
2. Know about Symmetrical Component transformation

TEACHING AIDS : LCD PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Symmetrical Component Theory, Symmetrical component transformation.
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: Develop fault impedance matrix in sequence component form for a three phase fault at a bus in a power system for short circuit studies (Obj;- 1,3,4 Out;-1,2,3)

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Lesson No: ……………………..51&52…………….Duration of Lesson: ……... 90min……………….

Lesson Title: Positive, Negative and Zero sequence components : voltages, currents and impedances

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Know the sequence components

TEACHING AIDS : LCD PROJECTOR, WHITEBOARD, MARKER, DUSTER

TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Positive, Negative and Zero sequence components of voltages, currents and impedances.
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: Derivetheexpressionsforfaultcurrentatbusesandlines,voltagesatthefaulted andother buseswhenasinglelinetogroundfaultoccursatabusonconventional phase ‘a’, using fault impedance and Bus impedance matrices in phase component form (Obj;- 1,2,3,4 Out;-1,2,3)

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Lesson No: …………………….53&54…………….Duration of Lesson: ……... 90min……………….

Lesson Title: Problems on Positive, Negative and Zero sequence networks

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Solve different problems on the sequence networks

TEACHING AIDS : LCD PROJECTOR, WHITEBOARD, MARKER, DUSTER

TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Numerical problems.
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: Derive the expressions for fault current at buses and lines, voltages at the faulted and other buses when a single line to ground fault occurs at a bus on conventional phase ‘a’, using fault impedance and Bus impedance matrices in phase component form (Obj;- 1,3,4Out;-1,2,3)

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Lesson No: …………………….55&56…………….Duration of Lesson: ……... 90min……………….
Lesson Title: Introduction to Unsymmetrical fault analysis and its different types

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Know the different types of Unsymmetrical faults
2. Analyze the Unsymmetrical faults

TEACHING AIDS : LCD PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Unsymmetrical fault analysis and its different types
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: What are the different types of Unsymmetrical faults(Obj;- 1,3,4Out;-1,2,3)

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Lesson No: …………………….57&58…………….Duration of Lesson: ……... 90min……………….
Lesson Title: Numerical problems on different unsymmetrical faults with and without fault impedance
INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Solve problems on different unsymmetrical faults with fault impedance
2. Solve problems on different unsymmetrical faults without fault impedance

TEACHING AIDS : LCD PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Numerical problems
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: Derive the expressions for fault Current at the buses and lines , Voltages at the faulted bus and at other buses when a single ?line-to-ground fault occurs at a bus on conventional phase ‘a’, using fault impedance and Bus impedance matrices , in sequence component form. (Obj;- 1,3,4Out;-1,2,3)

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Lesson No: ……………………..59&60…………….Duration of Lesson: ……... 90min……………….
Lesson Title: Introduction to power system steady state stability analysis, concepts of steady state, dynamic and transient stabilities

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Know about power system steady state stability analysis
2. Know the concepts of steady state, dynamic and transient stabilities

TEACHING AIDS : LCD PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Power system steady state stability analysis, concepts of steady state, dynamic and transient stabilities
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: 1) (a) Define the following terms :
i. Steady state stability limit.
ii. Dynamic state stability limit.
iii. Transient state stability limit .
2.List the assumptions made in the transient stability solution techniques (Obj;- 1,2,4Out;-2,4)

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Lesson No: …………………….61&62…………….Duration of Lesson: ……... 90min……………….
Lesson Title: Description of Steady state stability power limit, transfer reactance

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Know about Steady state stability power limit
2. Know about transfer reactance

TEACHING AIDS : LCD PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Steady state stability power limit, transfer reactance
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: 1) The steady state limit of a power system is 100 MW. A generator with constant excitation is supplying 50 MW to the system. Estimate the maximum permissible sudden increase in generator output without causing instability (Obj;- 1,2,4 Out;-2,4)

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Lesson No: …………………….63&64…………….Duration of Lesson: ……... 90min……………….
Lesson Title: Description of synchronizing power coefficient and power angle curve

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Know about synchronizing power coefficient
2. Know about power angle curve

TEACHING AIDS : LCD PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Synchronizing power coefficient and power angle curve
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: 1.What is synchronizing power coefficient
2.What is power angle curve (Obj;- 1,2,4 Out;-2,4)

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Lesson No: …………………….65&66…………….Duration of Lesson: ……... 90min……………….
Lesson Title: Determination of Steady state stability and methods to improve Steady state stability

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Know about Steady state stability
2. Know how to improve Steady state stability

TEACHING AIDS : LCD PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Steady state stability and methods to improve Steady state stability
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: 1.Define Steady state stability
2.Desribe the methods to improve Steady state stability (Obj;- 1,2,4Out;-2,4)

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Lesson No: …………………….67&68…………….Duration of Lesson: ……... 90min……………….
Lesson Title: Introduction to power system Transient state stability analysis, derivation of Swing equation

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:
1.Analyze the power system Transient state stability
2. Derive the Swing equation

TEACHING AIDS : LCD PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Power system Transient state stability analysis, derivation of Swing equation
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions:1. Derive the Swing equation
2.Define the power system Transient state stability (Obj;- 1,2,5Out;-2,5)

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Lesson No: …………………….69&70…………….Duration of Lesson: ……... 90min……………….
Lesson Title: Equal Area Criterion, its applications, Critical clearing angle calculation, few problems

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Know Equal Area Criterion, its applications
2. Calculate Critical clearing angle

TEACHING AIDS : LCD PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Equal Area Criterion, Critical clearing angle, few problems
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: A 50 Hz, three-phase synchronous generator delivers 1.00 p.u. power to an in_nite busbar through a network in which resistance is negligible. A fault occurs which reduces the maximum power transferable to 0.40 p.u. whereas, before the fault, this power was 1.8 p.u. and, after the clearance of the fault 1.30 p.u. By the use of equal area criterion, determine the critical angle.(Obj;- 1,2,5Out;-2,5)

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Lesson No: …………………….71&72…………….Duration of Lesson: ……... 90min……………….
Lesson Title: Point-by-Point method

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Know the Point-by-Point method

TEACHING AIDS : LCD PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Point-by-Point method
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: Describe the Point-by-Point method.(Obj;- 1,2,5Out;-2,5)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering
LESSON PLAN

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ………………..**Electrical**…Year: ………**III**..………...Section: A&B

Course/Subject: ……………**Computer Methods in power System**……………..……………..

Name of the Faculty: **V.Vijaya Rama Raju/M.Prashanth** …………………Dept.:…**EEE**…………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

Lesson No: …………………….73&74…………….Duration of Lesson: ……... 90min……………….
Lesson Title: Modified Euler's method

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

2. Know the Modified Euler's method

TEACHING AIDS : LCD PROJECTOR, WHITEBOARD, MARKER, DUSTER
TEACHING POINTS :

- 5 min.: Taking attendance
- 15 min.: Re collecting the contents of previous class.
- 60 min.: Modified Euler's method
- 10min.: Doubts clarification and Review of the class.

Assignment / Questions: Describe the Modified Euler's method.(Obj;- 1,2,5Out;-2,5)

Signature of faculty

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering
ASSIGNMENT SHEET – 1

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ……..…**Electrical**……..… Year: ……**III**……….. Section: A&B

Course/Subject: … **Computer Methods in power System** …Course Code: .. GR15A3021.

Name of the Faculty: …… **V.Vijaya Rama Raju/M.Prashanth** ………………..Dept.: …**EEE**………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR
This Assignment corresponds to Unit No. / Lesson ………………**1**………………………….

Q1. Discuss the advantages and disadvantages of finding Ybus by

Q2. (a) Prove that when there is no mutual coupling, the diagonal and off-diagonal elements of YBus can be computed from $Y_{ii} = \sum y_{ij}$ and $Y_{ij} = -y_{ij}$.

Objective Nos.: ……………………1,3,4…………………………………………………………….

Outcome Nos.: ……………………1,2,3,4………………………………………………………….

Signature of HOD

Date:

Signature of faculty

Date:

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

ASSIGNMENT SHEET – 2

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech …….….**Electrical**……..… Year: ……**III**……….. Section: A&B

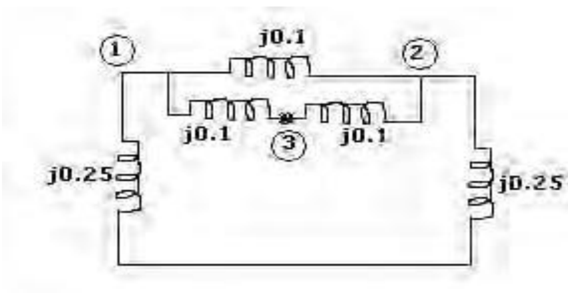
Course/Subject: … **Computer Methods in power System** …Course Code: .. GR15A3021.

Name of the Faculty: …… **V.Vijaya Rama Raju/M.Prashanth** ………………..Dept.: …**EEE**………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

This Assignment corresponds to Unit No. / Lesson ………………**2**………………………….

Q1. For the 3-bus system shown, obtain Zbus.



Q2. Derive the formulae for the Z_{BUS} using building algorithm for the addition of a new bus with mutual coupling to other elements.

Q3. Derive the formulae for the Z_{BUS} using building algorithm for the addition of link with mutual coupling to other elements.

Objective Nos.: …………………………1,2,3……………………………………………………….

Outcome Nos.: ……………………1,2,3……………………………………………………….

Signature of HOD | Signature of faculty

Date: | Date:

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

ASSIGNMENT SHEET – 3

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ……..…**Electrical**……..… Year: ……**III**……….. Section: A&B

Course/Subject: … **Computer Methods in power System** …Course Code: .. GR15A3021.

Name of the Faculty: …… **V.Vijaya Rama Raju/M.Prashanth** ………………..Dept.: …**EEE**………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

This Assignment corresponds to Unit No. / Lesson ………………**3**………………………….

Q1.Derive the basic equations for load flow studies and also write the assumptions and approximations to get the simple equations.

Q2. Write short notes on the following:
(a) Data for power flow studies.
(b) Merits and demerits of using polar and rectangular coordinates in load flow studies.
(c) Choice of Acceleration factors.

Q3. (a) Explain the load flow solution using G-S method with the help of a flow chart.
(b) How do you classify system variables in terms of state, input and output variables, in power flow studies.

Objective Nos.: 1,2,3,4……………………………………………………….

Outcome Nos.: ……………………1,2,3……………………………………………………….

Signature of HOD

Date:

Signature of faculty

Date:

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering
ASSIGNMENT SHEET – 4

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ……..…**Electrical**……..… Year: ……**III**……….. Section: A&B

Course/Subject: … **Computer Methods in power System** …Course Code: .. GR15A3021.

Name of the Faculty: …… **V.Vijaya Rama Raju/M.Prashanth** ………………..Dept.: …**EEE**………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

This Assignment corresponds to Unit No. / Lesson ………………**4**………………………….

1. (a) Derive the expressions for bus voltages , line currents when a three phase symmetrical fault through a fault impedance occurs at a particular bus , using bus impedance matrix.
A three phase fault with a fault impedance of 0.16 p.u. occurs at bus 3 , for which ZBUS is given by :Compute the fault current, the bus Voltages, and

$$Z_{BUS} = \begin{matrix} 1 \\ 2 \\ 3 \end{matrix} \begin{bmatrix} j0.016 & j0..8 & j0.12 \\ j0.08 & j0.24 & j0.16 \\ j0.12 & j0.16 & j0.34 \end{bmatrix}$$

the line currents during the fault. Assume prefault bus voltages 1.0 per unit.

Q2. Four bus bar sections have each a generator of 40 MVA 10% reactance and a busbar reactor of 8% reactance. Determine the maximum MVA fed into a fault on anybus bar section and also the maximum MVA if the number of similar bus bars in sections is very large

Q3. A 65-MVA star-connected 16 kV synchronous generator is connected to 20kV/120kV, 75 MVA _/Y transformer. The sub-transient reactance of the machine is 0.32p.u. and the reactance of transformer is 0.1 p. u. When the machine is unloaded, a 3-phase fault takes place on the HT side of the transformer. Determine:a)the sub transient symmetrical fault current on both sides of the transformer,b)the maximum possible value of the d.c. current. Assume 1 p.u. generator voltage.

Objective Nos.: ……………………1,2,3,4………………………………………………………….

Outcome Nos.: ………………………1,2,3……………………………………………………….

Signature of HOD

Date:

Signature of faculty

Date:

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering
ASSIGNMENT SHEET – 5

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ……..…**Electrical**……..… Year: ……**III**……….. Section: A&B

Course/Subject: … **Computer Methods in power System** …Course Code: .. GR15A3021.

Name of the Faculty: …… **V.Vijaya Rama Raju/M.Prashanth** ………………..Dept.: …**EEE**………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

This Assignment corresponds to Unit No. / Lesson ………………**5**………………………….

Q1. (a) Give details of assumptions made in the study of steady state and transient stability solution techniques.
(b) Give important difference between steady state, dynamic state and transient state stability studies.

Q2. (a) Define the following terms :
i. Steady state stability limit.
ii. Dynamic state stability limit.
iii. Transient state stability limit .
(b) List the assumptions made in the transient stability solution techniques.
(c) Derive the expression for steady state stability limit using ABCD parameters.
Q3. (a) Give details of assumptions made in the study of steady state and transient stability solution techniques.
(b) Give important difference between steady state, dynamic state and transient state stability studies.
(c) Give the list of methods to improve transient state stability limits.

Objective Nos.: ……………………………………1,4,5………………………………………….

Outcome Nos.: ………………………………………1,2,5……………………………………….

Signature of HOD | Signature of faculty

Date: | Date:

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

TUTOTIAL SHEET - 1

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ……..…**Electrical**……..… Year: ……**III**……….. Section: A&B

Course/Subject: … **Computer Methods in power System** …Course Code: .. GR15A3021.

Name of the Faculty: …… **V.Vijaya Rama Raju/M.Prashanth** ………………..Dept.: …**EEE**………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

This Tutorial corresponds to Unit No. / Lesson ………1…………………………….

Q1. (a) What is the load flow study and explain the need for load flow solution.

(b) What are the assumptions in SLFE(static load ow equations) and derive the approximate load flow equations.

Q2. The following is the system data for load flow solution. The line admittances are given in table 1 and active and reactive powers are given in table 2.

Bus Code	P, pu	Q, pu	V, pu	Remarks
1	-	-	1+j0	Slack bus
2	1	0.1	-	PQ bus
3	3.5	0.3	-	PQ bus

Table 2:

Bus Code	Impedance
1-2	-j5
1-3	-j5
2-3	-j10

Table 1:

Find the voltages at the end of first iteration by using G-S method.

Q3. (a) Derive the static load flow equations of a n-bus system.

(b) Explain the advantages and disadvantages of G-S method

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: …………………………1,2,3,4………………………………………………………

Outcome Nos.: ……………………….…1,2,3…………………………………………………………

Signature of HOD

Date:

Signature of faculty

Date:

TUTOTIAL SHEET - 2

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ……..…**Electrical**……..… Year: ……**III**……….. Section: A&B

Course/Subject: … **Computer Methods in power System** …Course Code: .. GR15A3021.

Name of the Faculty: …… **V.Vijaya Rama Raju/M.Prashanth** ………………..Dept.: …**EEE**………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

This Tutorial corresponds to Unit No. / Lesson ………2…………………………….

Q1. (a) Write the algorithm for FDLF method.
(b) Compare G-S method and N-R methods

Q2. (a) What are the assumptions in FDLF method?
(b) Compare the different methods of load flow techniques.

Q3. Develop load flow equations suitable for solution by N-R method using rectangular coordinates when only PQ buses are present.

Q4. (a) Compare G-S method and N-R methods.
(b) Write the algorithm for N-R method using rectangular coordinates when PV buses are absent

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: ………………………1,2,3,4…………………………………………………………….

Outcome Nos.: ……………………..…1,2,3……………………………………………………………….

Signature of HOD | Signature of faculty

Date: | Date:

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

TUTOTIAL SHEET - 3

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ……..…**Electrical**……..… Year: ……**III**……….. Section: A&B

Course/Subject: … **Computer Methods in power System** …Course Code: .. GR15A3021.

Name of the Faculty: …… **V.Vijaya Rama Raju/M.Prashanth** ………………..Dept.: …**EEE**………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR
This Tutorial corresponds to Unit No. / Lesson ………3…………………………….

Q1. Explain the p.u. system of analyzing power system problems. Discuss the advan- tages of this method over the absolute method of analysis.
Q2. A 65-MVA star-connected 16 kV synchronous generator is connected to 20kV/120kV, 75 MVA _/Y transformer. The sub-transient reactance of the machine is 0.32p.u. and the reactance of transformer is 0.1 p. u. When the machine is unloaded, a 3-phase fault takes place on the HT side of the transformer. Determine:

(a) the sub transient symmetrical fault current on both sides of the transformer,
(b) the maximum possible value of the d.c. current. Assume 1 p.u. generator voltage.

Q3. Four bus bar sections have each a generator of 40 MVA 10% reactance and a busbar reactor of 8% reactance. Determine the maximum MVA fed into a fault on anybus bar section and also the maximum MVA if the number of similar bus bars in sections is very large.
Q4. A three-phase transmission line operating at 33 kV and having a resistance andreactance of 5 ohms and 20 ohms respectively is connected to the generating stationbus bar through a 5,000 kVA step-up transformer which has a reactance of 6 percent, which is connected to the bus bar being supplied by two alternators, one10,000 kVA having 10% reactance, and another 5,000 kVA having 7.5% reactance.

Calculate the kVA at a short-circuit fault between phases occurring
(a) at the high voltage terminals of the transformers at load end of transmission line

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: ……………………………1,2,3,4…………………………………………………….

Outcome Nos.: ……………………………1,2,3………………………………………………………

Signature of HOD   Signature of faculty

Date: Date:

TUTOTIAL SHEET - 4

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ……..…**Electrical**……..… Year: ……**III**……….. Section: A&B

Course/Subject: … **Computer Methods in power System** …Course Code: .. GR15A3021.

Name of the Faculty: …… **V.Vijaya Rama Raju/M.Prashanth** ………………..Dept.: …**EEE**………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR
This Tutorial corresponds to Unit No. / Lesson ………4…………………………….

Q1 (a) Distinguish between steady state and dynamic stability of a power system network.
(b) What is meant by power angle curve and write its signi_cance.
(c) How can the steady state stability of power system be increased?

Q2 (a) Explain breifly the two forms of instability in power system.
(b) Does over compensation of a transmission line a_ects the stability of a power sytem? Justify the answer..

Q3. The steady state limit of a power system is 100 MW. A generator with constant excitation is supplying 50 MW to the system. Estimate the maximum permissible sudden increase in generator output without causing instability.

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: ……………1,2,3,5…………………………………………………………………….

Outcome Nos.: ……………1,2,4,5……..…………………………………………………………………….

Signature of HOD — Signature of faculty

Date: — Date:

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

TUTOTIAL SHEET - 5

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ……..…**Electrical**……..… Year: ……**III**……….. Section: A&B

Course/Subject: … **Computer Methods in power System** …Course Code: .. GR15A3021.

Name of the Faculty: …… **V.Vijaya Rama Raju/M.Prashanth** ………………..Dept.: …**EEE**………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR
This Tutorial corresponds to Unit No. / Lesson ………5…………………………….

Q1. A synchronous generator is operating at an in_nite bus and supplying 45% of its peak power capacity. As soon as a fault occurs, the reactance between the generator and the line becomes four times its value before the fault. The peak power that can be delivered after the fault is cleared is 70% of the original maximum value. Determine the critical clearing angle.
Q2. A 50 Hz, three-phase synchronous generator delivers 1.00 p.u. power to an in_nite busbar through a network in which resistance is negligible. A fault occurs which reduces the maximum power transferable to 0.40 p.u. whereas, before the fault, this power was 1.8 p.u. and, after the clearance of the fault 1.30 p.u. By the use of equal area criterion, determine the critical angle.
Q3. A motor is receiving 25% of the power that it is capable of receiving from an infinite bus. If the load on the motor is doubled, calculate the maximum value of load angle during the winging of the rotor around its new equilibrium position.
Q4. (a) Define the following terms:

i) Steady state stability limit
ii) Dynamic state stability limit
iii) Transient state stability limit.

(b) What are the assumptions made in deriving swing equation? Also derive the swing equation.

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: …………………1,2,4,5…………………………………………………………………….

Outcome Nos.: ………………….………1,4,5……………………………………………………………….

Signature of HOD

Date:

Signature of faculty

Date:

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering
LIST OF VARIOUS MAPPINGS/MATRIX COURSE

1. **Program Educational Objectives (PEOs) – Vision/Mission Matrix** (Indicate the relationships by mark “X”)

Vision/Mission \ PEOs	Vision of the Institute	Mission of the Institute	Mission of the Program
1	X		X
2	X	X	X
3	X	X	X
4		X	X

2. **Program Educational Objectives(PEOs)-Program Outcomes(POs) Relationship Matrix** (Indicate the relationships by mark “X”)

P-Outcomes \ PEOs	A	b	c	d	e	F	g	H	i	J	K	l
1	**X**	**X**			**X**			**X**		**X**		**X**
2	**X**	**X**			**X**			**X**			**X**	
3			**X**	**X**	**X**	**X**	**X**					**X**
4					**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**

3. **Course Objectives-Course Outcomes Relationship Matrix** (Indicate the relationships by mark “X”)

Course-Outcomes \ Course-Objectives	1	2	3	4	5	6	7
1	X						
2	X	X	X	X			
3	X				X	X	X
4	X				X	X	X
5	X		X	X		X	

4. **Course Objectives-Program Outcomes(POs) Relationship Matrix** (Indicate the relationships by mark "X")

P-Outcomes / C-Objectives	a	b	c	d	e	F	g	H	i	J	k	l
1	X				X		X	X	X	X	X	
2	X	X	X	X	X	X	X	X			X	
3	X	X	X	X	X	X	X	X	X		X	X
4	X	X	X	X	X	X	X	X		X	X	
5	X		X			X		X	X		X	X

5. Course Outcomes-Program Outcomes(POs) Relationship Matrix (Indicate the relationships by mark "X")

P-Outcomes / C-Outcomes	a	b	c	d	E	f	g	h	i	J	k	l
1	X		X			X		X		X		X
2	X	X			X		X		X		X	X
3	X	X		X	X	X				X		
4	X	X			X		X	X	X		X	X
5	X	X	X	X		X			X		X	X

6. **Courses (with title & code)-Program Outcomes (POs) Relationship Matrix** (Indicate the relationships by mark "X")

P-Outcomes / Courses	a	b	c	d	E	f	g	h	i	J	k	L
Computer Methods in Power Systems	X	X	X				X				X	X

7. Program Educational Objectives (PEOs)-Course Outcomes Relationship Matrix (Indicate the relationships by mark "X")

P-Objectives (PEOs) / Course-Outcomes	1	2	3	4

1	X		X	
2	X		X	
3	X	X		
4	X		X	
5	X	X		X

8. Assignments and Assessments - Program Outcomes (POs) Relationship Matrix (Indicate the relationships by mark "X"**)**

P-Outcomes / Assessments	a	b	c	d	E	f	g	h	i	J	k	l
Mid Exam	X		X		X			X			X	
Assignments	X	X		X	X	X		X			X	
Seminars/ Conferences	X	X	X	X			X		X	X	X	
Project Work	X	X		X	X	X		X			X	
Main Exam	X		X		X			X			X	
Behavioral Observation	X	X	X	X	X	X	X				X	X

9. Assignments and Assessments – Program Educational Objectives (PEOs) Relationship Matrix (Indicate the relationships by mark "X")

P-Outcomes / Assessments	1	2	3	4
Mid Exam	X	X		X
Assignments	X	X	X	
Seminars/ Conferences	X	X		X
Project Work	X	X	X	
Main Exam	X		X	X
Behavioral Observation	X		X	X

Power System Components and Perunit System:-

⇒ A complete circuit diagram of a power system for all the three-phases is very complicated. It is very much practical to represent a power system using simple symbols for each component resulting in what is called a single-line diagram.

⇒ Power system engineers have devised the per-unit systems such that different physical quantities such as current, voltage, power and impedance are expressed as a decimal fraction or multiple of base quantities.

⇒ In this system, the different voltage levels disappear and a power network consisting synchronous generators, transformers and lines reduces to a system of simple impedances.

Single Phase Representation of a Balanced Three phase system:

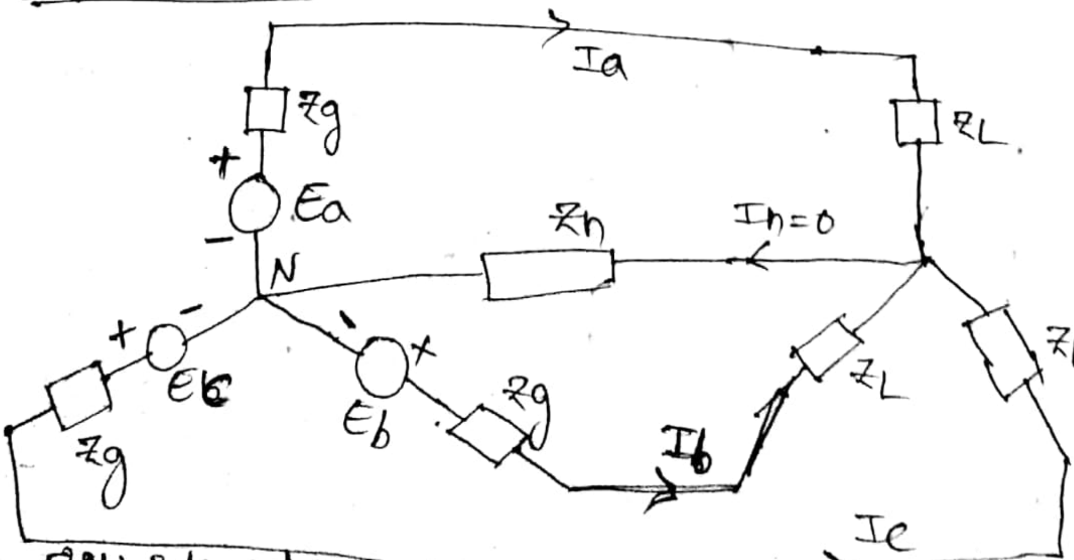


Fig1: Balanced 3-ϕ Network

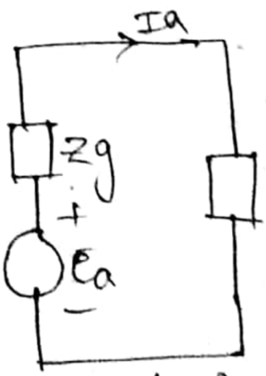


Fig 2: 1-ϕ representation of a balanced 3-ϕ N/w of fig. 1.

⇒ Fig. 1 shows a simple balanced 3-φ network.
As the network is balanced, the neutral impedance Z_n does not affect the behaviour of the network,
For the reference phase a,

$$E_a = (Z_g + Z_L) I_a \longrightarrow (1)$$

⇒ Fig. 2 gives the single phase equivalent of a balanced Three-phase network of fig. 1.

⇒ As the system is balanced, the voltage and Currents in other phases have the same magnitude but are shifted in phase by 120°.

__Three-Phase Transformer Connections :-__

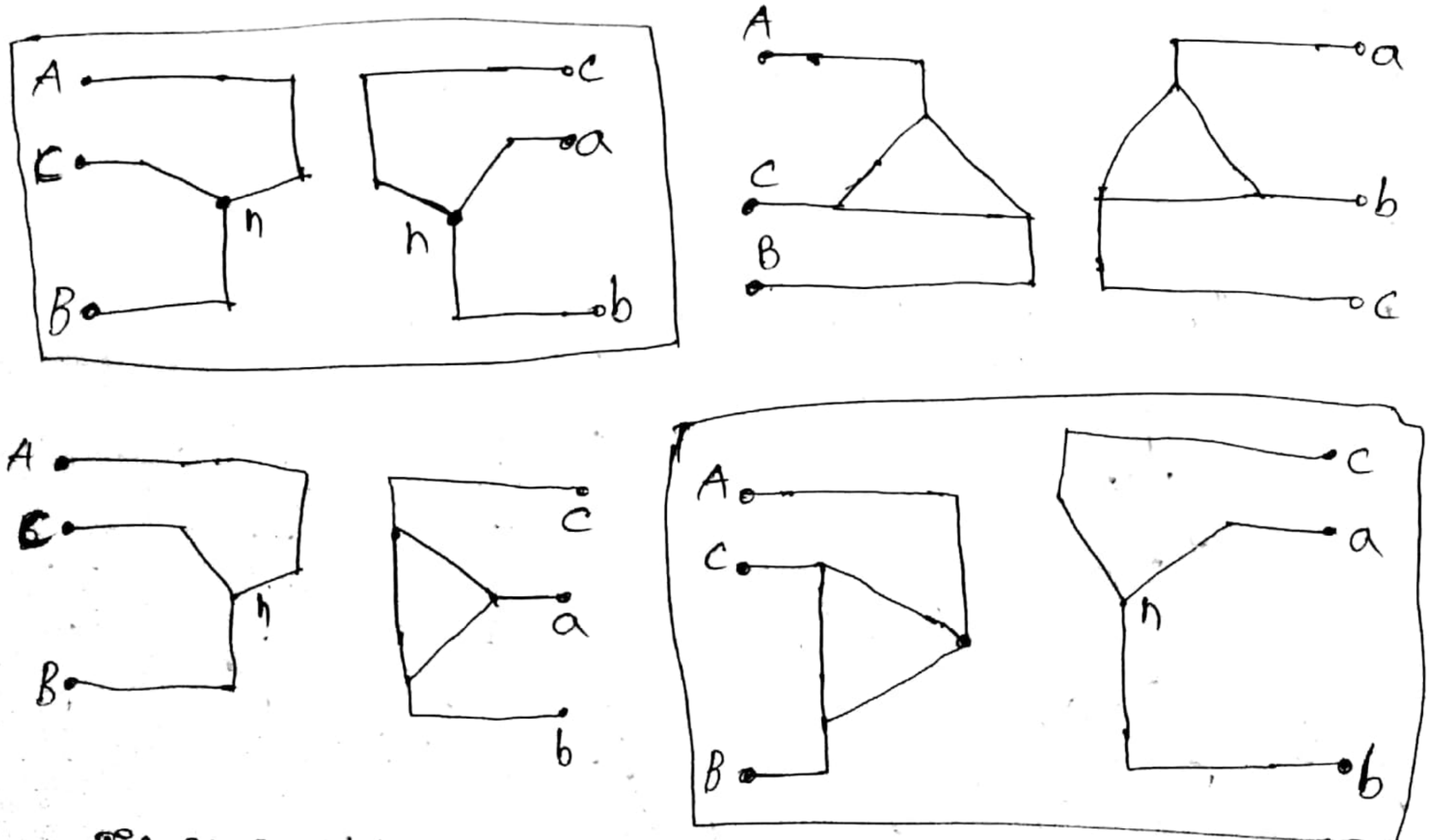


Fig. 3: 3-φ transformer Connections.

⇒ 3-φ power is transformed by use of 3-φ units. However, in large extra high voltage (EHV) units, the insulation clearances and shipping limitations may require a bank of three single-phase transformers connected in 3-φ arrangements.

⇒ The primary and secondary windings can be connected in either Y or Δ configurations. This results in four possible combinations of connections: Y–Y, Δ–Δ, Y–Δ and Δ–Y shown by the simple schematic in fig. 3.

⇒ Y–Y ⇒ It offers advantages of decreased insulation costs and the availability of the neutral for grounding purposes. However, because of problems associated with third harmonics and unbalanced operation, this connection is rarely used.

⇒ To eliminate the harmonics, a third set of windings called a tertiary winding, connected in Δ is normally fitted on the core to provide a path for the third harmonic currents. This is known as three-winding transformer.

⇒ The tertiary winding can be loaded with switched reactors or capacitors for reactive power compensation.

⇒ Δ-Δ ⇒ It provides no neutral connection and each transformer must withstand full line-to-line voltage. The Δ connection does, however, provide a path for third harmonic currents to flow. This connection has the advantage that one transformer can be removed for repair and the remaining two can continue to deliver 3-ϕ power at a reduced rating of 58% of the original bank. This is known as 'V' connection.

⇒ The most common connection is the Y-Δ or Δ-Y. This connection is more stable with respect to unbalanced loads, and if the 'Y' connection is used on the high voltage side, insulation costs are reduced.

⇒ Y-Δ ⇒ this connection is commonly used to step down a high voltage to a lower voltage. The neutral point on the high voltage side can be grounded. This is desirable in most cases.

⇒ Δ-Y ⇒ this connection is commonly used for stepping up to a high voltage.

The per-phase Model of A Three phase Transformer:-

⇒ In Y-Y and Δ-Δ connections, the ratio of line voltages on HV and LV sides are the same as the ratio of the phase voltages on the HV and LV sides.

⇒ Further more, there is no phase shift between the corresponding line voltages on the HV and LV sides.

⇒ However, the Y–Δ and the Δ–Y connections will result in a phase shift of 30° between the primary and secondary line to line voltages.

⇒ Consider the Y–Δ schematic diagram shown in fig. 3. The voltage phasor diagram for this connection is shown in Fig. 3(a), when V_{An} is taken as reference.

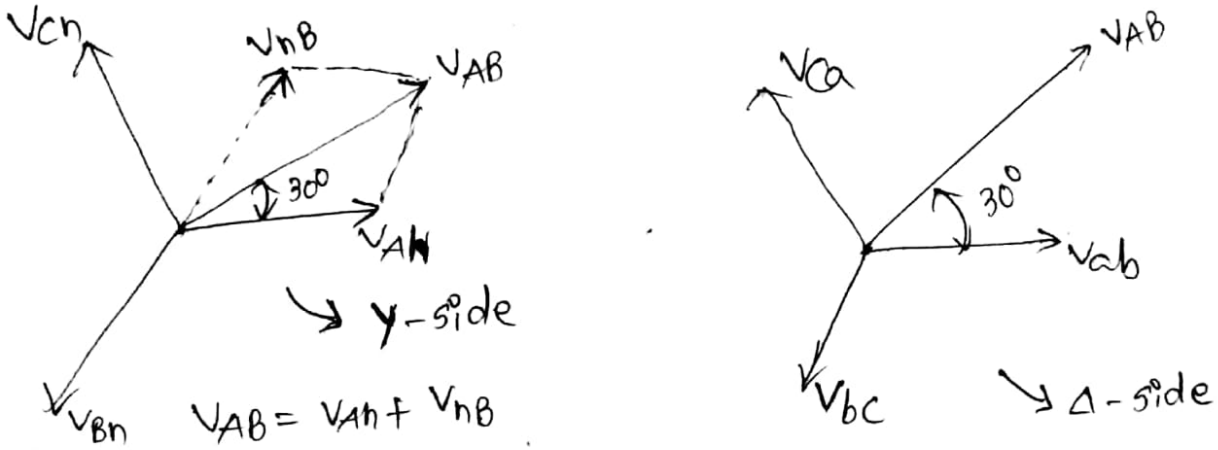


Fig. 3(a) 30° phase shift in line to line voltages of Y–Δ connection.

Let

⇒ the Y connection be the high voltage side shown by letter "H".

⇒ Δ connection, the low voltage side shown by letter "X".

⇒ we will consider phase "a" only.

⇒ use subscript "L" for line and "P" for phase quantities.

N_1 = number of turns on one phase of high voltage winding.

N_2 = number of turns on one phase of low voltage winding.

⇒ The transformer turns ratio is $a = \frac{N_1}{N_2}$

$$= \frac{V_{HP}}{V_{XP}}.$$

⇒ The relationship between the line voltage and phase voltage magnitudes is

$$V_{HL} = \sqrt{3}\, V_{HP}$$

$$V_{XL} = V_{XP}$$

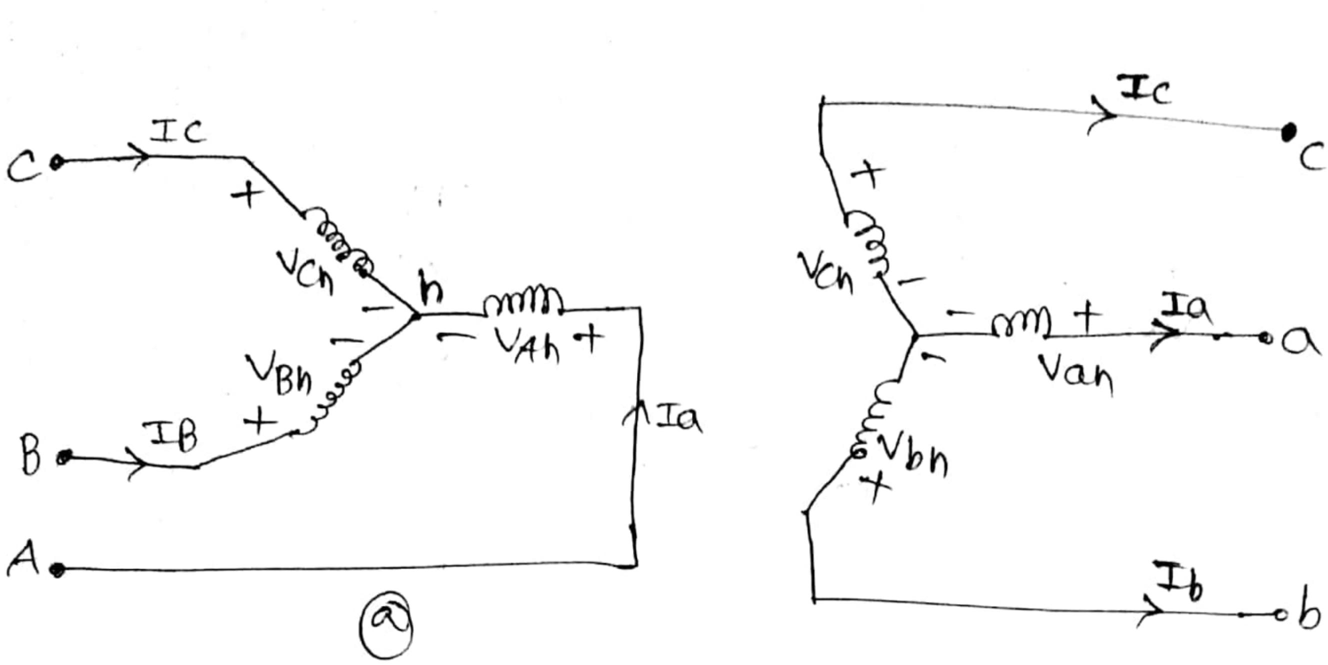
Therefore, the ratio of the line voltage magnitudes for Y − Δ transformer is

$$\frac{V_{HL}}{V_{XL}} = \frac{\sqrt{3}\, V_{HP}}{V_{XP}} = \sqrt{3} \cdot a = \sqrt{3} \cdot \frac{N_1}{N_2} = \frac{N_1}{\left(\frac{N_2}{\sqrt{3}}\right)}$$

⇒ In dealing with Y − Δ or Δ − Y banks, it is convenient to replace the Δ connection by an equivalent Y connection and then work with only one phase.

⇒ Since for balanced operation, the Y-neutral and the neutral of the equivalent Y of the Δ connection are at the same potential, they can be connected together and represented by a neutral conductor.

⇒ Y−Y: schematic representation of Y−Y transformer is shown in Fig. 4ⓐ and Fig. 4ⓑ shows the single phase equivalent of three phase Y−Y transformer and Fig 4ⓒ shows the single line diagram.



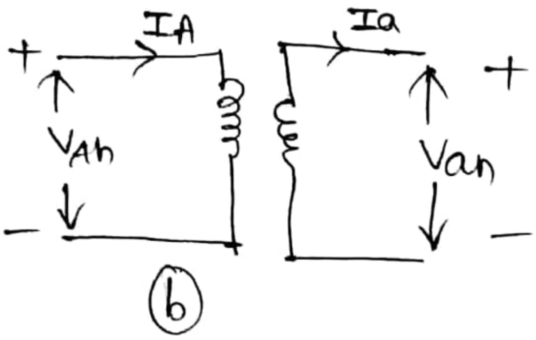
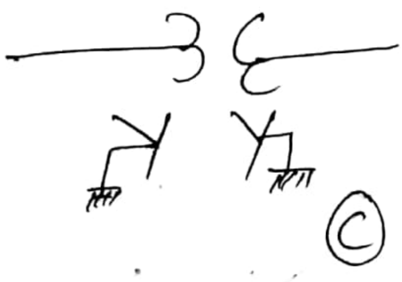


Fig. 4 ⓐ schematic representation of Y–Y transformer ⓑ 1–φ equivalent ⓒ single line diagram.



Y–Δ :–

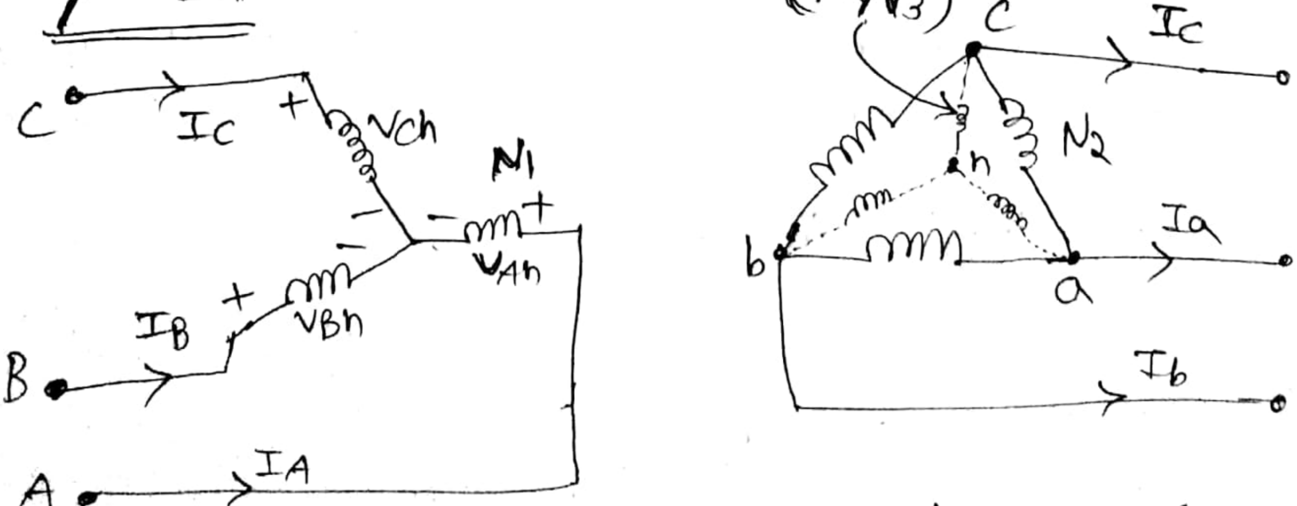


Fig. 5 : Y–Δ transformer with equivalent star connection.

we know,

$$\frac{V_{HL}}{V_{XL}} = \sqrt{3}\,\frac{N_1}{N_2}$$

$$\therefore \frac{V_{An}}{V_{an}} = \sqrt{3}\cdot\frac{N_1}{N_2} = \frac{N_1}{(N_2/\sqrt{3})}$$

$V_{HL} = \sqrt{3}\cdot V_{An}$

$V_{XL} = \sqrt{3}\cdot V_{an}$

$$\therefore \frac{V_{HL}}{V_{XL}} = \frac{\sqrt{3}\cdot V_{An}}{\sqrt{3}\cdot V_{an}} = \frac{V_{An}}{V_{an}}$$

$\therefore V_{An} : V_{an} = N_1 : N_2/\sqrt{3}$

⇒ Fig. 5 shows the Δ-side has to be replaced by an equivalent Y connection.

⇒ Fig. 6 shows the single-phase equivalent of Y-Δ transformer and Fig. 7 shows the single line diagram.

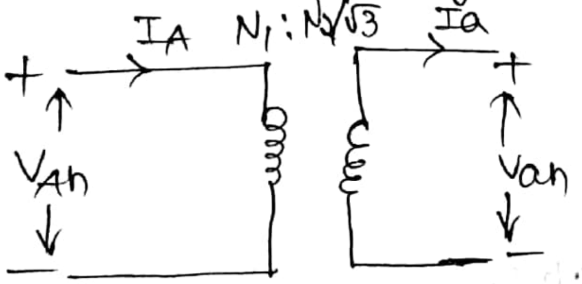


Fig. 6: 1-ϕ equivalent of Y-Δ Transformer

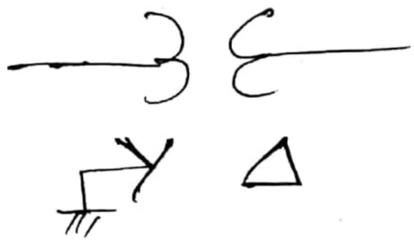


Fig. 7: single line diagram.

Per unit (PU) System :-

⇒ power system quantities such as current, voltage, impedance and power are often expressed in per-unit values.

⇒ For example, if base voltage is 220KV is specified, then the voltage 220KV is $210/220 = 0.954$ pu.

⇒ one major advantage of the perunit is that by properly specifying base quantities, the equivalent circuit of transfor-mer can be simplified. when expressed in per-unit values, the equivalent impedance of a transformer whether referr-ed to primary or secondary, is the same.

⇒ Another advantage of the per-unit system is that the comparison of the characteristics of the various electrical apparatus of different types and ratings is facilitated by expressing the impedances in per-unit based on their rat-ings.

⇒ when all the quantities are converted in per-unit values, the different voltage levels disappear and power network involving synchronous generators, transformers, and lines red-uces to a system of simple impedances.

$$\text{Per unit quantity} = \frac{\text{actual quantity}}{\text{base value of quantity}} \longrightarrow (2)$$

Let us define,

$$S_{pu} = \frac{S}{S_B}\ ; \quad V_{pu} = \frac{V}{V_B}\ ; \quad I_{pu} = \frac{I}{I_B}$$

$$\text{and} \quad Z_{pu} = \frac{Z}{Z_B} \longrightarrow (3)$$

where, S(apparent power), V(voltage), I(current) and Z(impedance) are phasor or complex quantities and -

⇒ denominators (i.e; S_B, V_B, I_B and Z_B) are always real numbers.

⇒ To completely define a per unit system, minimum four base quantities are required.

⇒ Two independent base values can be arbitarily selected at one point in a power system.

⇒ usually, 3-ϕ base volt-ampere S_B or $(MVA)_B$ and the line to line base voltage. V_B or $(KV)_B$ are selected.

⇒ In order for electrical laws to be valid in the per-unit system, following relations must be used for other base values:

$$\sqrt{3} \cdot (KV)_B \cdot I_B = (MVA)_B$$

$$\therefore I_B = \frac{(MVA)_B}{\sqrt{3}\,(KV)_B} \longrightarrow (4)$$

and

$$Z_B = \frac{(KV)_B/\sqrt{3}}{I_B} \longrightarrow (5)$$

Now substituting for I_B from eq (4), the base impedance becomes

$$Z_B = \frac{(KV)_B^2}{(MVA)_B} \longrightarrow (6)$$

Note that phase and line quantities expressed in per-unit values are the same, and the circuit laws are valid i.e;

$$S_{p.u} = V_{pu} \cdot I_{pu}^{*} \longrightarrow (7)$$

Here,

S_{pu} = Per-unit Complex Power = $P_{pu} + jQ_{pu}$

V_{pu} = Per-unit Voltage.

I^*_{pu} = Complex Conjugate of per-unit Current.

and also $V_{pu} = Z_{pu} \cdot I_{pu} \longrightarrow (8)$

⇒ The power consumed by the load at its rated voltage can also be expressed by per-unit impedance.

⇒ The 3-ϕ Complex load power can be given as:

$$S_{load\,(3\phi)} = 3\, V_{phase}\, I_L^* \longrightarrow (9)$$

Here,

$S_{load\,(3\phi)}$ = Three-phase Complex load Power

V_{phase} = phase voltage.

I_L^* = Complex Conjugate of per-phase load Current I_L.

⇒ The phase load Current can be given as:

$$I_L = \frac{V_{phase}}{Z_L} \longrightarrow (10)$$

where Z_L is load Impedance per phase

Substituting I_L from eq (10) in eq (9)

$$S_{load\,(3\phi)} = 3\, V_{phase} \left(\frac{V_{phase}}{Z_L} \right)^*$$

$$\therefore S_{load\,(3\phi)} = \frac{3 \cdot |V_{phase}|^2}{Z^*}$$

$$Z_L^* = \frac{3|V_{phase}|^2}{S_{load(3\phi)}}$$

$$Z_L = \frac{3|V_{phase}|^2}{S^*_{load(3\phi)}} \longrightarrow (11)$$

Also, load impedance in per-unit can be given as:

$$Z_{pu} = \frac{Z_L}{Z_B} \longrightarrow (12)$$

Substituting Z_L from eq (11) and Z_B from eq (6) into eq (12), we obtain

$$Z_{pu} = \frac{3|V_{phase}|^2}{S^*_{load(3\phi)}} \cdot \frac{(MVA)_B}{(KV)^2_B} \longrightarrow (13)$$

Now $|V_{L-L}| = \sqrt{3}\,|V_{phase}|$

$$\therefore 3|V_{phase}|^2 = |V_{L-L}|^2 \longrightarrow (14)$$

using eq (13) and (14), we get,

$$Z_{pu} = \frac{|V_{L-L}|^2}{(KV)^2_B} \cdot \frac{(MVA)_B}{S^*_{load(3\phi)}}$$

$$= \left[\frac{V_{L-L}}{(KV)_B}\right]^2 \cdot \frac{1}{\frac{S^*_{load(3\phi)}}{(MVA)_B}}$$

$$\therefore Z_{pu} = \frac{|V_{pu}|^2}{S^*_{load(pu)}} \longrightarrow (15)$$

⇒ The impedance of generators, transformers and motors supplied by the manufacturer are generally given pu values on their own ratings. For power system analysis, all impedances must be expressed in pu values on a common base.

⇒ * when base quantities are changed from $(MVA)_{B,old}$ to $(MVA)_{B,new}$ and from $(KV)_{B,old}$ to $(KV)_{B,new}$, the new pu impedance can be given by,

$$Z_{pu,new} = Z_{pu,old} \times \left[\frac{(KV)_{B,old}}{(KV)_{B,new}}\right]^2 \times \left[\frac{(MVA)_{B,new}}{(MVA)_{B,old}}\right] \quad \longrightarrow (16)$$

⇓

$$Z_{pu,old} = \frac{Z(\Omega)}{Z_{B,old}}$$

$$Z(\Omega) = Z_{pu,old} \times Z_{B,old}$$

$$Z_{B,old} = \frac{(KV)^2_{B,old}}{(MVA)_{B,old}}$$

$$\therefore Z_{\Omega} = Z_{pu,old} \times \frac{(KV)^2_{B,old}}{(MVA)_{B,old}}$$

$$Z_{pu,new} = \frac{Z(\Omega)}{Z_{B,new}}$$

$$= \frac{Z_{pu,old} \cdot \dfrac{(kV)^2_{B,old}}{(MVA)_{B,old}}}{\dfrac{(kV)^2_{B,new}}{(MVA)_{B,new}}}$$

$$Z_{pu,new} = Z_{pu,old} \cdot \frac{(kV)^2_{B,old}}{(MVA)_{B,old}} \times \frac{(MVA)_{B,new}}{(kV)^2_{B,new}}$$

$$\therefore Z_{pu,new} = Z_{pu,old} \times \left[\frac{(kV)_{B,old}}{(kV)_{B,new}}\right]^2 \times \left[\frac{(MVA)_{B,new}}{(MVA)_{B,old}}\right] \quad \rightarrow (16)$$

Per-Unit Representation of Transformer:-

⇒ It has been discussed before that a 3-φ transformer can be represented by a single-phase Transformer for obtaining per phase solution of the system.

⇒ Fig. 8 shows a 1-φ transformer in terms of primary and secondary leakage reactance Z_p and Z_s and transformation ratio is 1 : a.

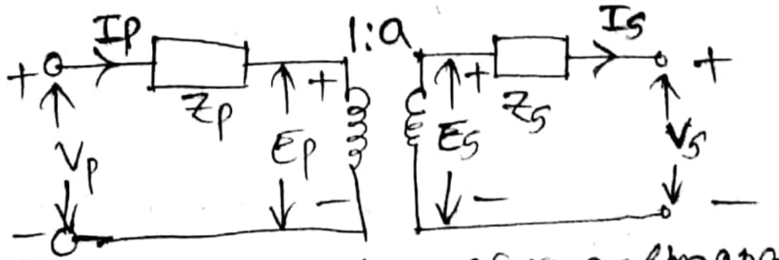


Fig. 8: Representation of 1-φ transformer (magnetizing impedance neglected).

⇒ Let us choose voltage base on the primary side V_{PB} and on the secondary side V_{SB}. Also choose a common volt ampere base of $(VA)_B$.

Now

$$\frac{V_{PB}}{V_{SB}} = \frac{1}{a} \longrightarrow (17)$$

As the $(VA)_B$ is common, we can also write

$$\frac{I_{PB}}{I_{SB}} = a \longrightarrow (18)$$

$$Z_{PB} = \frac{V_{PB}}{I_{PB}} \longrightarrow (19)$$

$$Z_{SB} = \frac{V_{SB}}{I_{SB}} \longrightarrow (20)$$

From Fig. 8; we can write,

$$V_S = E_S - Z_S I_S \longrightarrow (21)$$

$$E_P = V_P - Z_P I_P \longrightarrow (22)$$

Also,

$$E_S = a . E_P \longrightarrow (23)$$

Substituting E_S from eq (23) into eq (21), we obtain

$$V_S = a \cdot E_P - Z_S I_S \longrightarrow (24)$$

Substituting E_P from eq (22) into eq (24), we get,

$$V_S = a(V_P - Z_P I_P) - Z_S I_S \longrightarrow (25)$$

Eq (25), can be converted in pu form, i.e.

$$V_S(pu) \cdot V_{SB} = a\left[V_P(pu)\, V_{PB} - Z_P(pu)\, Z_{PB}\, I_P(pu)\, I_{PB}\right] - Z_S(pu)\, Z_{SB}\, I_S(pu) \cdot I_{SB} \quad \longrightarrow (26)$$

Dividing eq (26) by V_{SB} and using the base relationships of eq (17), (18), (19) and (20), we get

$$V_S(pu) = V_P(pu) - I_P(pu)\, Z_P(pu) - I_S(pu)\, Z_S(pu) \quad \longrightarrow (27)$$

$\frac{V_P}{V_{PB}} = V_P(pu)$; $\therefore V_P = V_P(pu)\, V_{PB}$

$\frac{Z_P}{Z_{PB}} = Z_P(pu)$; $\therefore Z_P = Z_P(pu) \cdot Z_{PB}$

similarly,

$I_P = I_P(pu) \cdot I_{PB}$

$Z_S = Z_S(pu) \cdot Z_{SB}$

$I_S = I_S(pu) \cdot I_{SB}$

Now we can write,

$$\frac{I_P}{I_S} = \frac{I_{PB}}{I_{SB}} = a$$

$$\therefore \frac{I_P}{I_{PB}} = \frac{I_S}{I_{SB}}$$

$$\therefore I_P(pu) = I_S(pu) = I(pu) \quad \longrightarrow (28)$$

using eq (27) and (28), we get

$$V_S(pu) = V_P(pu) - I(pu)\, Z(pu) \quad \longrightarrow (29)$$

where,

$$Z(pu) = Z_P(pu) + Z_S(pu) \quad \longrightarrow (30)$$

Fig. 9 shows the per-unit equivalent circuit of the transformer.

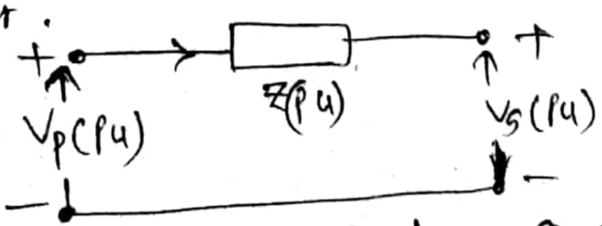


Fig. 9: per-unit equivalent circuit of single-phase transformer.

Z (pu) can be determined from the equivalent impedance on primary or secondary side of a transformer.

on the primary side,

$$Z_1 = Z_P + \frac{Z_S}{a^2}$$

$$\therefore \frac{Z_1}{Z_{PB}} = \frac{Z_P}{Z_{PB}} + \frac{Z_S}{Z_{PB}\, a^2}$$

$$\therefore Z_1(pu) = Z_P(pu) + \frac{Z_S}{Z_{SB}}$$

$\therefore Z_{SB} = Z_{PB}\, a^2$

eq (19) ÷ eq (20)

$$\frac{Z_{PB}}{Z_{SB}} = \frac{V_{PB}}{I_{PB}} \times \frac{I_{SB}}{V_{SB}}$$

$$\frac{Z_{PB}}{Z_{SB}} = \frac{1}{a} \times 1/a = 1/a^2$$

$\therefore Z_{SB} = a^2 Z_{PB}$

$$\therefore Z_1(pu) = Z_P(pu) + Z_S(pu) = Z(pu) \longrightarrow (31)$$

similarly on the secondary side

$$Z_2(pu) = Z_S(pu) + Z_P(pu) = Z(pu) \longrightarrow (32)$$

Therefore per-unit impedance of a transformer is the same whether computed from primary or secondary side.

Ex:- 1) A single phase two-winding transformer is rated 25KVA, 1100/440 volts, 50Hz. The equivalent leakage impedance of the transformer referred to the low voltage side is $0.06\angle 78^\circ\ \Omega$ using transformer rating as base values, determine the percunit leakage impedance referred to low voltage winding and referred to high voltage winding.

Sol Let us assume high voltage side is primary and low voltage side is secondary windings.

Transformer rating = 25 KVA = 0.025 MVA.

$V_p = 1100$ volt $= 1.1$ KV

$V_s = 440$ volt $= 0.44$ KV

Therefore,

$(MVA)_B = 0.025$; $V_{PB} = 1.1 KV$; $V_{SB} = 0.44 KV$

Base impedance on the 440 volt side of the transformer.

$$Z_{SB} = \frac{V_{SB}^2}{(MVA)_B} = \frac{(0.44)^2}{0.025} = 7.744 \Omega$$

perunit leakage impedance referred to the low voltage side is

$$Z_s(pu) = \frac{Z_{s,eq}}{Z_{SB}} = \frac{0.06\angle 78^0}{7.744} = 7.74 \times 10^{-3} \angle 78^0 \text{ pu}$$

If $Z_{p,eq}$ referred to primary winding (HV side)

$$Z_{p,eq} = \frac{Z_{s,eq}}{a^2} = \left(\frac{N_1}{N_2}\right)^2 \cdot Z_{s,eq}$$

$$\therefore Z_{p,eq} = \left(\frac{1.1}{0.44}\right)^2 \times 0.06\angle 78^0$$

$$\therefore Z_{p,eq} = 0.375\angle 78^0 \Omega$$

Base impedance on the 1.1 KV side is:

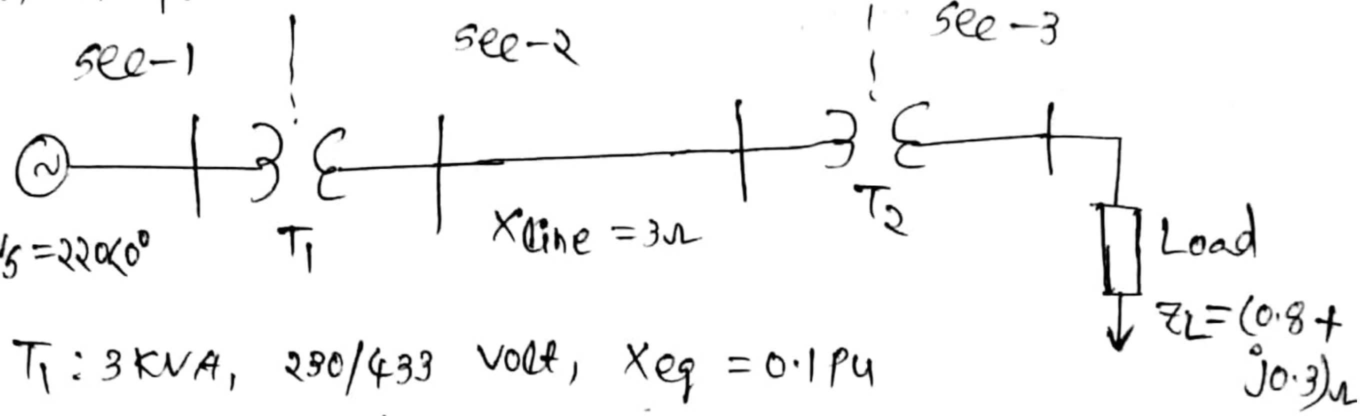
$$Z_{PB} = \frac{V_{PB}^2}{MVA_B} = \frac{(1.1)^2}{0.025} = 48.4 \Omega$$

$$\therefore Z_p(pu) = \frac{Z_{p,eq}}{Z_{PB}} = \frac{0.375\angle 78^0}{48.4} = 7.74 \times 10^{-3} \angle 78^0 \text{ pu}$$

Therefore, perunit leakage impedance remains unchanged and this has been achieved by specifying,

$$\frac{V_{PB}}{V_{SB}} = \frac{V_{p,rated}}{V_{s,rated}} = \frac{1.1}{0.44} = 2.5$$

Ex:-2) Fig. 10 shows single line diagram of a 1-ϕ circuit. using the base values of 3KVA and 230 volt, draw the per-unit circuit diagram and determine the per-unit impedances and the per-unit source voltage. Also calculated the load current both in per-unit and in amperes.



T_1 : 3KVA, 230/433 volt, $X_{eq} = 0.1$ pu

T_2 : 2KVA, 440/120 volt, $X_{eq} = 0.1$ pu

Fig. 10: Single-phase Circuit.

Sol: First, base values in each section have to be obtained.

$$\text{Base MVA} = \frac{3}{1000} = 0.003$$ and this base value will remain same for the entire network.

Also, $V_{B1} = 230$ volt $= 0.23$ KV, as specified in section-1

when moving across a transformer, the voltage base is changed in proportion to the transformer voltage ratings.

Therefore,
$$V_{B2} = \left(\frac{433}{230}\right) \times 230 = 433 \text{ volt} = 0.433 \text{ KV}$$

and
$$V_{B3} = \left(\frac{120}{440}\right) \times 433 = 118.09 \text{ volt} = 0.11809 \text{ KV}.$$

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$$Z_{B1} = \frac{(V_{B1})^2}{(MVA)_B} = \frac{(0.23)^2}{0.003} = 17.63\,\Omega$$

$$Z_{B2} = \frac{(V_{B2})^2}{(MVA)_B} = \frac{(0.433)^2}{0.003} = 62.5\,\Omega$$

$$Z_{B3} = \frac{(V_{B3})^2}{(MVA)_B} = \frac{(0.11809)^2}{0.003} = 4.64\,\Omega$$

Base current in section-3 is

$$I_{B3} = \frac{(MVA)_B}{(V_{B3})} = \frac{0.003}{0.11809}\,kA = 25.4\ Amp$$

given that

$$x_{1,old} = x_{eq} = 0.10\ pu$$

$$x_{1,new} = 0.10\,pu = x_{1,old}$$

Therefore, for transformer T_1, no change in per-unit value of leakage reactance.

For Transformer T_2,

$$Z_{BT_2} = \frac{(0.44)^2}{(2/1000)} = 96.8\,\Omega$$

$$x_2(\Omega) = x_2(pu) \times Z_{BT_2} = 0.1 \times 96.8\,\Omega = 9.68\,\Omega$$

$$x_{2,new} = \frac{9.68}{62.5} \quad \left[= \frac{x_2(\Omega)}{Z_{B2}} \right],\ Z_{B2} = 62.5\,\Omega$$

$$x_{2,new} = 0.1548\ pu$$

$$x_{line}(pu) = \frac{x_{line}(\Omega)}{Z_{B2}} = \frac{3}{62.5} = 0.048\ pu.$$

$$Z_L(pu) = \frac{Z_L(\Omega)}{Z_{B3}} = \frac{0.8+j0.3}{4.64} = (0.1724 + j0.0646)\ pu$$

Per unit circuit is shown in fig. 11

$$V_s = \frac{220\angle 0^\circ}{230} = 0.956\angle 0^\circ$$

$$Z_T(pu) = (j0.10 + j0.048 + j0.1548 + 0.1724 + j0.0646)$$

$$\therefore Z_T(pu) = 0.4058\angle 64.86^\circ$$

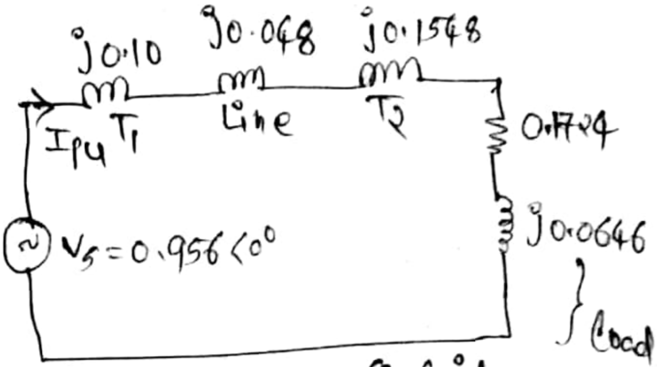


Fig. 11: Per-unit circuit

$$\therefore I_L(pu) = I_{pu} = \frac{V_s}{Z_T} = \frac{0.956\angle 0^\circ}{0.4058\angle 64.86^\circ}$$

$$\therefore I_L(pu) = 2.355\angle -64.86^\circ\ pu.$$

$$I_L(Amp) = I_L(pu) \times I_{B3} = 2.355\angle -64.86^\circ \times 25.4\ Amp$$

$$\therefore I_L(Amp) = 59.83\angle -64.86^\circ\ Amp.$$

Ex-3):– Fig. 12 shows single-line diagram of a power system. The ratings of the generators and transformers are given below.

G_1: 25 MVA, 6.6 KV, $x_{g1} = 0.20$ pu

G_2: 15 MVA, 6.6 KV, $x_{g2} = 0.15$ pu

G_3: 30 MVA, 13.2 KV, $x_{g3} = 0.15$ pu

T_1: 30 MVA, 6.6Δ – 115Y KV, $x_{T_1} = 0.1$ pu

T_2: 15 MVA, 6.6Δ – 115Y KV, $x_{T_2} = 0.10$ pu

T_3: single-phase unit, each rated 10 MVA, 6.9/69 KV, $x_{T_3} = 0.10$ pu

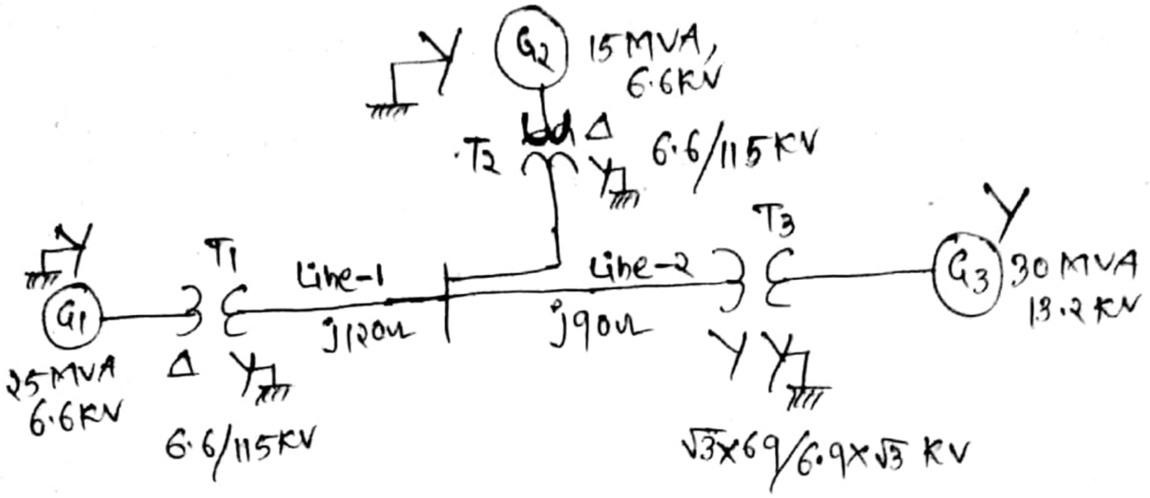


Fig.12: single line diagram.

Draw per-unit circuit diagram using base values of 30MVA and 6.6KV in the circuit of generator-1.

Sol: The chosen base values are 30MVA and 6.6KV in the generator 1 circuit.

Consequently, the transmission line base voltage of line-1 is 115KV.

For generator-2 base voltage is also 6.6KV.

⇒ As the transformer T_3 is rated 6.9KV and 69KV per phase, the line voltage ratio is $6.9\sqrt{3}/69\sqrt{3}$ = 12/120 KV.

Therefore, base line voltage for generator-3 circuit is

$$\left(\frac{12}{120}\right) \times 115 = 11.5 \text{ KV.}$$

Therefore, line KV base on HV side of transformer T_3 is the same as that of transmission line, i.e; 115KV.

$$(MVA)_B = 30 \text{ MVA.}$$

$$x_{g_1} = 0.2 \times \frac{30}{25} = 0.24 \text{ PU}$$

$$x_{g_2} = 0.15 \times \frac{30}{15} = 0.30 \text{ PU}$$

$$x_{g_3} = 0.15 \times \left(\frac{13.2}{11.5}\right)^2 = 0.20 \text{ PU}$$

$$x_{T_1} = 0.10 \text{ PU}$$

$x_{T_2} = 0.10 \times \left(\frac{30}{15}\right) = 0.20\ pu$

$x_{T_3} = 0.10 \times \left(\frac{120}{115}\right)^2 = 0.11\ pu$

$x_{g_3}(\Omega) = 0.15 \times \frac{(13.2)^2}{(MVA)_B}\ \Omega$

$Z_{B3} = \frac{(11.5)^2}{(MVA)_B}$

$\therefore x_{g_3}(pu) = \frac{x_{g_3}(\Omega)}{Z_{B3}}$;

$\therefore x_{g_3}(pu) = \frac{x_{g_3}(\Omega)}{Z_{B3}}$

$\therefore x_{g_3}(pu) = 0.15 \times \frac{(13.2)^2}{(11.5)^2}\ pu$

$x_{T_3}(\Omega) = 0.10 \times \frac{(120)^2}{(MVA)_B}$

$Z_B = \frac{(115)^2}{(MVA)_B}$

$x_{T_3}(pu) = \frac{x_{T_3}(\Omega)}{Z_B}$

$= 0.10 \left(\frac{120}{115}\right)^2\ pu$

$Z_{B,\ line} = \frac{(115)^2}{30} = 440\ \Omega$

$x_{Line-1} = \frac{120}{440} = 0.27\ pu$

$x_{Line-2} = \frac{90}{440} = 0.205\ pu$

Fig.13. shows the per-unit circuit diagram

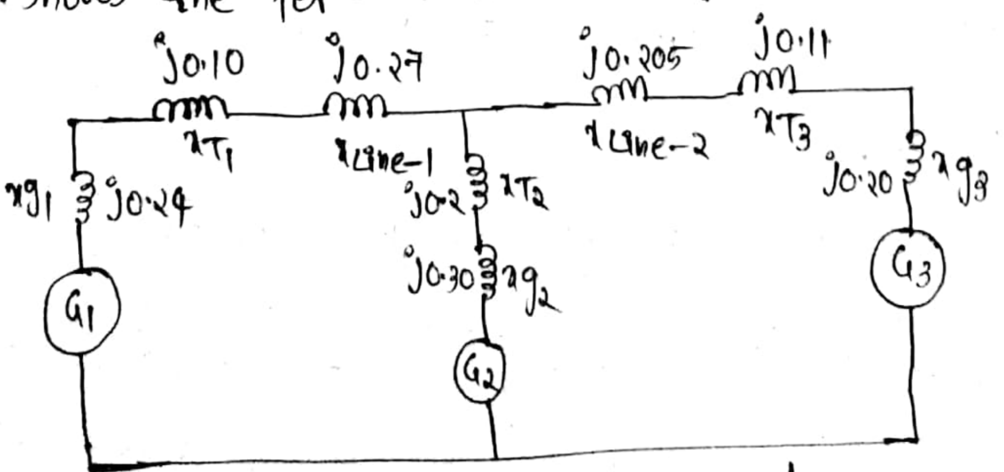


Fig.13: Per-unit Circuit diagram.

Ex-4):— A 100 MVA, 33 kV, three phase generator has a reactance of 15%. The generator is connected to the motors through a transmission line and transformers as shown in Fig.4. Motors have rated inputs of 40 MVA, 30 MVA and 20 MVA at 30 kV with 20% reactance each. Draw the per-unit circuit diagram.

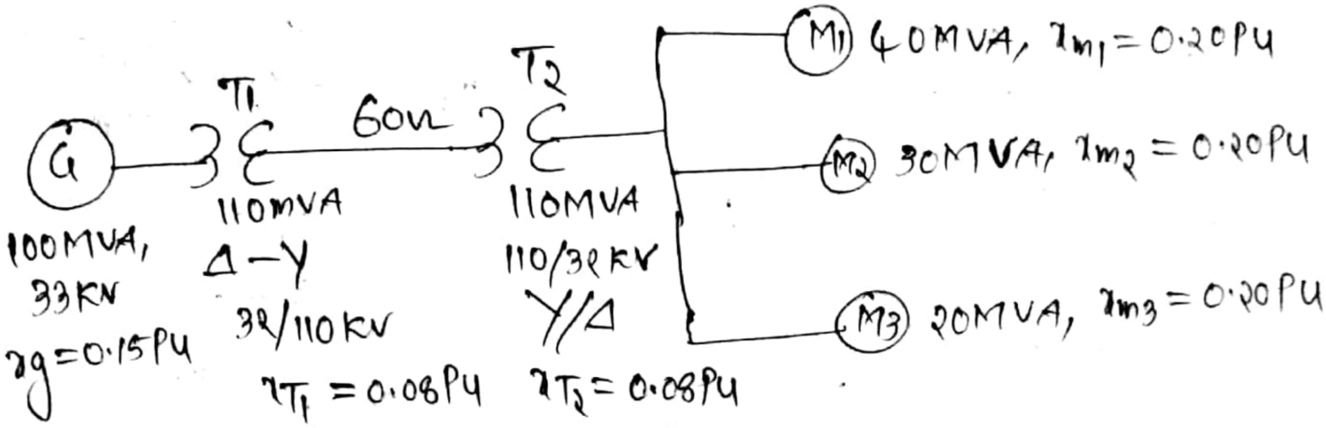


Fig.4: Single-line diagram.

Soln: Assuming, $(MVA)_B = 100$ and $(kV)_B = 33$ in the generator circuit

$$x_g = 0.15\ pu$$

$$(kV)_{B,\ line} = 33 \times \frac{110}{32} = 113.43\ kV$$

$$\text{Now } Z_B = \frac{(kV)^2_B}{(MVA)_B} = \frac{(33)^2}{100} = 10.89\ \Omega$$

$$Z_{B,T_1} = Z_{B,T_2} = \frac{(32)^2}{110}\ \Omega = 9.309\ \Omega$$

$$x_{T_1} = x_{T_2} = 0.08\ pu$$

$$\therefore x_{T_1}(\Omega) = x_{T_2}(\Omega) = 0.08 \times 9.309 = 0.744\ \Omega$$

$$\therefore x_{T_1,\ new} = x_{T_2,\ new} = \frac{0.744}{10.89} = 0.0683\ pu$$

$$Z_{B,line} = \frac{(113.43)^2}{100} = 128.66\,\Omega$$

$$\therefore x_{line} = \frac{x_{line}(\Omega)}{Z_{B,\,line}} = \frac{60}{128.66} = 0.466\ PU$$

$$x_{m_1}(\Omega) = 0.20 \times \frac{(30)^2}{40} = 4.5\,\Omega$$

$$\therefore x_{m_1,new} = \frac{4.5}{Z_B} = \frac{4.5}{10.89} = 0.413\ PU$$

Similarly,

$$x_{m_2,new} = 0.2 \times \left(\frac{100}{30}\right) \times \left(\frac{30}{33}\right)^2 = 0.551\ PU$$

$$x_{m_3,new} = 0.2 \times \left(\frac{100}{20}\right) \times \left(\frac{30}{33}\right)^2 = 0.826\ PU$$

Fig. 15 shows the per-unit reactance diagram.

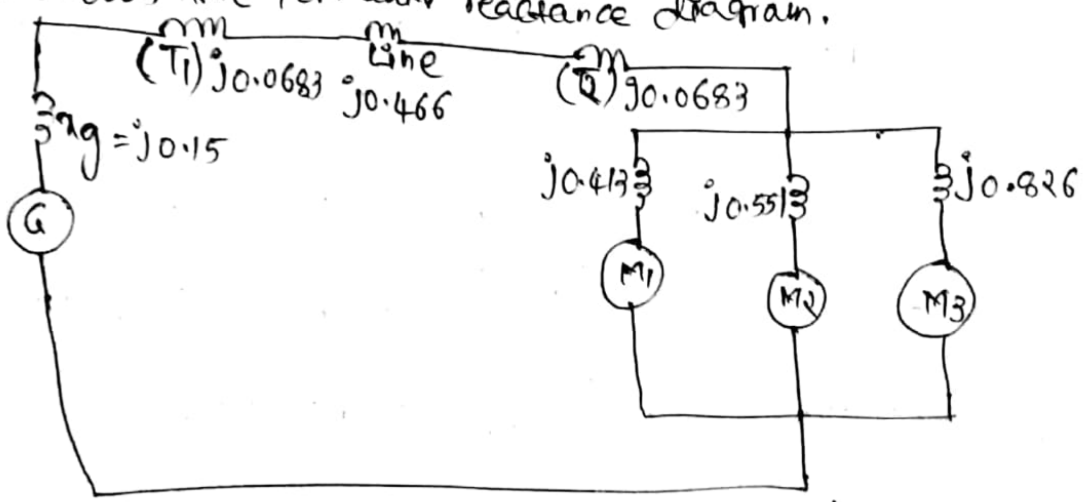


Fig. 15: Per-unit reactance diagram.

Ex-5):– Three single-phase transformers are given with their name plate ratings. Determine the reactance diagram Y–Y and Y–Δ connections, picking the voltage and power bases for the three phase bank.

Transformer ratings (1-ϕ): 1000 KVA, 12.66/66 KV, $x_l = 0.10$ PU, $x_m = 50$ PU.

Sol:

For single phase transformer

$(KV)_{B1} = 12.66\,KV, \quad (KV)_{B2} = 66\,KV$

$$(MVA)_B = \frac{1000}{1000} = 1.0$$

$$Z_{B1} = \frac{(KV)^2_{B1}}{(MVA)_B} = \frac{(12.66)^2}{1} = 160.27\,\Omega$$

$$Z_{B2} = \frac{(KV)^2_{B2}}{(MVA)_B} = \frac{(66)^2}{1} = 4356\,\Omega$$

Actual reactance (referred to the primary) are:

$$x_1 = 0.10 \times 160.27 = 16.027\,\Omega$$

$$x_m = 50 \times 160.27 = 8013.5\,\Omega$$

Let us consider now the 3-ϕ interconnections of these 1-ϕ transformers.

If we connect the primaries in Y (secondaries can be Y or Δ) and assume $(MVA)_{B,3\phi}$ and $(KV)_{B,LL}$, then,

$(MVA)_{B,3\phi} = 3 \times 1 = 3.0 \;;\; (KV)_{B,LL} = \sqrt{3} \times 12.66\,KV$

Therefore,

$$Z_{B1} = \frac{(KV)^2_{B,LL}}{(MVA)_{B,3\phi}} = \frac{(\sqrt{3} \times 12.66)^2}{3} = 160.27\,\Omega$$

$$\therefore x_1 = \frac{16.027}{160.27} = 0.1\,PU$$

$$\therefore x_m = \frac{8013.5}{160.27} = 50\,PU$$

Reactance diagram of Y-Y and Y-Δ connections is shown in fig.16. Note that reactance diagram for Δ-Y and Δ-Δ is also same.

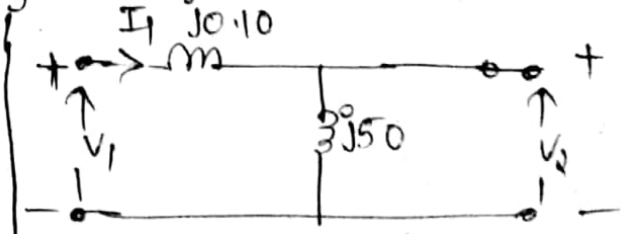
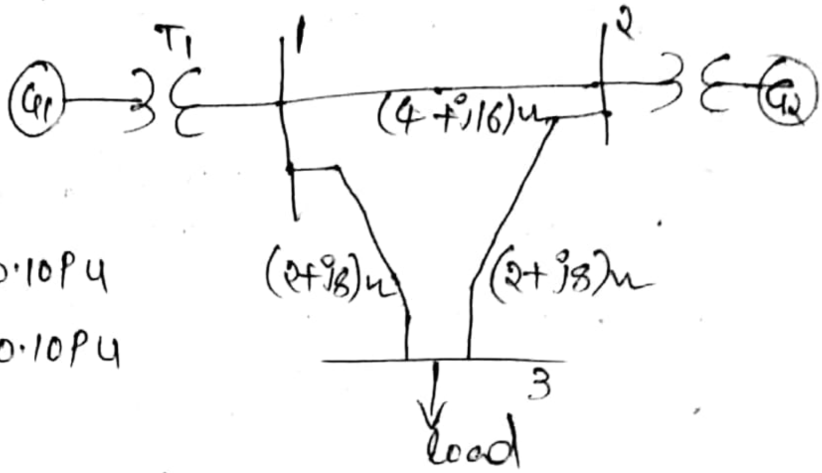


Fig.16: Reactance diagram of Three-phase transformers (Y-Y, Y-Δ, Δ-Y and Δ-Δ).

Ex-6): Draw the per-unit impedance diagram of the system shown in fig. 17. Assumed base values are 100 MVA and 100 KV.



G_1 : 50 MVA, 12.2 KV, $x_{g_1} = 0.10$ PU

G_2 : 20 MVA, 13.8 KV, $x_{g_2} = 0.10$ PU

T_1 : 80 MVA, 12.2/132 KV, $x_{T_1} = 0.10$ PU

T_2 : 40 MVA, 13.8/132 KV, $x_{T_2} = 0.10$ PU

Load: 50 MVA, 0.80 Pf lagging operating at 124 KV.

Fig. 17: Sample Power System

Sol: Base KV in the transmission line = 100 KV

Base KV in the generator circuit $G_1 = 100 \times \frac{12.2}{132} = 9.24$ KV

Base KV in the generator circuit $G_2 = 100 \times \frac{13.8}{132} = 10.45$ KV

Now, for G_1, (Applying eq (16))

$$x_{g_1,new} = x_{g_1,old} \times \frac{(MVA)_{B,new}}{(MVA)_{B,old}} \times \frac{(KV)^2_{B,old}}{(KV)^2_{B,new}}$$

$(MVA)_{B,new} = (MVA)_B = 100$

$(MVA)_{B,old}$ = Rated MVA of G_1 = 50 MVA

$(KV)_{B,old} = 12.2$ KV

$(KV)_{B,new} = 9.24$ KV ; $x_{g_1,old} = x_{g_1} = 0.10$ PU

$$\therefore x_{g_1,new} = 0.10 \times \left(\frac{100}{50}\right) \times \left(\frac{12.2}{9.24}\right)^2 = 0.3486 \text{ PU}$$

Similarly for G_2,

$$x_{g_2,new} = 0.10 \times \left(\frac{100}{20}\right) \times \left(\frac{13.8}{10.45}\right)^2 = 0.8719 \text{ PU}$$

For T_1,

$$x_{T_1,new} = 0.1 \times \left(\frac{100}{80}\right) \times \left(\frac{12.2}{9.24}\right)^2 = 0.2179 \text{ pu}$$

For T_2,

$$x_{T_2,new} = 0.1 \times \left(\frac{100}{40}\right) \times \left(\frac{13.8}{10.45}\right)^2 = 0.39 \text{ pu}$$

Base impedance of the transmission-line circuit,

$$Z_{B,line} = \frac{(100)^2}{100} = 100\Omega$$

$$Z_{12}(pu) = \frac{Z_{12}(\Omega)}{Z_{B,line}} = \frac{(4+j16)}{100} = (0.04+j0.16) \text{ pu}$$

$$Z_{13}(pu) = Z_{23}(pu) = \frac{2+j8}{100} = (0.02+j0.08) \text{ pu}$$

The load is specified as:

$$S = 50(0.8+j0.6) = (40+j30) \text{ MVA}.$$

(a) Series combination of resistance and reactance

using eq (11),

$$Z^*_{Load}(\Omega) = \frac{(124)^2}{(40+j30)} = 307.52\angle{-36.87^\circ}\ \Omega.$$

$$\therefore Z^*_{Load}(pu) = \frac{Z^*_{Load}(\Omega)}{Z_{B,line}} = \frac{307.52\angle{-36.87}}{100} \text{ pu}$$

$$\therefore Z_{load}(pu) = (2.46+j1.845) \text{ pu}$$

$$\therefore R_{series} = 2.46 \text{ pu}; \quad X_{series} = 1.845 \text{ pu}$$

(b) Parallel Combination of Resistance and Reactance.

$$R_{parallel} = \frac{(124)^2}{40} = 384.4\Omega$$

$$\therefore R_{parallel}(pu) = \frac{384.4}{100} = 3.844\ pu$$

$$X_{parallel} = \frac{(124)^2}{30} = 512.5\,\Omega$$

$$\therefore X_{parallel}(pu) = \frac{512.5}{100} = 5.125\ pu$$

⇒ The reactance diagram is shown in Fig. 18. The load is represented as series combination of R and L

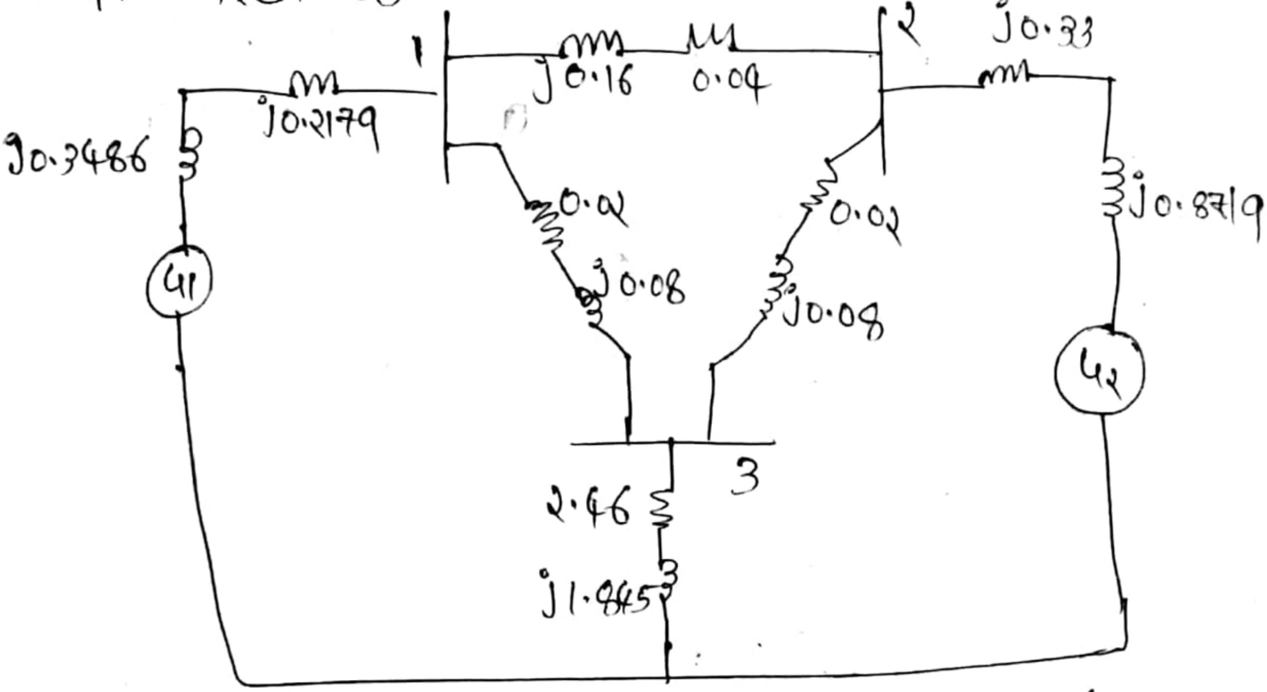


Fig. 18: Reactance diagram of ex-6.

Ex-7) :— The single line diagram of a three phase power system is shown in Fig. 19. Select a common base of 100MVA and 13.8KV on the generator side. Draw per unit impedance diagram.

G: 90MVA, 13.8KV,

$x_g = 18\%$

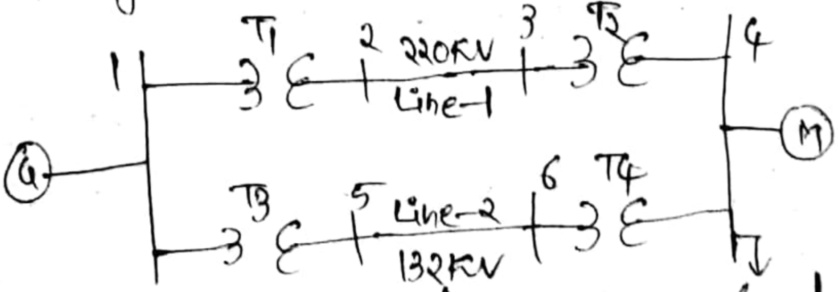


Fig. 19: Single line diagram of ex-7. load

T_1 : 50MVA, 13.8/220KV, $x_{T_1} = 10\%$

T_2 : 50MVA, 220/11KV, $x_{T_2} = 10\%$

T_3 : 50MVA, 13.8/132KV, $x_{T_3} = 10\%$

T_4 : 50MVA, 132/11KV, $x_{T_4} = 10\%$

M : 80MVA, 10.45KV, $x_m = 10\%$

Load : 57MVA, 0.8pf (lagging) at 10.45KV;

$x_{line1} = 50\Omega$ and $x_{line2} = 70\Omega$

Sol: The generator rated voltage is given as the base voltage at bus1. This fixes the voltage bases for other buses in accordance to the transformer turns ratio.

$\Rightarrow V_{B1} = 13.8KV$, $V_{B2} = 13.8\left(\frac{220}{13.8}\right) = 220KV$

Base voltage on the high voltage side of T_2 is 220KV.

$\therefore V_{B3} = 220KV$

and on its low voltage side,

$$V_{B4} = 220\left(\frac{11}{220}\right) = 11KV$$

Similarly, $V_{B5} = V_{B6} = 13.8\left(\frac{132}{13.8}\right) = 132KV$

Now Base MVA = 100

$$\therefore x_{g1} = 0.18 \times \frac{100}{90} = 0.20pu$$

$$x_{T_1} = x_{T_2} = x_{T_3} = x_{T_4} = 0.10\left(\frac{100}{50}\right) = 0.20pu$$

using eq (16)

$$x_{m,new}(pu) = x_{m,old}(pu) \times \frac{(MVA)_{B,new}}{(MVA)_{B,old}} \times \frac{(KV)^2_{B,old}}{(KV)^2_{B,new}}$$

Here, $x_{m,old}(pu) = 0.20pu$; $(MVA)_{B,old} = 80$;
$(KV)_{B,old} = 10.45KV$; $(MVA)_{B,new} = 100$; $(KV)_{B,new} = 11KV$

$$x_{m,new}(pu) = 0.2 \times \frac{100}{80} \times \left(\frac{10.45}{11}\right)^2 = 0.2256\ pu$$

Base impedance for lines

$$Z_{B,2-3} = \frac{(V_{B2})^2}{(MVA)_B} = \frac{(220)^2}{100} = 484\Omega$$

$$Z_{B,5-6} = \frac{(V_{B5})^2}{(MVA)_B} = \frac{(132)^2}{100} = 174.24\Omega$$

$$x_{line-1} = \frac{50}{484} = 0.1033\ pu$$

$$x_{line-2} = \frac{70}{174.24} = 0.4017\ pu$$

The load is at 0.80 pf lagging is given by

$$S_L(3\phi) = 57\angle 36.87^0\ MVA.$$

Load impedance is given by

$$Z_L = \frac{(V_{LL})^2}{S_L^*(3\phi)} = \frac{(10.45)^2}{57\angle -36.87^0}$$

$$\therefore Z_L = (1.532 + j1.1495)\Omega$$

Base impedance for the load is

$$Z_{B,load} = \frac{(11)^2}{100} = 1.21\Omega$$

$$\therefore Z_L(pu) = \frac{(1.532 + j1.1495)}{1.21}$$

$$= (1.266 + j0.95)\ pu$$

The per-unit equivalent circuit diagram is shown in Fig. 20.

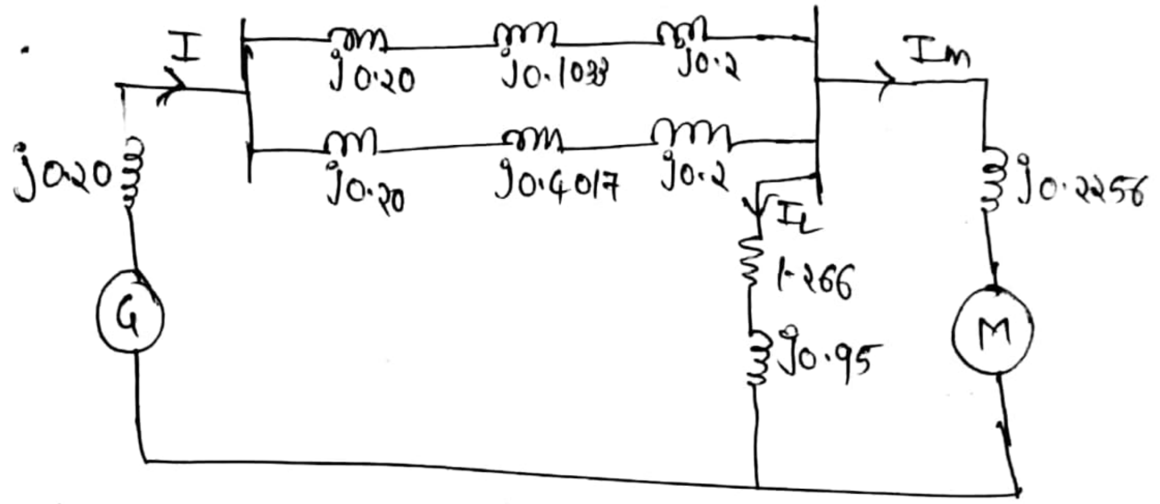


Fig. 20: Per-unit impedance diagram of example-7.

Load flow Analysis

⇒ Power flow studies, Commonly referred to as load flow, are essential of power system analysis and design.

⇒ load flow studies are necessary for planning, economic operation, scheduling and exchange of power between utilities.

⇒ Load flow study is also required for transient stability, dynamic stability, contingency and state estimation.

⇒ Node voltage method is commonly used for power system analysis.

⇒ The load flow results give the bus voltage magnitude and phase angles and hence the power flow through the transmission lines, line losses, and power injection at all the buses.

Bus Classification:—

⇒ Four quantities are associated with each bus.

These are:

voltage magnitude = |V|,

Phase angle = δ

Real power = P

Reactive power = Q

⇒ In a load flow study, two out of four quantities are specified and the remaining two quantities are to be obtained through the solutions of equations.

⇒ The system buses are generally classified into three Categories:

1). Slack Bus:

⇒ Also known as swing bus and taken reference where the magnitude and phase angle of the voltage are specified.

⇒ This bus provides the additional real and reactive power to supply the transmission losses, since these are unknown until the final solution is obtained.

2). Load Buses:—

⇒ Also known as P–Q bus.

⇒ At these buses the real and reactive powers are specified.

⇒ The magnitude and phase angle of the bus voltage are unknown until the final solution is obtained.

3). Voltage Controlled buses:—

⇒ Also known as generator buses or regulated buses or P–|V| buses.

⇒ At these buses, the real power and voltage magnitude are specified.

⇒ The phase angles of the voltages and the reactive power are unknown until the final solution is obtained.

⇒ The limits on the value of reactive power are also specified.

⇒ The following table summarises the above discussion:

Bus type	specified quantities	unknown quantities
slack bus	$\|V\|, \delta$	P, Q
Load bus	P, Q	$\|V\|, \delta$
Voltage Controlled bus	P, $\|V\|$	Q, δ

Bus Admittance Matrix:-

⇒ Consider the sample 4-bus power system as shown in Fig. 1:

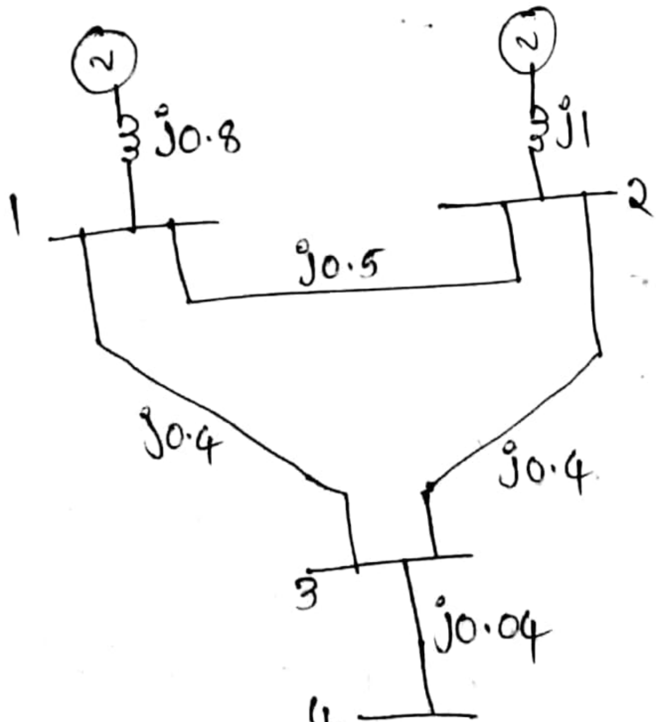


Fig. 1: The impedance diagram of sample 4-bus Power system.

Line admittance,

$$y_{ik} = \frac{1}{z_{ik}} = \frac{1}{(r_{ik} + j\,x_{ik})} \longrightarrow (1)$$

⇒ Fig. 2 shows the admittance diagram and transformation to current sources and injects currents I_1 and I_2 at buses 1 and 2 respectively. Node 0 (which is normally ground) is taken as reference.

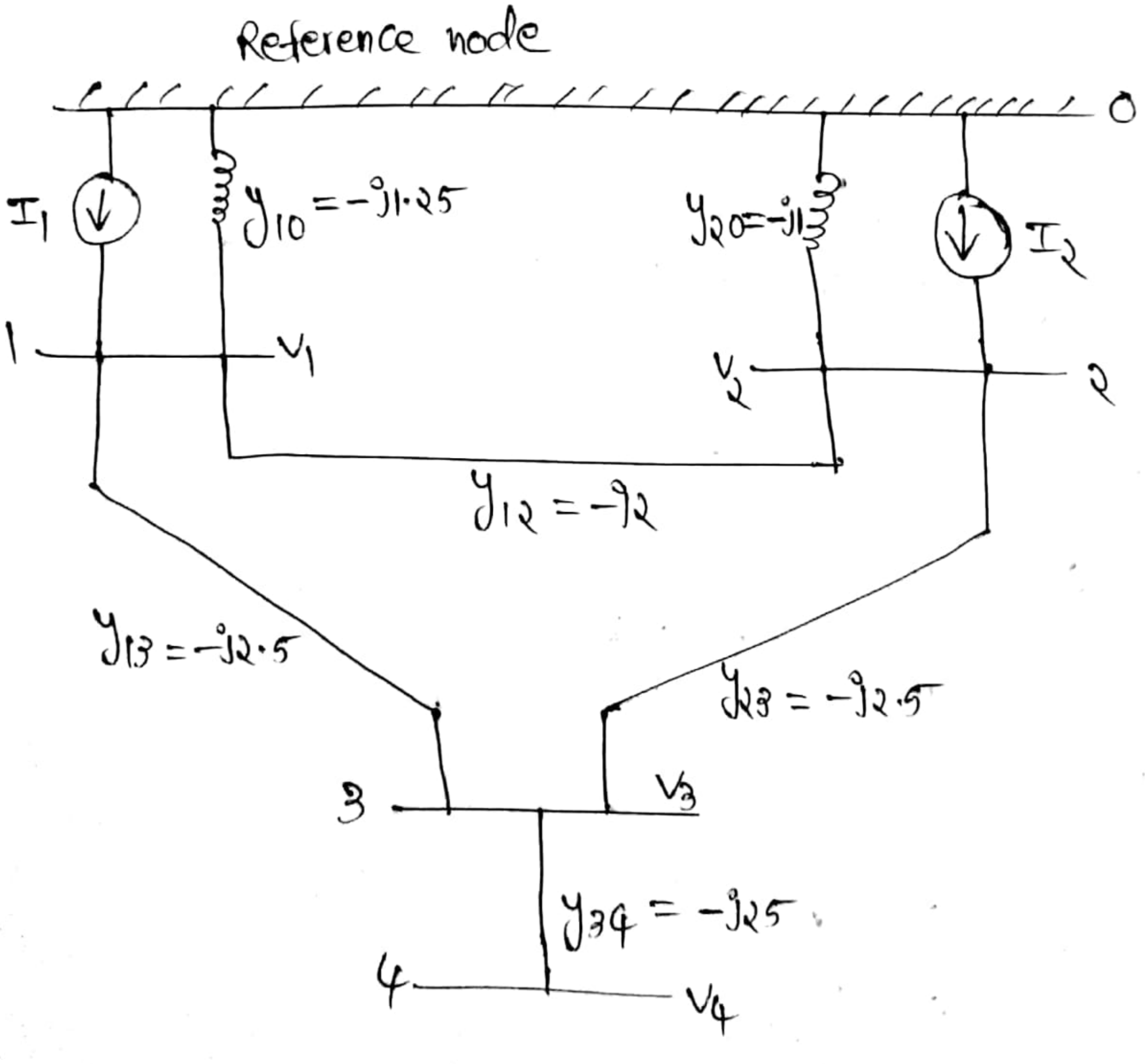


Fig. 2: The admittance diagram of Fig. 1.

Applying KCL to the independent nodes 1, 2, 3, 4 we have,

$$\left.\begin{aligned} I_1 &= y_{10} V_1 + y_{12}(V_1 - V_2) + y_{13}(V_1 - V_3) \\ I_2 &= y_{20} V_2 + y_{12}(V_2 - V_1) + y_{23}(V_2 - V_3) \\ 0 &= y_{23}(V_3 - V_2) + y_{13}(V_3 - V_1) + y_{34}(V_3 - V_4) \\ 0 &= y_{34}(V_4 - V_3) \end{aligned}\right\}$$

Re arranging the above equations, we get

$$\left.\begin{aligned} I_1 &= (y_{10} + y_{12} + y_{13}) V_1 - y_{12} V_2 - y_{13} V_3 \\ I_2 &= -y_{12} V_1 + (y_{20} + y_{12} + y_{23}) V_2 - y_{23} V_3 \\ 0 &= -y_{13} V_1 - y_{23} V_2 + (y_{13} + y_{23} + y_{34}) V_3 - y_{34} V_4 \\ 0 &= -y_{34} V_3 + y_{34} V_4 \end{aligned}\right\}$$

Let,

$$\left.\begin{aligned} Y_{11} &= (y_{10} + y_{12} + y_{13}) \\ Y_{22} &= (y_{20} + y_{12} + y_{23}) \\ Y_{33} &= (y_{13} + y_{23} + y_{34}) \\ Y_{44} &= y_{34} \end{aligned}\right\} \Rightarrow \text{Diagonal Elements.}$$

$$\left.\begin{aligned} Y_{12} &= Y_{21} = -y_{12} \\ Y_{13} &= Y_{31} = -y_{13} \\ Y_{23} &= Y_{32} = -y_{23} \\ Y_{34} &= Y_{43} = -y_{34} \end{aligned}\right\} \Rightarrow \text{Off-diagonal Elements}$$

The node equations reduce to,

$$\left.\begin{aligned} I_1 &= Y_{11}V_1 + Y_{12}V_2 + Y_{13}V_3 + Y_{14}V_4 \\ I_2 &= Y_{21}V_1 + Y_{22}V_2 + Y_{23}V_3 + Y_{24}V_4 \\ I_3 &= Y_{31}V_1 + Y_{32}V_2 + Y_{33}V_3 + Y_{34}V_4 \\ I_4 &= Y_{41}V_1 + Y_{42}V_2 + Y_{43}V_3 + Y_{44}V_4. \end{aligned}\right\}$$

Note that, in Fig.2, there is no connection between bus1 and bus4,

$$\therefore Y_{14} = Y_{41} = 0$$

Similarly,

$$Y_{24} = Y_{42} = 0$$

Also note that in this case,

$$I_3 = 0 \; ; \; I_4 = 0$$

Above equation can be written in matrix form,

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} & Y_{14} \\ Y_{21} & Y_{22} & Y_{23} & Y_{24} \\ Y_{31} & Y_{32} & Y_{33} & Y_{34} \\ Y_{41} & Y_{42} & Y_{43} & Y_{44} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix} \longrightarrow (2)$$

Or in general,

$$I_{Bus} = Y_{Bus} V_{Bus} \longrightarrow (3)$$

where,

V_{Bus} = vector of bus voltages.

I_{Bus} = vector of the injected currents [the current is positive when flowing into the bus and negative when flowing out of the bus].

Y_{Bus} = admittance matrix.

⇒ Diagonal element of Y matrix is known as self-admittance or driving point admittance, i.e;

$$Y_{ii} = \sum_{k=0}^{n} y_{ik}, \quad k \neq i \longrightarrow (4)$$

off-diagonal element of Y matrix is known as transfer admittance or mutual admittance i.e;

$$Y_{ik} = Y_{ki} = -y_{ik} \longrightarrow (5)$$

V_{bus} can be obtained from eq ③, i.e;

$$V_{bus} = Y_{bus}^{-1} \cdot I_{Bus} \longrightarrow ⑥$$

From fig. 2, elements of Y matrix can be written as:

$$Y_{11} = y_{10} + y_{12} + y_{13} = -j1.25 - j2 - j2.5$$
$$= -j5.75$$

$$Y_{22} = y_{20} + y_{12} + y_{23} = -j1 - j2 - j2.5$$
$$= -j5.5$$

$$Y_{33} = y_{34} + y_{13} + y_{23} = -j25 - j2.5 - j2.5$$
$$= -j30$$

$$Y_{44} = y_{34} = -j25$$

$Y_{12} = Y_{21} = -y_{12} = j2$; $Y_{13} = Y_{31} = -y_{13} = j2.5$

$Y_{14} = Y_{41} = 0.0$; $Y_{24} = Y_{42} = 0.0$

$Y_{23} = Y_{32} = -y_{23} = j2.5$; $Y_{34} = Y_{43} = -y_{34} = j25$

$$\therefore Y_{Bus} = \begin{bmatrix} -j5.75 & j2 & j2.5 & 0 \\ j2 & -j5.5 & j2.5 & 0 \\ j2.5 & j2.5 & -j30 & j25 \\ 0 & 0 & j25 & -j25 \end{bmatrix}$$

Ex:- 1):- Find out the Y matrix of the sample power system as shown in Fig.3. Data for this system are given in Table-1.

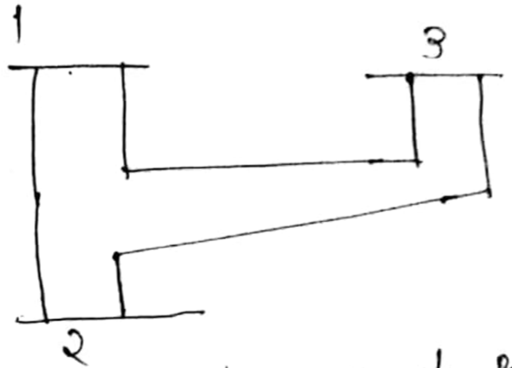


Fig.3: 3-bus sample power system.

Table-1: Per-unit impedances and line charging for sample power system shown in Fig.3.

Bus Code i-k	Impedance Z_{ik}	Line charging $y'_{ik}/2$
1-2	0.02+j0.06	j0.03
1-3	0.08+j0.24	j0.025
2-3	0.06+j0.18	j0.020

Sol ⇒ Note that line charging admittance is considered in this example. One should represent each line as π-equivalent.

⇒ First composite the total charging admittance at each bus i.e;

$$y_{10} = \frac{1}{2}y'_{13} + \frac{1}{2}y'_{12} = j0.025 + j0.03 = j0.055$$

$$y_{20} = \frac{1}{2}y'_{21} + \frac{1}{2}y'_{23} = \frac{1}{2}y'_{12} + \frac{1}{2}y'_{23}$$

$$= j0.03 + j0.020 = j0.05$$

$$y_{30} = \frac{1}{2}y'_{31} + \frac{1}{2}y'_{32} = \frac{1}{2}y'_{13} + \frac{1}{2}y'_{23} = j0.025 + j0.020 = j0.045$$

$$\Rightarrow y_{12} = \frac{1}{z_{12}} = \frac{1}{0.02 + j0.06} = \frac{1}{0.0632\angle 71.56}$$

$$= 15.82\angle -71.56$$

$$y_{13} = \frac{1}{z_{13}} = \frac{1}{0.08 + j0.024} = 3.955\angle -71.56^0$$

$$y_{23} = \frac{1}{z_{23}} = \frac{1}{0.06 + j0.18} = 5.273\angle -71.56^0$$

$$Y_{11} = y_{10} + y_{12} + y_{13} = j0.055 + (15.82 + 3.955)\angle -71.56^0$$

$$= 6.255 - j18.704.$$

$$Y_{22} = y_{20} + y_{12} + y_{23} = j0.05 + (15.82 + 5.273)\angle -71.56^0$$

$$= 6.672 - j19.96$$

$$Y_{33} = y_{30} + y_{31} + y_{32} = j0.045 + (3.955 + 5.273)\angle -71.56^0$$

$$= 2.918 - j8.709$$

$$Y_{12} = Y_{21} = -y_{12} = -15.82\angle -71.56^0$$

$$= -5 + j15$$

$$Y_{13} = Y_{31} = -y_{13} = -3.955\angle -71.56^0$$

$$= -1.25 + j3.75$$

$$Y_{23} = Y_{32} = -y_{23} = -5.273\angle -71.56^0$$

$$= -1.667 + j5$$

$$Y_{Bus} = \begin{bmatrix} (6.255 - j18.704) & (-5 + j15) & (-1.25 + j3.75) \\ (-5 + j15) & (6.672 - j19.96) & (-1.667 + j5) \\ (-1.25 + j3.75) & (-1.667 + j5) & (2.918 - j8.709) \end{bmatrix}$$

Bus Loading Equations:-

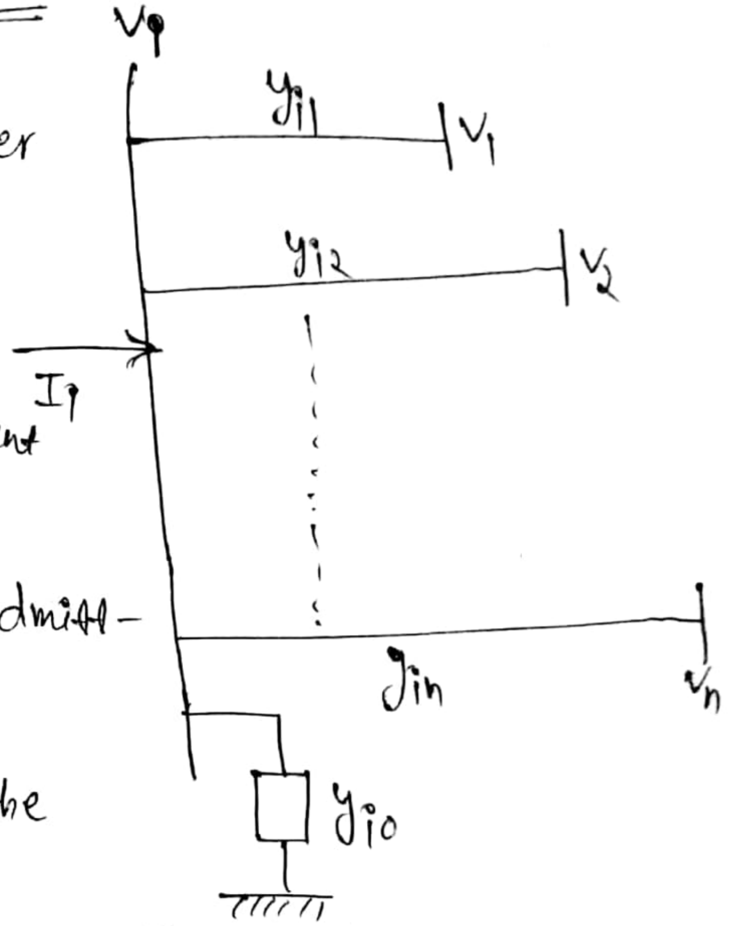


Fig. 4: i-th bus of a Power System

⇒ Consider i-th bus of a power system as shown in Fig. 4.

⇒ Transmission lines are represented by their equivalent π-models.

⇒ y_{i0} is the total charging admittance at bus i.

⇒ Net injected current I_i into the bus-i can be written as:

$$I_i = y_{i0}V_i + y_{i1}(V_i - V_1) + y_{i2}(V_i - V_2) + \cdots + y_{in}(V_i - V_n)$$

$$\therefore I_i = (y_{i0} + y_{i1} + y_{i2} + \cdots + y_{in})V_i - y_{i1}V_1 - y_{i2}V_2 - \cdots - y_{in}V_n \quad \rightarrow (7)$$

Let us define,

$$Y_{ii} = (y_{i0} + y_{i1} + y_{i2} + \cdots + y_{in})$$

$$Y_{i1} = -y_{i1}$$

$$Y_{i2} = -y_{i2}$$

$$\vdots$$

$$Y_{in} = -y_{in}$$

$$\therefore I_i = Y_{ii} V_i + Y_{i1} V_1 + Y_{i2} V_2 + \cdots\cdots + Y_{in} V_n \longrightarrow (8)$$

or

$$I_i = Y_{ii} V_i + \sum_{\substack{K=1 \\ K \neq i}}^{n} Y_{iK} V_K \longrightarrow (9)$$

⇒ The real and reactive power injected at bus-i is

$$P_i - jQ_i = V_i^* I_i$$

$$\therefore I_i = \frac{P_i - jQ_i}{V_i^*} \longrightarrow (10)$$

From eq (9) and eq (10), we get

$$\frac{P_i - jQ_i}{V_i^*} = Y_{ii} V_i + \sum_{\substack{K=1 \\ K \neq i}}^{n} Y_{iK} V_K \longrightarrow (11)$$

$$\therefore Y_{ii} V_i = \frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{K=1 \\ K \neq i}}^{n} Y_{iK} V_K$$

$$\therefore V_i = \frac{1}{Y_{ii}} \left[\frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{K=1 \\ K \neq i}}^{n} Y_{iK} V_K \right] \longrightarrow (12)$$

Gauss-seidel iterative method:-

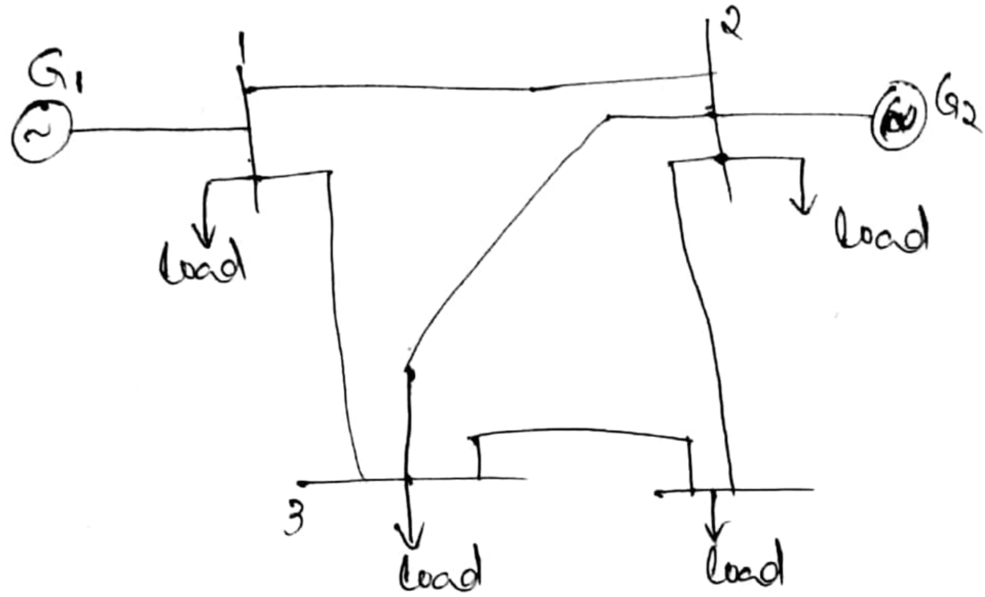


Fig.5: 4-bus power system.

⇒ Consider a 4-bus sample power system as shown in fig.5.

⇒ Bus-1 is considered as slack bus, where voltage magnitude and its angle are known.

⇒ In this case n = 4 and slack bus s = 1.

From eq (11), we can write,

$$V_i = \frac{1}{Y_{ii}}\left[\frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{k=1\\k\neq i}}^{4} Y_{ik}V_k\right]$$

$i = 1, 2, 3, 4$

$i \neq s$; i.e; $i \neq 1$

$$\therefore V_2 = \frac{1}{Y_{22}}\left[\frac{P_2 - jQ_2}{V_2^*} - \sum_{\substack{k=1\\k\neq 2}}^{4} Y_{2k}V_k\right]$$

$$\therefore V_2 = \frac{1}{Y_{22}}\left[\frac{P_2 - jQ_2}{V_2^*} - Y_{21}V_1 - Y_{23}V_3 - Y_{24}V_4\right]$$

similarly,

$$V_3 = \frac{1}{Y_{33}}\left[\frac{P_3 - jQ_3}{V_3^*} - Y_{31}V_1 - Y_{32}V_2 - Y_{34}V_4\right]$$

$$V_4 = \frac{1}{Y_{44}}\left[\frac{P_4 - jQ_4}{V_4^*} - Y_{41}V_1 - Y_{42}V_2 - Y_{43}V_3\right]$$

⇒ In the Gauss-seidel method, the new calculated voltage at (P+1), i.e; $V_i^{(P+1)}$ immediately replaces $V_i^{(P)}$ and is used in the solution of the subsequent equations.

⇒ Therefore, above set of equations can be written in iterative form, i.e;

$$V_2^{(P+1)} = \frac{1}{Y_{22}}\left[\frac{P_2 - jQ_2}{(V_2^{(P)})^*} - Y_{21}V_1 - Y_{23}V_3^{(P)} - Y_{24}V_4^{(P)}\right]$$

$$V_3^{(P+1)} = \frac{1}{Y_{33}}\left[\frac{P_3 - jQ_3}{(V_3^{(P)})^*} - Y_{31}V_1 - Y_{32}V_2^{(P+1)} - Y_{34}V_4^{(P)}\right]$$

$$V_4^{(P+1)} = \frac{1}{Y_{44}}\left[\frac{P_4 - jQ_4}{(V_4^{(P)})^*} - Y_{41}V_1 - Y_{42}V_2^{(P+1)} - Y_{43}V_3^{(P+1)}\right]$$

⇒ Note that Bus-1 is slack bus. Under normal operating conditions, the voltage magnitude of buses are in the neighbour-

-hood of 1.0 per unit or close to the voltage magnitude of slack bus.

⇒ Therefore, an initial starting voltage of (1.0 + j0.0) for unknown voltages is satisfactory, and the converged solution corelates with the actual operating states.

Calculation of Net injected Power :-

⇒ From eq (11), we get,

$$\frac{P_i - jQ_i}{V_i^*} = Y_{ii} V_i + \sum_{\substack{k=1 \\ k \neq i}}^{n} Y_{ik} V_k$$

$$\therefore P_i - jQ_i = V_i^* \left[Y_{ii} V_i + \sum_{\substack{k=1 \\ k \neq i}}^{n} Y_{ik} V_k \right] \longrightarrow (13)$$

Let

$$Y_{ii} = |Y_{ii}| \angle \theta_{ii} \; ; \quad Y_{ik} = |Y_{ik}| \angle \theta_{ik}$$

$$V_i = |V_i| \angle \delta_i$$

$$\therefore V_i^* = |V_i| \angle -\delta_i$$

$$V_k = |V_k| \angle \delta_k$$

$$\therefore P_i - jQ_i = |V_i| \angle -\delta_i \, |Y_{ii}| \angle \theta_{ii} \, |V_i| \angle \delta_i + \sum_{\substack{k=1 \\ k \neq i}}^{n} |V_i| \angle -\delta_i \, |Y_{ik}| \angle \theta_{ik} \, |V_k| \angle \delta_k$$

$$\therefore P_i - jQ_i = |V_i|^2 |Y_{ii}| \angle \theta_{ii} + \sum_{\substack{K=1 \\ K \neq i}}^{n} |Y_{iK}| |V_i| |V_K| \angle \theta_{iK} + \delta_K - \delta_i$$

$$\therefore P_i - jQ_i = |V_i|^2 |Y_{ii}| \cos\theta_{ii} + j |V_i|^2 |Y_{ii}| \sin\theta_{ii} + \sum_{\substack{K=1 \\ K \neq i}}^{n} |Y_{iK}| |V_i| |V_K| \cos(\theta_{iK} + \delta_K - \delta_i) + j \sum_{\substack{K=1 \\ K \neq i}}^{n} |Y_{iK}| |V_i| |V_K| \sin(\theta_{iK} + \delta_K - \delta_i) \longrightarrow (14)$$

Separating real and imaginary part of eq (14)

$$\therefore P_i = |V_i|^2 |Y_{ii}| \cos\theta_{ii} + \sum_{\substack{K=1 \\ K \neq i}}^{n} |Y_{iK}| |V_i| |V_K| \cos(\theta_{iK} + \delta_K - \delta_i)$$

$$\therefore P_i = \sum_{K=1}^{n} |V_i| |V_K| |Y_{iK}| \cos(\theta_{iK} - \delta_i + \delta_K) \longrightarrow (15)$$

and

$$-Q_i = |V_i|^2 |Y_{ii}| \sin\theta_{ii} + \sum_{\substack{K=1 \\ K \neq i}}^{n} |Y_{iK}| |V_i| |V_K| \sin(\theta_{iK} + \delta_K - \delta_i)$$

$$\therefore Q_i = - \sum_{K=1}^{n} |V_i| |V_K| |Y_{iK}| \sin(\theta_{iK} - \delta_i + \delta_K) \longrightarrow (16)$$

Consideration of P–|V| Buses

⇒ For P–Q buses, the real and reactive powers $P_i^{scheduled}$ and $Q_i^{scheduled}$ are known. Starting with initial values of the voltages, set of voltage equations can be solved iteratively. For the voltage controlled buses [P–|V| buses], where $P_i^{scheduled}$ and $|V_i|$ are specified, First Eq (16) is solved for $Q_i^{(p+1)}$, i.e;

$$Q_i^{(p+1)} = -\sum_{k=1}^{n} |V_i|^{(p)} |V_k|^{(p)} |Y_{ik}| \sin\left(\theta_{ik} - \delta_i^{(p)} + \delta_k^{(p)}\right) \longrightarrow (17)$$

⇒ Then set of voltage equations are solved. However, at P–|V| buses, since $|V_i|$ is specified, only the imaginary part of $V_i^{(p+1)}$ is retained and its real part is selected in order to satisfy,

$$\left(e_i^{(p+1)}\right)^2 + \left(f_i^{(p+1)}\right)^2 = |V_i|^2 \longrightarrow (18)$$

$$\therefore \; e_i^{(p+1)} = \left\{ |V_i|^2 - \left(f_i^{(p+1)}\right)^2 \right\}^{1/2} \longrightarrow (19)$$

where

$e_i^{(p+1)}$ = real part of $V_i^{(p+1)}$

$f_i^{(p+1)}$ = imaginary part of $V_i^{(p+1)}$

Convergence procedure:-

⇒ The updated voltages immediatly replace the previous valu-
-es in the solution of the subsequent equations. This process
is Continued until changes of bus voltages between succe-
-ssive iterations are with in a specified accuracy.

Define

$$\Delta V = \max \left| V_i^{(P+1)} - V_i^{(P)} \right|, \quad i = 2, 3, \ldots n \longrightarrow (20)$$

⇒ If $\Delta V \leq \epsilon$, then the solution has converged.
Usually, $\epsilon = 0.0001$ or 0.00001 may be considered.

⇒ Another Convergence Criteria is the maximum difference of mismatch of real and reactive power between sucessive iterations.

Define,

$$\Delta P = \max \left| P_i^{\text{Calculated}} - P_i^{\text{scheduled}} \right| \longrightarrow (21)$$

$$\Delta Q = \max \left| Q_i^{\text{Calculated}} - Q_i^{\text{scheduled}} \right| \longrightarrow (22)$$

If $\{ (\Delta P \,\&\, \Delta Q) \leq \epsilon \}$, the solution has converged.
In this case, ϵ may be taken as 0.001 or 0.00001.

Computation of Line flows and Line losses:-

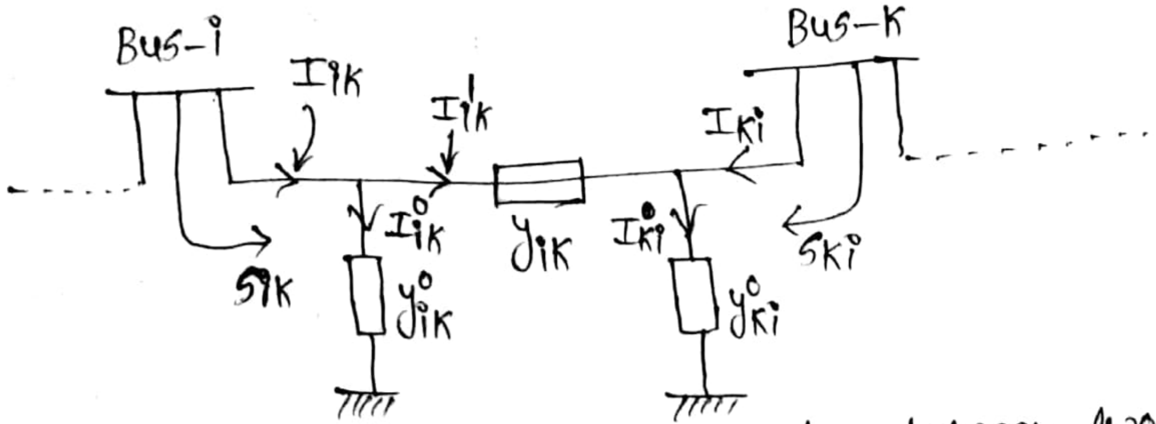


Fig. 6: π- representation of a line between two buses.

Consider the line connecting buses i and K. ~~From~~

From Fig. 6, we can write,

$$I_{ik} = I'_{ik} + I^0_{ik} \longrightarrow (23)$$

$$I'_{ik} = (V_i - V_k)\, y_{ik} \longrightarrow (24)$$

$$I^0_{ik} = V_i\, y^0_{ik} \longrightarrow (25)$$

From eqs (23), (24) and (25), we get,

$$I_{ik} = (V_i - V_k)\, y_{ik} + V_i\, y^0_{ik} \longrightarrow (26)$$

The power fed into the line from bus-i is:

$$S_{ik} = P_{ik} + j\, Q_{ik} \longrightarrow (27)$$

$$\therefore P_{ik} + j\, Q_{ik} = V_i \cdot I^*_{ik} \longrightarrow (28)$$

using eqs (28) and (26), we get,

$$P_{ik} + jQ_{ik} = V_i\left[(V_i - V_K)\, y_{ik} + V_i\, y_{ik}^0\right]^*$$

$$\therefore P_{ik} + jQ_{ik} = V_i\,(V_i^* - V_K^*)\, y_{ik}^* + V_i V_i^* \,(y_{ik}^0)^*$$

$$\therefore P_{ik} - jQ_{ik} = V_i^*(V_i - V_K)\, y_{ik} + V_i^* V_i\, y_{ik}^0$$

$$\therefore P_{ik} - jQ_{ik} = |V_i|^2 y_{ik} - V_i^* V_K\, y_{ik} + |V_i|^2 y_{ik}^0 \longrightarrow (29)$$

similarly power fed into the line from bus 'K' is

$$P_{Ki} - jQ_{Ki} = |V_K|^2 y_{ik} - V_K^* V_i\, y_{ik} + |V_K|^2 y_{Ki}^0 \longrightarrow (30)$$

Now

$$Y_{ik} = -y_{ik}$$

$$\therefore y_{ik} = -Y_{ik} \longrightarrow (31)$$

From eq (29) and (31), we get,

$$P_{ik} - jQ_{ik} = -|V_i|^2 Y_{ik} + V_i^* V_K Y_{ik} + |V_i|^2 y_{ik}^0 \longrightarrow (32)$$

$$Y_{ik} = |Y_{ik}|\angle\theta_{ik}\ ;\ V_i = |V_i|\angle\delta_i\ ;\ V_i^* = |V_i|\angle -\delta_i\ ;$$

$$y_{ik}^0 = j|y_{ik}|$$

$$\therefore P_{ik} - jQ_{ik} = \left[-|V_i|^2 |Y_{ik}| \cos\theta_{ik} + |V_i||V_k||Y_{ik}| \cos(\theta_{ik} - \delta_i + \delta_k) \right]$$
$$- j\left[|V_i|^2 |Y_{ik}| \sin\theta_{ik} - |V_i||V_k||Y_{ik}| \sin(\theta_{ik} - \delta_i + \delta_k) - |V_i|^2 |y_{ik}^{o}| \right] \longrightarrow (33)$$

separating real and imaginary part of eq (33)

$$\therefore P_{ik} = -|V_i|^2 |Y_{ik}| \cos\theta_{ik} + |V_i||V_k||Y_{ik}| \cos(\theta_{ik} - \delta_i + \delta_k) \longrightarrow (34)$$

$$\therefore Q_{ik} = |V_i|^2 |Y_{ik}| \sin\theta_{ik} - |V_i||V_k||Y_{ik}| \sin(\theta_{ik} - \delta_i + \delta_k) - |V_i|^2 |y_{ik}^{o}| \longrightarrow (35)$$

Similarly power flows from bus k to i can be written as:

$$P_{ki} = -|V_k|^2 |Y_{ik}| \cos\theta_{ik} + |V_i||V_k||Y_{ik}| \cos(\theta_{ik} - \delta_k + \delta_i) \longrightarrow (36)$$

$$Q_{ki} = |V_k|^2 |Y_{ik}| \sin\theta_{ik} - |V_i||V_k||Y_{ik}| \sin(\theta_{ik} - \delta_k + \delta_i) - |V_k|^2 |y_{ki}^{o}| \longrightarrow (37)$$

Now real power loss in the line i–k is the sum of the real power flows determined from eq (34) and (36)

$$\therefore P_{Loss\,ik} = P_{ik} + P_{ki}$$

$$\therefore P_{Loss\,ik} = -|V_i|^2|Y_{ik}|\cos\theta_{ik} + |V_i||V_k||Y_{ik}|\cos(\theta_{ik}-\delta_i+\delta_k)$$
$$-|V_k|^2|Y_{ik}|\cos\theta_{ik} + |V_i||V_k||Y_{ik}|\cos(\theta_{ik}-\delta_k+\delta_i)$$

$$= -\left(|V_i|^2+|V_k|^2\right)|Y_{ik}|\cos\theta_{ik} + |V_i||V_k||Y_{ik}|\left[\cos\{\theta_{ik}-(\delta_i-\delta_k)\} + \cos\{\theta_{ik}+(\delta_i-\delta_k)\}\right]$$

$$= -\left(|V_i|^2+|V_k|^2\right)|Y_{ik}|\cos\theta_{ik} + 2|V_i||V_k||Y_{ik}|\cos\theta_{ik}\cos(\delta_i-\delta_k)$$

$$\therefore P_{Loss\,ik} = \left[2|V_i||V_k|\cos(\delta_i-\delta_k) - |V_i|^2 - |V_k|^2\right]|Y_{ik}|\cos\theta_{ik} \longrightarrow (38)$$

Let,

$$Y_{ik} = G_{ik} + jB_{ik}$$
$$G_{ik} = |Y_{ik}|\cos\theta_{ik}$$
$$B_{ik} = |Y_{ik}|\sin\theta_{ik}$$

$$\therefore P_{Loss\,ik} = G_{ik}\left[2|V_i||V_k|\cos(\delta_i-\delta_k) - |V_i|^2 - |V_k|^2\right] \longrightarrow (39)$$

Reactive power loss in the line i–k is the sum of the reactive power flows determined from eqs (35) and (37).

$$\therefore Q_{Loss\,ik} = Q_{ik} + Q_{ki}$$

$$\therefore Q_{Loss\,ik} = B_{ik}\left[|V_i|^2+|V_k|^2-2|V_i||V_k|\cos(\delta_i-\delta_k)\right]$$
$$-\left[|V_i|^2|y_{ik}^0| + |V_k|^2|y_{ik}^0|\right] \longrightarrow (40)$$

Algorithm for Gauss–seidel Method

Step-1: Initial Computation

⇒ with the load profile known at each bus (i.e, P_{Li} and Q_{Li} are known), allocate P_{gi} and Q_{gi} to all generating units.

⇒ while active and reactive generations are not allocated to the slack bus, these are permitted to vary during iterative process. This is must as voltage magnitude and phase angle are specified at slack bus.

⇒ with this data, net bus injected power ($P_i + jQ_i$) at all buses are known other than slack bus.

Step-2:– Formation of Ybus matrix

⇒ with the line and shunt admittance data, form Y_{Bus} matrix.

Step-3:– Iterative Computation of Bus voltage.

⇒ To start the iterative computation, a set of initial voltage value is assumed.

⇒ Since in a power system, the voltage variation is not too wide, it is usual practice to use a flat voltage start, i.e; initially all voltages are set equal to $(1+j0)$ except the voltage of the slack bus which is specified and fixed.

⇒ It should be noted that $(n-1)$ voltage equations are to be solved iteratively for finding $(n-1)$ complex voltages $V_2, V_3, \ldots, V_n$.

⇒ The iterative computation is continued till the change in maximum magnitude of bus voltage, (ΔV) is less than a certain tolerance for all bus voltages, i.e;

$$\Delta V = \max \left| V_i^{(P+1)} - V_i^{(P)} \right| < \epsilon, \quad i = 1, 2, 3, \ldots, n.$$

Step-4:- Computation of slack bus power.

⇒ slack bus power can be computed using eq (15) & (16), i.e;

$$P_1 = \sum_{K=1}^{n} |V_1||V_K||Y_{1K}| \cos(\theta_{1K} - \delta_1 + \delta_K) \longrightarrow (41)$$

$$Q_1 = -\sum_{K=1}^{n} |V_1||V_K||Y_{1K}| \sin(\theta_{1K} - \delta_1 + \delta_K) \longrightarrow (42)$$

Step-5:- Computation of Line Flows

⇒ This is the last step in the load flow analysis.

⇒ The power flows on the various lines are computed using eqs (34) & (35).

⇒ Real and reactive power loss can be computed using eqs (39) & (40), respectively.

Problems:- Ex(2):-

(a) using the G-S method, determine the values of the voltage at buses 2 & 3. [perform only two iterations]

(b) Find the slack bus real and reactive power after second iteration.

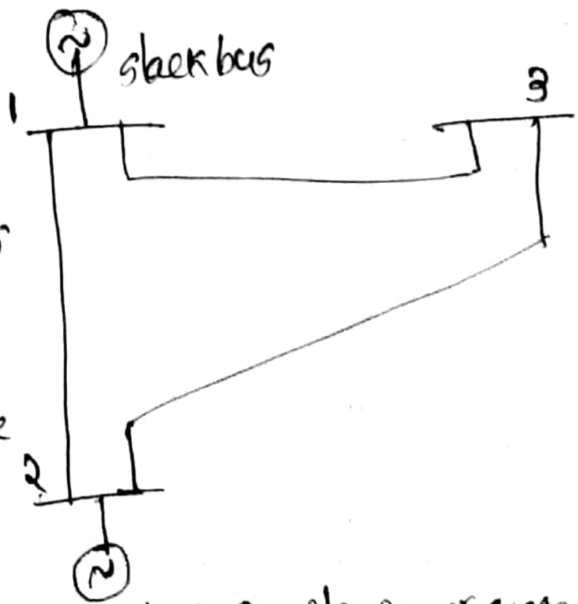


Fig.7: 3-bus sample power system.

(c). Determine the line flows and line losses after second iteration. Neglect line charging admittance.

DATA

Table-2: Scheduled generation and loads assumed bus voltage for sample power system. [Base MVA = 100].

Bus Code i	Assumed bus voltage	Generation		Load	
		MW	MVAr	MW	MVAr
1 (slack bus)	(1.05 + j0.0)	–	–	0	0
2	(1.0 + j0.0)	50	30	305.6	140.2
3	1.0 + j0.0	0.0	0.0	138.6	45.2

Table-3: Line Impedances.

Bus Code i–k	Impedance, Z_{ik}
1–2	0.02 + j0.04
1–3	0.01 + j0.03
2–3	0.0125 + j0.025

Sol: Step-1 :- Initial Computations.

⇒ Convert all the loads in per-unit values

$P_{L2} = \frac{305.6}{100} = 3.056 \text{ pu};$

$Q_{L2} = \frac{140.2}{100} = 1.402 \text{ pu}$

$P_{L3} = \frac{138.6}{100} = 1.386 \text{ pu}$; $Q_{L3} = \frac{45.2}{100} = 0.452 \text{ pu}$

⇒ Convert all the generation in per-unit values.

$P_{g2} = \frac{50}{100} = 0.5 \text{ pu}$; $Q_{g2} = \frac{30}{100} = 0.30 \text{ pu}$

⇒ Compute net-injected power at bus-2 and 3.

$P_2 = P_{g2} - P_{L2} = (0.5 - 3.056) = -2.556 \text{ pu}$

$Q_2 = Q_{g2} - Q_{L2} = (0.3 - 1.402) = -1.102 \text{ pu}$

$P_3 = P_{g3} - P_{L3} = (0 - 1.386) = -1.386 \text{ pu}$

$Q_3 = Q_{g3} - Q_{L3} = (0 - 0.452) = -0.452 \text{ pu}.$

Step-2 : Formation of Ybus matrix.

$y_{12} = y_{21} = \frac{1}{Z_{12}} = \frac{1}{0.02 + j0.04} = 10 - j20$

$y_{13} = y_{31} = \frac{1}{Z_{13}} = \frac{1}{0.01 + j0.03} = 10 - j30$

$y_{23} = y_{32} = \frac{1}{Z_{23}} = \frac{1}{0.0125 + j0.025} = 16 - j32$

Now $Y_{11} = y_{12} + y_{13} + y_{10}$

Charging admittance is neglected, i.e; $y_{10} = 0.0$

$$Y_{11} = y_{12} + y_{13} = (10 - j20) + (10 - j30)$$

$$= 20 - j50$$

$$Y_{22} = y_{21} + y_{23} = y_{12} + y_{23} = 26 - j52$$

$$Y_{33} = y_{13} + y_{23} = 26 - j62$$

$$Y_{11} = 53.85 \angle -68.2^\circ$$

$$Y_{22} = 58.13 \angle -63.4^\circ$$

$$Y_{33} = 67.23 \angle -67.2^\circ$$

$$Y_{12} = -y_{12} = -(10 - j20) = 22.36 \angle 116.6^\circ$$

$$Y_{12} = Y_{21} = 22.36 \angle 116.6^\circ$$

$$Y_{13} = Y_{31} = -y_{13} = -(10 - j30) = 31.62 \angle 108.4^\circ$$

$$Y_{23} = Y_{32} = -y_{23} = -(16 - j32) = 35.77 \angle 116.6^\circ$$

$$\therefore Y_{BUS} = \begin{bmatrix} 53.85 \angle -68.2^\circ & 22.36 \angle 116.6^\circ & 31.62 \angle 108.4^\circ \\ 22.36 \angle 116.6^\circ & 58.13 \angle -63.4^\circ & 35.77 \angle 116.6^\circ \\ 31.62 \angle 108.4^\circ & 35.77 \angle 116.6^\circ & 67.23 \angle -67.2^\circ \end{bmatrix}$$

Step-3 :— Iterative Computation

$$V_2^{(P+1)} = \frac{1}{Y_{22}} \left[\frac{P_2 - jQ_2}{(V_2^{(P)})^*} - Y_{21} V_1 - Y_{23} V_3^{(P)} \right]$$

(P)

$$V_3^{(P+1)} = \frac{1}{Y_{33}}\left[\frac{P_3 - jQ_3}{(V_3^{(P)})^*} - Y_{31}V_1 - Y_{32}V_2^{(P+1)}\right] \longrightarrow (ii)$$

slack bus voltage $V_1 = (1.05 + j0.0)$

starting voltage $V_2^{(0)} = (1+j0)$; $V_3^{(0)} = (1+j0)$

Now

$$\frac{P_2 - jQ_2}{Y_{22}} = \frac{(-2.556 + j1.102)}{58.13\angle -63.4^\circ} = 0.0478\angle 220.1^\circ$$

$$\frac{Y_{21}}{Y_{22}} = \frac{22.36\angle 116.6^\circ}{58.13\angle -63.4^\circ} = 0.3846\angle 180^\circ = -0.3846$$

$$\frac{Y_{23}}{Y_{22}} = \frac{35.77\angle 116.6^\circ}{58.13\angle 63.4} = 0.6153\angle 180^\circ = -0.6153$$

Therefore eq (i) can be written as:

$$V_2^{(P+1)} = \left[\frac{0.0478\angle 220.1^\circ}{(V_2^{(P)})^*} + 0.3846\,V_1 + 0.6153\,V_3^{(P)}\right] \longrightarrow (iii)$$

Now,

$$\frac{P_3 - jQ_3}{Y_{33}} = \frac{(-1.386 + j0.452)}{67.23\angle -67.2^\circ} = 0.0217\angle 224.2^\circ$$

$$\frac{Y_{31}}{Y_{33}} = \frac{31.62\angle 108.4^\circ}{67.23\angle -67.2^\circ} = 0.47\angle 175.6^\circ$$

$$\frac{Y_{32}}{Y_{33}} = \frac{35.77\angle 116.6^\circ}{67.23\angle -67.2^\circ} = 0.532\angle 183.8^\circ$$

Therefore eq (iii) can be written as:

$$V_3^{(p+1)} = \left[\frac{0.0217\angle 229.2^\circ}{\left(V_3^{(p)}\right)^*} - 0.47\angle 175.6^\circ V_1 - 0.532\angle 183.8^\circ V_2^{(p+1)}\right] \quad \rightarrow \text{(iv)}$$

Now solve eqs (iii) and (iv) iteratively.

First Iteration:-

set $p=0$

$$\therefore V_2^{(1)} = \frac{0.0478\angle 220.1^\circ}{\left(V_2^{(0)}\right)^*} + 0.3846 V_1 + 0.6153 V_3^{(0)}$$

$$\therefore V_2^{(1)} = \frac{0.0478\angle 220.1^\circ}{(1+j0)^*} + 0.3846(1.05+j0.0) + 0.6153(1.0+j0.0)$$

$$\therefore V_2^{(1)} = 0.98305\angle -1.8^\circ$$

$$V_3^{(1)} = \frac{0.0217\angle 229.2^\circ}{\left(V_3^{(0)}\right)^*} - 0.47\angle 175.6^\circ V_1 - 0.532\angle 183.8^\circ V_2^{(1)}$$

$$\therefore V_3^{(1)} = \frac{0.0217\angle 229.2^\circ}{(1+j0)^*} - 0.47\angle 175.6^\circ(1.05+j0) - 0.532\angle 183.8^\circ \times 0.98305\angle -1.8^\circ$$

$$V_3^{(1)} = 1.0011\angle -2.06^\circ$$

After first iteration

$$V_2^{(1)} = 0.98305\angle -1.8^\circ$$

$$V_3^{(1)} = 1.0011\angle -2.06^\circ$$

2nd iteration :-

set $p=1$

$$V_2^{(2)} = \frac{0.0478\angle 220.1^\circ}{(0.98305\angle -1.8^\circ)^*} + 0.3846\times(1.05+j0.0) + 0.6153\times 1.0011\angle -2.06^\circ$$

$$\therefore V_2^{(2)} = 0.98265\angle -3.048^\circ$$

$$V_3^{(2)} = \frac{0.0217\angle 229.2^\circ}{(1.0011\angle -2.06^\circ)^*} - 0.47\angle 175.6^\circ\times(1.05+j0.0) - 0.532\angle 183.8^\circ \times 0.98265\angle -3.048^\circ$$

$$\therefore V_3^{(2)} = 1.00099\angle -2.68^\circ$$

After second Iteration

$$V_2^{(2)} = 0.98265\angle -3.048^\circ$$

$$V_3^{(2)} = 1.00099\angle -2.68^\circ$$

Step-4 :- Computation of slack Bus Power

After 2nd iteration slack bus power is computed.

From eq (41)

$$P_1 = \sum_{k=1}^{3} |V_1||V_k||Y_{1k}| \cos(\theta_{1k} - \delta_1 + \delta_k)$$

$$\therefore P_1 = |V_1|^2 |Y_{11}| \cos\theta_{11} + |V_1||V_2||Y_{12}| \cos(\theta_{12} - \delta_1 + \delta_2) + |V_1||V_3||Y_{13}| \cos(\theta_{12} - \delta_1 + \delta_3)$$

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$\therefore |V_1| = 1.05 \; ; \; \delta_1 = 0^\circ$

$|V_2| = 0.98265 \; ; \; \delta_2 = -3.048^\circ$

$|V_3| = 1.00099 \; ; \; \delta_3 = -2.68^\circ$

$|Y_{11}| = 53.85 \; ; \; \theta_{11} = -68.2^\circ$

$|Y_{12}| = 22.36 \; ; \; \theta_{12} = 116.56^\circ$

$|Y_{13}| = 31.62 \; ; \; \theta_{13} = 108.4^\circ$

$$\therefore P_1 = (1.05)^2 \times 53.85 \cos(-68.2^\circ) + 1.05 \times 0.98265 \times 22.36 \cos(116.56^\circ - 0 - 3.048^\circ)$$
$$+ 1.05 \times 1.00099 \times 31.62 \cos(108.4^\circ - 0 - 2.68^\circ).$$

$\therefore P_1 = 3.84$ PU MW $= 3.84 \times 100 = 384$ MW

From eq (42),

$$Q_1 = -\sum_{k=1}^{3} |V_1||V_k||Y_{1k}| \sin(\theta_{1k} - \delta_1 + \delta_k)$$

$$Q_1 = -|V_1|^2 |Y_{11}| \sin\theta_{11} - |V_1||V_2||Y_{12}| \sin(\theta_{12} - \delta_1 + \delta_2)$$
$$- |V_1||V_3||Y_{13}| \sin(\theta_{13} - \delta_1 + \delta_3)$$

$$\therefore Q_1 = -(1.05)^2 \times 53.85 \sin(-68.2^\circ) - 1.05 \times 0.98265 \times 22.36 \sin(116.56^\circ - 3.048^\circ)$$
$$- 1.05 \times 1.00099 \times 31.62 \sin(108.4^\circ - 2.68^\circ)$$

$\therefore Q_1 = 1.9786$ PU MVAr $= 1.9786 \times 100 = 197.86$ MVAr

Step-5:- Calculation of Line flows and Line Losses

From eq (34)

$$P_{ik} = -|V_i|^2 |Y_{ik}| \cos\theta_{ik} + |V_i||V_k||Y_{ik}| \cos(\theta_{ik} - \delta_i + \delta_k)$$

$$\therefore P_{12} = -|V_1|^2 |Y_{12}| \cos\theta_{12} + |V_1||V_2||Y_{12}| \cos(\theta_{12} - \delta_1 + \delta_2)$$

$$\therefore P_{12} = -(1.05)^2 \times 22.36 \cos(116.56^\circ) + 1.05 \times 0.98265 \times 22.36 \cos(116.56^\circ - 0 - 3.048^\circ).$$

$$\therefore P_{12} = 1.8189 \text{ pu MW} = 181.89 \text{ MW}$$

$$P_{13} = -|V_1|^2 |Y_{13}| \cos(\theta_{13}) + |V_1||V_3||Y_{13}| \cos(\theta_{13} - \delta_1 + \delta_3)$$

$$\therefore P_{13} = -(1.05)^2 \times 31.62 \cos(108.4^\circ) + 1.05 \times 1.00099 \times 31.62 \cos(108.4^\circ - 0 - 2.68^\circ)$$

$$\therefore P_{13} = 2.0 \text{ pu MW} = 200 \text{ MW}$$

$$P_{23} = -|V_2|^2 |Y_{23}| \cos\theta_{23} + |V_2||V_3||Y_{23}| \cos(\theta_{23} - \delta_2 + \delta_3)$$

$$\therefore P_{23} = -(0.98265)^2 \times 35.77 \cos(116.6^\circ) + 0.98265 \times 1.00099 \times 35.77 \cos(116.6^\circ + 3.048^\circ - 2.68^\circ)$$

$$\therefore P_{23} = -0.4903 \text{ pu MW} = -49.03 \text{ MW}$$

From eq (36),

$$P_{ki} = -|V_k|^2 |Y_{ik}| \cos\theta_{ik} + |V_i||V_k||Y_{ik}| \cos(\theta_{ik} - \delta_k + \delta_i)$$

$$P_{21} = -|V_2|^2 |Y_{12}| \cos\theta_{12} + |V_1||V_2||Y_{12}| \cos(\theta_{12} - \delta_2 + \delta_1)$$

$$\therefore P_{21} = -(0.98265)^2 \times 22.36 \cos(116.56^\circ) + 1.05 \times 0.98265 \times 22.36 \cos(116.56^\circ + 3.048^\circ + 0^\circ)$$

$$\therefore P_{21} = -1.744 \text{ pu MW} = -174.4 \text{ MW}$$

$$P_{31} = -|V_3|^2 |Y_{13}| \cos\theta_{13} + |V_1||V_3||Y_{13}| \cos(\theta_{13} - \delta_3 + \delta_1)$$

$$= -(1.00099)^2 \times 31.62 \cos(108.4^\circ) + 1.05 \times 1.00099 \times 31.62 \cos(108.4^\circ + 2.68^\circ + 0^\circ)$$

$$\therefore P_{31} = -1.95 \text{ pu MW} = -195 \text{ MW}$$

$$P_{32} = -|V_3|^2 |Y_{23}| \cos\theta_{23} + |V_3||V_2||Y_{23}| \cos(\theta_{23} - \delta_3 + \delta_2)$$

$$\therefore P_{32} = -(1.00099)^2 \times 35.77 \cos(116.6^\circ) + 1.00099 \times 0.98265 \times 35.77 \cos(116.6^\circ + 2.68 - 3.048^\circ)$$

$$\therefore P_{32} = 0.496 \text{ PU MW} = 49.6 \text{ MW}$$

Real power losses in line 1-2, 1-3, and 2-3.

$$P_{LOSS12} = P_{12} + P_{21} = (181.89 - 174.4) = 7.49 \text{ MW}$$

$$P_{LOSS13} = P_{13} + P_{31} = (200 - 195) = 5 \text{ MW}.$$

$$P_{LOSS23} = P_{23} + P_{32} = (-49.03 + 49.6) = 0.57 \text{ MW}$$

Reactive line flows can be calculated from eq (35) and (37).

From eq (35), we get,

$$Q_{12} = |V_1|^2 |Y_{12}| \sin\theta_{12} - |V_1||V_2||Y_{12}| \sin(\theta_{12} - \delta_1 + \delta_2)$$

$$\therefore Q_{12} = (1.05)^2 \times 22.36 \sin(116.56^\circ) - 1.05 \times 0.98265 \times 22.36 \sin(116.56^\circ - 3.048^\circ)$$

$$\therefore Q_{12} = 0.8948 \text{ PU MVAr} = 89.48 \text{ MVAr}$$

Similarly,

$$Q_{13} = (1.05)^2 \times 31.62 \sin(108.4^\circ) - 1.05 \times 1.00099 \times 31.62 \sin(108.4^\circ - 2.68)$$

$$\therefore Q_{13} = 1.088 \text{ PU MVAr} = 108.8 \text{ MVAr}$$

$$Q_{23} = (0.98265)^2 \times 35.77 \sin(116.6^\circ) - 0.98265 \times 1.00099 \times 35.77 \sin(116.6^\circ + 3.048^\circ - 2.68^\circ)$$

$$\therefore Q_{23} = -0.4746 \text{ PU MVAr} = -47.46 \text{ MVAr}.$$

From eq (37),

$$Q_{21} = (0.98265)^2 \times 22.36 \sin(116.56^0) - 1.05 \times 0.98265 \times 22.36 \sin(116.56^0 + 3.048^0)$$

$$\therefore Q_{21} = -0.746 \text{ pu MVAR} = -74.6 \text{ MVAR}$$

$$Q_{31} = (1.00099)^2 \times 31.62 \sin(108.4^0) - 1.05 \times 1.00099 \times 31.62 \sin(108.4^0 + 2.68^0).$$

$$\therefore Q_{31} = -0.9469 = -94.69 \text{ MVAR}$$

$$Q_{32} = (1.00099)^2 \times 35.77 \sin(116.6^0) - 1.00099 \times 0.98265 \times 35.77 \sin(116.6^0 + 2.68^0 - 3.048^0)$$

$$\therefore Q_{32} = 0.4866 \text{ pu MVAR} = 48.66 \text{ MVAR}$$

Reactive power losses in line 1-2, 1-3 and 2-3.

$$\Rightarrow Q_{Loss12} = Q_{12} + Q_{21} = (89.48 - 74.6) = 14.88 \text{ MVAR}$$

$$\Rightarrow Q_{Loss13} = Q_{13} + Q_{31} = (108.8 - 94.69) = 14.11 \text{ MVAR}$$

$$\Rightarrow Q_{Loss23} = Q_{23} + Q_{32} = (-47.46 + 48.66) = 1.20 \text{ MVAR}$$

Note that all the results given above are computed after 2nd iteration.

Ex-3):-

Bus-2, is a P-|V| bus. Details are given in Fig.8. Use same line data as given in Table-3.

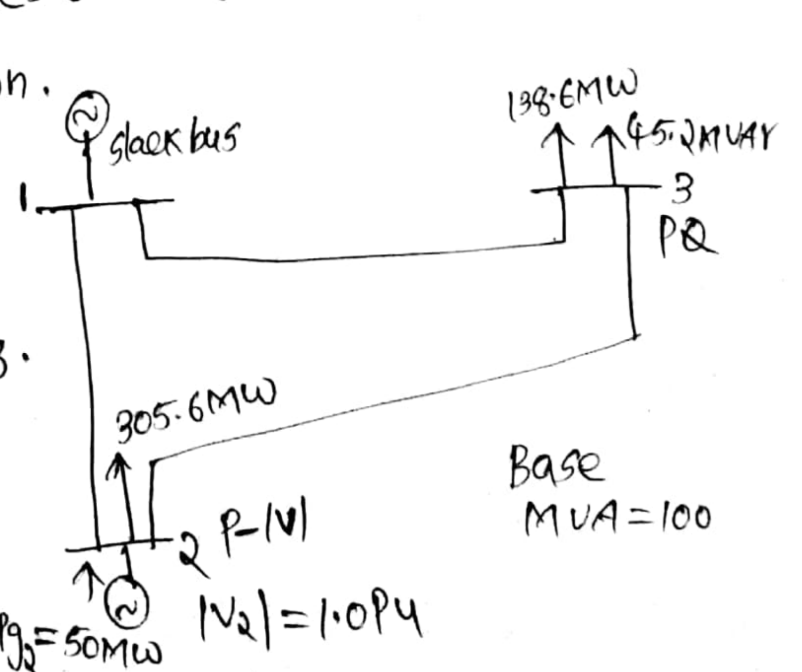


Fig.8: Sample power system

Sol:

$PL_2 = 305.6\,MW, \quad Pg_2 = 50\,MW$

$\therefore P_2 = (Pg_2 - PL_2) = 50 - 305.6 = -255.6\,MW$

$\therefore P_2 = -2.556\ pu\ MW$

$P_3 = Pg_3 - PL_3 = (0 - 138.6)\,MW = -138.6\,MW$

$\therefore P_3 = -1.386\ pu\ MW$

$Q_3 = Qg_3 - QL_3 = (0 - 45.2)\,MVAR = -45.2\,MVAR$

$\therefore Q_3 = -0.452\ pu\ MVAR$

Slack Bus voltage

$V_1 = (1.05 + j0.0)\,pu$

P-|V| bus $\Rightarrow$ $|V_2| = 1.0\,pu$

$\therefore V_2^{(0)} = (1.0 + j0.0)\,pu$

P-Q bus

$V_3^{(0)} = (1.0 + j0.0)\,pu.$

⇒ Bus-2 is a regulated bus [P-|V| bus], where voltage magnitude and real power are specified.

⇒ For the P-|V| bus, first the reactive power is computed using eq (16).

$$Q_2 = -\sum_{K=1}^{3} |V_2||V_K||Y_{2K}| \sin(\theta_{2K} - \delta_2 + \delta_K)$$

$$\therefore Q_2 = -|V_2||V_1||Y_{21}|\sin(\theta_{21}-\delta_2+\delta_1) - |V_2|^2|Y_{22}|\sin\theta_{22}$$
$$-|V_2||V_3||Y_{23}|\sin(\theta_{23}-\delta_2+\delta_3)$$

$$\therefore Q_2^{(P+1)} = -|V_2||V_1||Y_{21}|\sin(\theta_{21}-\delta_2^{(P)}+\delta_1) - (|V_2|)^2|Y_{22}|\sin\theta_{22}$$
$$-|V_2||V_3|^{(P)}|Y_{23}|\sin(\theta_{23}-\delta_2^{(P)}+\delta_3^{(P)})$$

$|Y_{21}| = 22.36$; $\theta_{21} = 116.6^0$

$|Y_{22}| = 58.13$; $\theta_{22} = -63.4^0$

$|Y_{23}| = 35.77$; $\theta_{23} = 116.6^0$

<u>Iteration-1:—</u>

set $P=0$

$$Q_2^{(1)} = -|V_2||V_1||Y_{21}|\sin(\theta_{21}-\delta_2^{(0)}+\delta_1) - |V_2|^2|Y_{22}|\sin\theta_{22}$$
$$-|V_2||V_3|^{(0)}|Y_{23}|\sin(\theta_{23}-\delta_2^{(0)}+\delta_3^{(0)})$$

$|V_1| = 1.05$; $\delta_1 = 0.0^0$

$|V_2| = 1.0$; $\delta_2^{(0)} = 0.0^0$

$|V_3|^{(0)} = 1.0$; $\delta_3^{(0)} = 0.0^0$

$$Q_2^{(1)} = -1.0\times1.05\times22.36\sin(116.6^0) - (1.0)^2\times58.13\sin(-63.4^0)$$
$$-1.0\times1.0\times35.77\sin(116.6^0)$$

$$\therefore Q_2^{(1)} = -1.0067 \text{ PU MVAr}$$

$\Rightarrow$ The value of $Q_2^{(1)}$ is taken as net reactive power injected at bus-2, i.e; $Q_2 = Q_2^{(1)} = -1.0067$ PU MVAr

Now Compute,

$$V_{C_2}^{(P+1)} = \frac{1}{Y_{22}}\left[\frac{P_2 - jQ_2^{(P+1)}}{\left(V_2^{(P)}\right)^*} - Y_{21}V_1 - Y_{23}V_3^{(P)}\right]$$

$$\therefore V_{C_2}^{(1)} = \frac{1}{Y_{22}}\left[\frac{P_2 - jQ_2^{(1)}}{\left(V_2^{(0)}\right)^*} - Y_{21}V_1 - Y_{23}V_3^{(0)}\right]$$

$$\frac{P_2 - jQ_2^{(1)}}{Y_{22}} = \frac{(-2.556 + j1.0067)}{58.13\angle -63.4^0} = 0.04725\angle 221.9^0$$

$$\frac{Y_{21}}{Y_{22}} = -0.3846 \;;\quad \frac{Y_{23}}{Y_{22}} = -0.6153$$

$$V_{C_2}^{(1)} = \left[\frac{0.04725\angle 221.9^0}{\left(V_2^{(0)}\right)^*} + 0.3846\,V_1 + 0.6153\,V_3^{(0)}\right]$$

$$\therefore V_{C_2}^{(1)} = \frac{0.04725\angle 221.9^0}{1.0} + 0.3846 \times 1.05 + 0.6153 \times 1.0$$

$$\therefore V_{C_2}^{(1)} = (0.98396 - j0.03155)$$

Since $|V_2|$ is held constant at 1.0 pu, only the imaginary part of $V_{C_2}^{(1)}$ is retained, i.e;

$f_2^{(1)} = -0.03155$ and its real part is obtained from,

$$e_2^{(1)} = \sqrt{|V_2|^2 - (0.03155)^2}$$

$$\therefore e_2^{(1)} = \sqrt{(1.0)^2 - (-0.03155)^2}$$

$$\therefore e_2^{(1)} = 0.9995$$

Thus,

$$V_2^{(1)} = (0.9995 - j0.03155)$$

$$\therefore V_2^{(1)} = 1.0\angle -1.807^\circ$$

Now,

$$V_3^{(P+1)} = \frac{1}{Y_{33}}\left[\frac{P_3 - jQ_3}{\left(V_3^{(P)}\right)^*} - Y_{31}V_1 - Y_{32}V_2^{(P+1)}\right]$$

$\Rightarrow$ set $P=0$

$$\therefore V_3^{(1)} = \frac{1}{Y_{33}}\left[\frac{P_3 - jQ_3}{\left(V_3^{(0)}\right)^*} - Y_{31}V_1 - Y_{32}V_2^{(1)}\right]$$

$$\therefore V_3^{(1)} = \left[\frac{0.0217\angle 229.2^\circ}{\left(V_3^{(0)}\right)^*} - 0.47\angle 175.6^\circ \cdot V_1 - 0.532\angle 183.8^\circ \cdot V_2^{(1)}\right]$$

$$\therefore V_3^{(1)} = \left[\frac{0.0217\angle 229.2^\circ}{1.0} - 0.47\angle 175.6^\circ \times 1.05 - 0.532\angle 183.8^\circ \times 1.0\angle -1.807^\circ\right]$$

$$\therefore V_3^{(1)} = (1.00949 - j0.035796)$$

$$\therefore V_3^{(1)} = 1.0101\angle -2.03^\circ$$

After 1st Iteration

$$V_2^{(1)} = 1.0\angle -1.807^\circ$$
$$V_3^{(1)} = 1.0101\angle -2.03^\circ$$

$\Rightarrow$ set $P=1$

$$Q_2^{(2)} = -|V_2||V_1||Y_{21}|\sin(\theta_{21}-\delta_2^{(1)}+\delta_1) - |V_2|^2|Y_{22}|\sin\theta_{22}$$
$$-|V_2||V_3|^{(1)}|Y_{23}|\sin(\theta_{23}-\delta_2^{(1)}+\delta_3^{(1)})$$

$\delta_1 = 0.0^\circ$; $\delta_2^{(1)} = -1.807^\circ$; $\delta_3^{(1)} = -2.03^\circ$

$|V_1| = 1.05$; $|V_2| = 1.0$; $|V_3|^{(1)} = 1.0101$

$$\therefore Q_2^{(2)} = -1\times 1.05\times 22.36\sin(116.56^\circ + 1.807^\circ) - (1.0)^2\times 58.13\sin(-63.4^\circ)$$
$$-1.0\times 1.0101\times 35.77\sin(116.6^\circ + 1.807^\circ - 2.03^\circ)$$

$$\therefore Q_2^{(2)} = -1.0507 \text{ pu MVAr}$$

$$\therefore VC_2^{(2)} = \left[\frac{0.04725\angle 221.9^\circ}{(V_2^{(1)})^*} + 0.3486\,V_1 + 0.6153\,V_3^{(1)}\right]$$

$$\therefore VC_2^{(2)} = \frac{0.04725\angle 221.9^\circ}{1\angle 1.807} + 0.3846\times 1.05 + 0.6153\times 1.0101\angle -2.03$$

$$\therefore VC_2^{(2)} = (0.9888 - j0.05244) = e_2^{(2)} + jf_2^{(2)}$$

Now, $f_2^{(2)} = -0.05244$

$$\therefore e_2^{(2)} = \sqrt{(1.0)^2 - (-0.05244)^2} = 0.9986$$

$$\therefore V_2^{(2)} = (0.9986 - j0.05244)$$

$$\therefore V_2^{(2)} = 1\angle -3^\circ$$

$$\therefore V_3^{(2)} = \left[\frac{0.0217\angle 229.2^\circ}{\left(V_3^{(1)}\right)^*} - 0.47\angle 175.6^\circ\, V_1 - 0.532\angle 183.8^\circ\, V_2^{(2)} \right]$$

$$\therefore V_3^{(2)} = \left[\frac{0.0217\angle 229.2^\circ}{1.0101\angle 2.03^\circ} - 0.47\angle 175.6^\circ \times 1.05 - 0.532\angle 183.8^\circ \times 1\angle -3^\circ \right]$$

$$\therefore V_3^{(2)} = (1.0093 - j0.04619)$$

$$\therefore V_3^{(2)} = 1.0103\angle -2.62^\circ$$

After 2nd iteration

$$V_2^{(2)} = 1.0\angle -3^\circ \;;\quad V_3^{(2)} = 1.0103\angle -2.62^\circ$$

Newton–Raphson Method

⇒ Newton-Raphson method is an iterative method which approximates the set of non-linear simultaneous equations to a set of linear equations using Taylor's series expansion and the terms are restricted to first order approximation.

⇒ Given a set of non-linear equations,

$$\left.\begin{aligned} y_1 &= f_1(x_1, x_2, \ldots\ldots, x_n) \\ y_2 &= f_2(x_1, x_2, \ldots\ldots, x_n) \\ &\ldots\ldots\ldots \\ &\ldots\ldots\ldots \\ y_n &= f_n(x_1, x_2, \ldots\ldots, x_n) \end{aligned}\right\} \rightarrow (43)$$

and the initial estimate for the solution vector,

$$x_1^{(0)}, x_2^{(0)}, \ldots\ldots, x_n^{(0)}$$

Assuming $\Delta x_1, \Delta x_2, \ldots\ldots, \Delta x_n$ are the corrections required for $x_1^{(0)}, x_2^{(0)}, \ldots\ldots x_n^{(0)}$ respectively,

so that the equations (43) are solved, i.e;

$$\left.\begin{aligned} y_1 &= f_1(x_1^{(0)}+\Delta x_1, x_2^{(0)}+\Delta x_2, \ldots\ldots, x_n^{(0)}+\Delta x_n) \\ y_2 &= f_2(x_1^{(0)}+\Delta x_1, x_2^{(0)}+\Delta x_2, \ldots\ldots, x_n^{(0)}+\Delta x_n) \\ &\ldots\ldots\ldots \\ &\ldots\ldots\ldots \\ y_n &= f_n(x_1^{(0)}+\Delta x_1, x_2^{(0)}+\Delta x_2, \ldots\ldots, x_n^{(0)}+\Delta x_n) \end{aligned}\right\} \rightarrow (44)$$

⇒ Each equation of the set (44) can be expanded by Taylor's series for a function of two or more variables.

⇒ For example, the following is obtained for the first equation of (44):

$$y_1 = f_1\left(x_1^{(0)} + \Delta x_1,\ x_2^{(0)} + \Delta x_2, \cdots\cdots, x_n^{(0)} + \Delta x_n\right)$$

$$= f_1\left(x_1^{(0)}, x_2^{(0)}, \cdots\cdots x_n^{(0)}\right) + \Delta x_1 \frac{\partial f_1}{\partial x_1}\Big|_0 + \Delta x_2 \frac{\partial f_1}{\partial x_2}\Big|_0$$

$$+ \cdots\cdots + \Delta x_n \frac{\partial f_1}{\partial x_n}\Big|_0 + \psi_1$$

⇒ where ψ_1 is a function of higher power of $\Delta x_1, \Delta x_2, \cdots\cdots, \Delta x_n$ and 2nd, 3rd, ⋯⋯ derivatives of the function f_1.

⇒ Neglecting ψ_1, the linear set of equations resulting is as follows:

$$\left.\begin{aligned}
y_1 &= f_1\left(x_1^{(0)}, x_2^{(0)}, \cdots, x_n^{(0)}\right) + \Delta x_1 \frac{\partial f_1}{\partial x_1}\Big|_0 + \cdots\cdots + \Delta x_n \frac{\partial f_1}{\partial x_n}\Big|_0 \\
y_2 &= f_2\left(x_1^{(0)}, x_2^{(0)}, \cdots\cdots x_n^{(0)}\right) + \Delta x_1 \frac{\partial f_2}{\partial x_1}\Big|_0 + \cdots\cdots + \Delta x_n \frac{\partial f_2}{\partial x_n}\Big|_0 \\
&\cdots\cdots\cdots\cdots \\
&\cdots\cdots\cdots\cdots \\
y_n &= f_n\left(x_1^{(0)}, x_2^{(0)}, \cdots\cdots x_n^{(0)}\right) + \Delta x_1 \frac{\partial f_n}{\partial x_1}\Big|_0 + \cdots\cdots + \Delta x_n \frac{\partial f_n}{\partial x_n}\Big|_0
\end{aligned}\right\}$$

⟶ (45)

$$\therefore \begin{bmatrix} y_1 - f_1(x_1^{(0)}, x_2^{(0)}, \ldots, x_n^{(0)}) \\ y_2 - f_2(x_1^{(0)}, x_2^{(0)}, \ldots, x_n^{(0)}) \\ \cdots \\ \cdots \\ y_n - f_n(x_1^{(0)}, x_2^{(0)}, \ldots, x_n^{(0)}) \end{bmatrix} = \begin{bmatrix} \frac{\partial f_1}{\partial x_1}\Big|_0 & \frac{\partial f_1}{\partial x_2}\Big|_0 & \cdots & \frac{\partial f_1}{\partial x_n}\Big|_0 \\ \frac{\partial f_2}{\partial x_1}\Big|_0 & \frac{\partial f_2}{\partial x_2}\Big|_0 & \cdots & \frac{\partial f_2}{\partial x_n}\Big|_0 \\ \cdots & \cdots & \cdots & \cdots \\ \frac{\partial f_n}{\partial x_1}\Big|_0 & \frac{\partial f_n}{\partial x_2}\Big|_0 & \cdots & \frac{\partial f_n}{\partial x_n}\Big|_0 \end{bmatrix} \begin{bmatrix} \Delta x_1 \\ \Delta x_2 \\ \vdots \\ \Delta x_n \end{bmatrix} \longrightarrow (46)$$

$\Downarrow$ D $\qquad$ $\Downarrow$ J $\qquad$ $\Downarrow$ R

$$\therefore D = J R \longrightarrow (47)$$

⇒ where J is the Jacobian for the function f_i, and R is the change vector Δx_i.

⇒ Eq. (47) may be written in iterative form, i.e;

$$D^{(P)} = J^{(P)} R^{(P)}$$

$$\therefore R^{(P)} = \left[J^{(P)}\right]^{-1} \cdot D^{(P)} \longrightarrow (48)$$

⇒ The new values for x_i's are calculated from

$$x_i^{(P+1)} = x_i^{(P)} + \Delta x_i^{(P)} \longrightarrow (49)$$

⇒ The process is repeated until two successive values for each x_i differ only by a specified tolerance. In this process J can be evaluated in each iteration may be evaluated only once provided Δx_i are changing slowly.

⇒ Because of quadratic convergence, Newton's method is mathematically superior to the Gauss-seidel method and is less prone to divergence with ill-conditioned problem.

Load flow using Newton - Raphson Method :-

⇒ Newton - Raphson (N-R) method is more efficient and practical for large power systems.

⇒ Main advantage of this method is that the number of iterations required to obtain a solution is independent of the size of the problem and computationally it is very fast.

⇒ Here load flow problem is formulated in polar form.

Rewriting eqs (15) and (16)

$$P_i = \sum_{K=1}^{n} |V_i||V_K||Y_{iK}| \cos(\theta_{iK} - \delta_i + \delta_K) \longrightarrow (50)$$

$$Q_i = -\sum_{K=1}^{n} |V_i||V_K||Y_{iK}| \sin(\theta_{iK} - \delta_i + \delta_K) \longrightarrow (51)$$

⇒ Eqs (50) and (51), constitute a set of nonlinear algebraic equations interms of the independent variables, voltage magnitude in per unit and phase angles in radians, we can easily observe that two equations for each load bus given by eqs (50) and (51) and one equation for each voltage controlled bus, given by eq (50).

⇒ Expanding eqs (50) and (51) in Taylor-series and neglecting higher order terms, we obtain,

$$\begin{bmatrix} \Delta P_2^{(p)} \\ \Delta P_3^{(p)} \\ \vdots \\ \Delta P_n^{(p)} \\ \hline \Delta Q_2^{(p)} \\ \Delta Q_3^{(p)} \\ \vdots \\ \Delta Q_n^{(p)} \end{bmatrix} = \left[\begin{array}{cccc|cccc} \left(\frac{\partial P_2}{\partial \delta_2}\right)^{(p)} & \left(\frac{\partial P_2}{\partial \delta_3}\right)^{(p)} & \cdots & \left(\frac{\partial P_2}{\partial \delta_n}\right)^{(p)} & \left(\frac{\partial P_2}{\partial |V_2|}\right)^{(p)} & \left(\frac{\partial P_2}{\partial |V_3|}\right)^{(p)} & \cdots & \left(\frac{\partial P_2}{\partial |V_n|}\right)^{(p)} \\ \left(\frac{\partial P_3}{\partial \delta_2}\right)^{(p)} & \left(\frac{\partial P_3}{\partial \delta_3}\right)^{(p)} & \cdots & \left(\frac{\partial P_3}{\partial \delta_n}\right)^{(p)} & \left(\frac{\partial P_3}{\partial |V_2|}\right)^{(p)} & \left(\frac{\partial P_3}{\partial |V_3|}\right)^{(p)} & \cdots & \left(\frac{\partial P_3}{\partial |V_n|}\right)^{(p)} \\ \vdots & \vdots & J_1 & \vdots & \vdots & \vdots & J_2 & \vdots \\ \left(\frac{\partial P_n}{\partial \delta_2}\right)^{(p)} & \left(\frac{\partial P_n}{\partial \delta_3}\right)^{(p)} & \cdots & \left(\frac{\partial P_n}{\partial \delta_n}\right)^{(p)} & \left(\frac{\partial P_n}{\partial |V_2|}\right)^{(p)} & \left(\frac{\partial P_n}{\partial |V_3|}\right)^{p} & \cdots & \left(\frac{\partial P_n}{\partial |V_n|}\right)^{(p)} \\ \hline \left(\frac{\partial Q_2}{\partial \delta_2}\right)^{(p)} & \left(\frac{\partial Q_2}{\partial \delta_3}\right)^{(p)} & \cdots & \left(\frac{\partial Q_2}{\partial \delta_n}\right)^{(p)} & \left(\frac{\partial Q_2}{\partial |V_2|}\right)^{(p)} & \left(\frac{\partial Q_2}{\partial |V_3|}\right)^{(p)} & \cdots & \left(\frac{\partial Q_n}{\partial |V_n|}\right)^{(p)} \\ \left(\frac{\partial Q_3}{\partial \delta_2}\right)^{(p)} & \left(\frac{\partial Q_3}{\partial \delta_3}\right)^{(p)} & \cdots & \left(\frac{\partial Q_3}{\partial \delta_n}\right)^{(p)} & \left(\frac{\partial Q_3}{\partial |V_2|}\right)^{(p)} & \left(\frac{\partial Q_3}{\partial |V_3|}\right)^{(p)} & \cdots & \left(\frac{\partial Q_n}{\partial |V_n|}\right)^{(p)} \\ \vdots & \vdots & J_3 & \vdots & \vdots & \vdots & J_4 & \vdots \\ \left(\frac{\partial Q_n}{\partial \delta_2}\right)^{(p)} & \left(\frac{\partial Q_n}{\partial \delta_3}\right)^{(p)} & \cdots & \left(\frac{\partial Q_n}{\partial \delta_n}\right)^{(p)} & \left(\frac{\partial Q_n}{\partial |V_2|}\right)^{(p)} & \left(\frac{\partial Q_n}{\partial |V_3|}\right)^{p} & \cdots & \left(\frac{\partial Q_n}{\partial |V_n|}\right)^{(p)} \end{array}\right] \times \begin{bmatrix} \Delta \delta_2^{(p)} \\ \Delta \delta_3^{(p)} \\ \vdots \\ \Delta \delta_n^{(p)} \\ \hline \Delta |V_2|^{(p)} \\ \Delta |V_3|^{(p)} \\ \vdots \\ \Delta |V_n|^{(p)} \end{bmatrix} \quad \rightarrow (52)$$

~~Now the diagonal elements of J_1 are~~

~~$$\frac{\partial P_i}{\partial \delta_i} = \sum_{\substack{k=1 \\ k \neq i}}^{n} |V_i||V_k||Y_{ik}| \sin(\theta_{ik} - \delta_i + \delta_k) \longrightarrow (54)$$~~

In eq (52), bus-1 is assumed to be the slack bus.

eq (52) can be written in short form, i.e;

$$\begin{bmatrix} \Delta P \\ \hline \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \hline \Delta |V| \end{bmatrix} \longrightarrow (53)$$

Decoupled Load flow Solution:—

⇒ Transmission lines of power systems have a very low R/X ratio. For such system, real power mismatch ΔP are less sensitive to changes in the voltage magnitude and are very sensitive to changes in phase angle Δδ.

⇒ Similarly, reactive power mismatch ΔQ is less sensitive to changes in angle and are very much sensitive to changes in voltage magnitude.

⇒ Therefore, it is reasonable to set elements of J_3 & J_2 of the Jacobian matrix to zero

Hence, eq (53) reduced to

$$\begin{bmatrix} \Delta P \\ \hline \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & 0 \\ \hline 0 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \hline \Delta |V| \end{bmatrix} \longrightarrow (54)$$

or,

$$\Delta P = J_1 \cdot \Delta \delta \longrightarrow (55)$$

$$\Delta Q = J_4 \cdot \Delta |V| \longrightarrow (56)$$

⇒ For voltage controlled buses, the voltage magnitudes are known. Therefore, if 'm' buses of the system are voltage controlled, J_1 is of the order $(n-1) \times (n-1)$ and J_4 is of the order $(n-1-m) \times (n-1-m)$.

Now the diagonal elements of J_1 are

$$\frac{\partial P_i}{\partial \delta_i} = \sum_{\substack{K=1 \\ K \neq i}}^{n} |V_i||V_K||Y_{iK}| \sin(\theta_{iK} - \delta_i + \delta_K) \longrightarrow (57)$$

n=4

$$P_i = \sum_{K=1}^{4} |V_i||V_K||Y_{iK}| \cos(\theta_{iK} - \delta_i + \delta_K)$$

i=2.

$$P_2 = \sum_{K=1}^{4} |V_2||V_K||Y_{2K}| \cos(\theta_{2K} - \delta_2 + \delta_K)$$

explanation of above equation

$$P_2 = |V_2||V_1||Y_{21}|\cos(\theta_{21} - \delta_2 + \delta_1) + |V_2|^2 |Y_{22}| \cos(\theta_{22})$$
$$+ |V_2||V_3||Y_{23}|\cos(\theta_{23} - \delta_2 + \delta_3) + |V_2||V_4||Y_{24}|\cos(\theta_{24} - \delta_2 + \delta_4)$$

$$\left(\frac{\partial P_i}{\partial \delta_i}\right)_{i=2} = \frac{\partial P_2}{\partial \delta_2} = |V_2||V_1||Y_{21}|\sin(\theta_{21} - \delta_2 + \delta_1) + 0$$
$$+ |V_2||V_3||Y_{23}|\sin(\theta_{23} - \delta_2 + \delta_3) + |V_2||V_4||Y_{24}|\sin(\theta_{24} - \delta_2 + \delta_4)$$

Explanation of above equation

Off-diagonal elements of J_1 are

$$\frac{\partial P_i}{\partial \delta_K} = -|V_i||V_K||Y_{iK}|\sin(\theta_{iK} - \delta_i + \delta_K) \quad K \neq i \longrightarrow (58)$$

$$P_2 = |V_2||V_1||Y_{21}|\cos(\theta_{21} - \delta_2 + \delta_1) + |V_2|^2 |Y_{22}|\cos(\theta_{22})$$
$$+ |V_2||V_3||Y_{23}|\cos(\theta_{23} - \delta_2 + \delta_3) + |V_2||V_4||Y_{24}|\cos(\theta_{24} - \delta_2 + \delta_4)$$

$$\left(\frac{\partial P_i}{\partial \delta_K}\right)_{K \neq i} = \frac{\partial P_2}{\partial \delta_3} = 0 + 0 - |V_2||V_3||Y_{23}|\sin(\theta_{23} - \delta_2 + \delta_3) + 0$$

$i = 2$

$K = 3$

Explanation of above equation

The diagonal elements of J_4 are

$$\frac{\partial Q_i}{\partial |V_i|} = -2|V_i||Y_{ii}|\sin\theta_{ii} - \sum_{\substack{K=1 \\ K \neq i}}^{n} |V_K||Y_{iK}|\sin(\theta_{iK} - \delta_i + \delta_K) \longrightarrow (59)$$

$i=2\ ;\ n=4$

$$Q_2 = -\sum_{K=1}^{4} |V_2||V_K||Y_{2K}| \sin(\theta_{2K} - \delta_2 + \delta_K)$$

$$\therefore Q_2 = -|V_2||V_1||Y_{21}|\sin(\theta_{21} - \delta_2 + \delta_1) - |V_2|^2|Y_{22}|\sin(\theta_{22})$$
$$-|V_2||V_3||Y_{23}|\sin(\theta_{23} - \delta_2 + \delta_3) - |V_2||V_4||Y_{24}|\sin(\theta_{24} - \delta_2 + \delta_4)$$

$$\left.\frac{\partial Q_i}{\partial |V_i|}\right|_{i=2} = \frac{\partial Q_2}{\partial |V_2|} = -|V_1||Y_{21}|\sin(\theta_{21} - \delta_2 + \delta_1) - 2|V_2||Y_{22}|\sin(\theta_{22})$$
$$- |V_3||Y_{23}|\sin(\theta_{23} - \delta_2 + \delta_3) - |V_4||Y_{24}|\sin(\theta_{24} - \delta_2 + \delta_4).$$

Explanation of above equation.

Off-diagonal elements of J_4.

$$\frac{\partial Q_i}{\partial |V_K|} = -|V_i||Y_{iK}|\sin(\theta_{iK} - \delta_i + \delta_K) \quad K \neq i \longrightarrow (60)$$

⇒ The terms $\Delta P_i^{(P)}$ and $\Delta Q_i^{(P)}$ are the difference between the scheduled and calculated values at bus-i, known as power residuals, given by

$$\Delta P_i^{(P)} = \left| P_i^{scheduled} - P_{i\,(Calculated)}^{(P)} \right| \longrightarrow (61)$$

$$\Delta Q_i^{(P)} = \left| Q_i^{scheduled} - Q_{i\,(Calculated)}^{(P)} \right| \longrightarrow (62)$$

⇒ The new estimates for bus voltage magnitudes and angles are:

$$|V_i|^{(P+1)} = |V_i|^{(P)} + \Delta|V_i|^{(P)} \longrightarrow (63)$$
$$\delta_i^{(P+1)} = \delta_i^{(P)} + \Delta\delta_i^{(P)} \longrightarrow (64)$$

Decoupled Load Flow Algorithm:—

Step-1:— Read system data.

Step-2:— Form Y_{Bus} matrix.

Step-3:— For load buses $P_i^{scheduled}$ and $Q_i^{scheduled}$ are specified.

⇒ voltage magnitudes and phase angles are set equal to the slack bus values, or, $|V_i|^{(0)} = 1.0$; $\delta_i^{(0)} = 0.0°$

⇒ For voltage controlled buses where $|V_i|$ and $P_i^{scheduled}$ are specified, phase angles are set equal to the slack bus angle, i.e; $\delta_i^{(0)} = 0.0$

Step-4:— for load buses, $P_i^{(P)}$ and $Q_i^{(P)}$ are calculated using eqs (50) and (51) and $\Delta P_i^{(P)}$ and $\Delta Q_i^{(P)}$ are calculated from eqs (61) and (62).

⇒ For voltage controlled buses, $P_i^{(P)}$ and $\Delta P_i^{(P)}$ are computed using eqs (50) and (61) respectively.

Step-5:— Compute elements of J_1 and J_4 using eqs (57), (58), (59) and (60).

Step-6:— solve eqs (55) and (56) for computing $\Delta\delta$ and $\Delta|V|$.

Step-7:— Compute new voltage magnitudes and phase angles using eqs (63) and (64)

Step-8:- Check for convergence, i.e; if $\{\max|\Delta P_i^{(p)}| \le \epsilon$ and $\max|\Delta Q_i^{(p)}| \le \epsilon\}$ solution has converged and go-to step-9, otherwise, go-to step-4.

Step-9:- Print Output Results.

~~Ex-4~~ **Problems:-**

Ex-4):- Solve the problem in Ex-2 using decoupled N-R method. Perform three iterations.

Sol: From eqs (50) and (51)

$$P_2 = |V_2||V_1||Y_{21}|\cos(\theta_{21}-\delta_2+\delta_1) + |V_2|^2|Y_{22}|\cos(\theta_{22}) + |V_2||V_3||Y_{23}|\cos(\theta_{23}-\delta_2+\delta_3)$$

$$P_3 = |V_3||V_1||Y_{31}|\cos(\theta_{31}-\delta_3+\delta_1) + |V_3||V_2||Y_{32}|\cos(\theta_{32}-\delta_3+\delta_2) + |V_3|^2|Y_{33}|\cos\theta_{33}$$

$$Q_2 = -|V_2||V_1||Y_{21}|\sin(\theta_{21}-\delta_3+\delta_1) - |V_2|^2|Y_{22}|\sin\theta_{22} - |V_2||V_3||Y_{23}|\sin(\theta_{23}-\delta_2+\delta_3)$$

$$Q_3 = -|V_3||V_1||Y_{31}|\sin(\theta_{31}-\delta_3+\delta_1) - |V_3||V_2||Y_{32}|\sin(\theta_{32}-\delta_3+\delta_2) - |V_3|^2|Y_{33}|\sin\theta_{33}.$$

$$\frac{\partial P_2}{\partial \delta_2} = |V_2||V_1||Y_{21}|\sin(\theta_{21}-\delta_2+\delta_1) + |V_2||V_3||Y_{23}|\sin(\theta_{23}-\delta_2+\delta_3)$$

$$\frac{\partial P_2}{\partial \delta_3} = -|V_3||V_2||Y_{32}|\sin(\theta_{32}-\delta_2+\delta_3)$$

$$\frac{\partial P_3}{\partial \delta_3} = |V_3||V_1||Y_{31}|\sin(\theta_{31}-\delta_3+\delta_1) + |V_3||V_2||Y_{32}|\sin(\theta_{32}-\delta_3+\delta_2)$$

$$\frac{\partial P_3}{\partial \delta_2} = -|V_3||V_2||Y_{32}|\sin(\theta_{32}-\delta_3+\delta_2)$$

$$\frac{\partial Q_2}{\partial |V_2|} = -|V_1||Y_{21}|\sin(\theta_{21}-\delta_2+\delta_1) - 2|V_2||Y_{22}|\sin\theta_{22}$$
$$-|V_3||Y_{23}|\sin(\theta_{23}-\delta_2+\delta_3)$$

$$\frac{\partial Q_2}{\partial |V_3|} = -|V_2||Y_{23}|\sin(\theta_{23}-\delta_2+\delta_3)$$

$$\frac{\partial Q_3}{\partial |V_2|} = -|V_3||Y_{32}|\sin(\theta_{32}-\delta_3+\delta_2)$$

$$\frac{\partial Q_3}{\partial |V_3|} = -|V_1||Y_{31}|\sin(\theta_{31}-\delta_3+\delta_1) - |V_2||Y_{32}|\sin(\theta_{32}-\delta_3+\delta_2) - 2|V_3||Y_{33}|\sin\theta_{33}$$

<u>DATA</u> (see <u>Ex-2</u>)

$|V_1| = 1.05$; $\delta_1 = 0.0$; $|V_2|^{(0)} = 1.0$; $\delta_2^{(0)} = 0.0$; $|V_3|^{(0)} = 1.0$; $\delta_3^{(0)} = 0.0$

$|Y_{22}| = 58.13$; $\theta_{22} = -63.4^0$; $|Y_{33}| = 67.23$; $\theta_{33} = -67.2^0$

$|Y_{21}| = 22.36$; $\theta_{21} = 116.6^0$; $|Y_{23}| = 35.77$; $\theta_{23} = 116.6^0$

$|Y_{31}| = 31.62$; $\theta_{31} = 108.4^0$

$$\frac{\partial P_2}{\partial \delta_2} = 1.05 \times 22.36 \sin(116.6^0) + 35.77\sin(116.6^0) = 52.97$$

$$\frac{\partial P_2}{\partial \delta_3} = -35.77\sin(116.6^0) = -31.98$$

Similarly

$$\frac{\partial P_3}{\partial \delta_2} = -31.98 \quad ; \quad \frac{\partial P_3}{\partial \delta_3} = 63.48$$

$$\frac{\partial Q_2}{\partial |V_2|} = -1.05 \times 22.36\sin(116.6^0) - 2 \times 58.13 \times \sin(-63.4^0) - 35.77\sin(116.6^0)$$
$$= 50.97$$

similarly,

$$\frac{\partial Q_3}{\partial |V_3|} = 60.47 \;;\; \frac{\partial Q_2}{\partial |V_3|} = -31.98 \;;\; \frac{\partial Q_3}{\partial |V_2|} = -31.98$$

$$\therefore J_1^{(0)} = \begin{bmatrix} 52.97 & -31.98 \\ -31.98 & 63.48 \end{bmatrix} \;;\; J_4^{(0)} = \begin{bmatrix} 50.97 & -31.98 \\ -31.98 & 60.47 \end{bmatrix}$$

⇒ For this problem J_1 and J_4 as computed above, assumed constant throughout the iterative process.

$$P_2^{(0)}(\text{calculated}) = 1.05 \times 22.36 \cos(116.6^\circ) + 58.13 \cos(-63.4^\circ) + 35.77 \cos(116.6^\circ)$$

$$\therefore P_2^{(0)}(\text{calculated}) = -0.50$$

$$P_3^{(0)}(\text{calculated}) = 1.05 \times 31.62 \cos(108.4^\circ) + 35.77 \cos(116.6^\circ) + 67.23 \cos(-67.2^\circ)$$

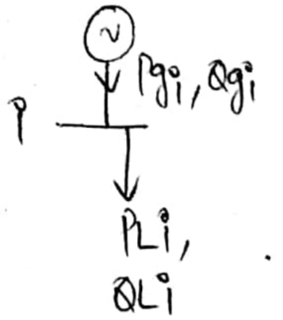
$$P_3^{(0)}(\text{calculated}) = -0.44$$

$$Q_2^{(0)}(\text{calculated}) = -1.05 \times 22.36 \sin(116.6^\circ) - 58.13 \sin(-63.4^\circ) - 35.77 \sin(116.6^\circ)$$

$$\therefore Q_2^{(0)}(\text{calculated}) = -1.0$$

$$Q_3^{(0)}(\text{calculated}) = -1.05 \times 31.62 \sin(108.4^\circ) - 35.77 \sin(116.6^\circ) - 67.23 \sin(-67.8^\circ)$$

$$\therefore Q_3^{(0)}(\text{calculated}) = -1.503.$$



$\Longrightarrow$ i

$P_i = P_{gi} - P_{Li} = P_i^{scheduled}$

$Q_i = Q_{gi} - Q_{Li} = Q_i^{scheduled}$

Base MVA = 100

$\therefore P_2^{scheduled} = P_{g_2} - P_{L_2} = (50 - 305.6)\,MW = -255.6\,MW = -2.556\ \text{pu MW}$

$Q_2^{scheduled} = Q_{g_2} - Q_{L_2} = (30 - 140.2) = -110.2\ MVAr = -1.102\ \text{pu MVAr}$

$P_3^{scheduled} = P_{g_3} - P_{L_3} = (0 - 138.6) = -138.6\,MW = -1.386\ \text{pu MW}$

$Q_3^{scheduled} = Q_{g_3} - Q_{L_3} = (0 - 45.2) = -45.2\ MVAr = -0.452\ \text{pu MVAr}.$

$\Delta P_2^{(0)} = P_2^{scheduled} - P_{2(Calculated)}^{(0)} = [-2.566 - (-0.5)] = -2.056$

$\Delta P_3^{(0)} = P_3^{scheduled} - P_{3(Calculated)}^{(0)} = [-1.386 - (-0.44)] = -0.946$

$\Delta Q_2^{(0)} = Q_2^{scheduled} - Q_{2(Calculated)}^{(0)} = -1.102 - (-1.0) = -0.102.$

$\Delta Q_3^{(0)} = Q_3^{scheduled} - Q_{3(Calculated)}^{(0)} = -0.452 - (-1.503) = 1.051.$

$$\therefore \begin{bmatrix} \Delta P_2^{(0)} \\ \Delta P_3^{(0)} \end{bmatrix} = \begin{bmatrix} 52.97 & -31.98 \\ -31.98 & 63.48 \end{bmatrix} \begin{bmatrix} \Delta \delta_2^{(0)} \\ \Delta \delta_3^{(0)} \end{bmatrix}$$

$$\therefore \begin{bmatrix} \Delta \delta_2^{(0)} \\ \Delta \delta_3^{(0)} \end{bmatrix} = \begin{bmatrix} 52.97 & -31.98 \\ -31.98 & 63.48 \end{bmatrix}^{-1} \begin{bmatrix} -2.056 \\ -0.946 \end{bmatrix}$$

Scanned by CamScanner

$\therefore \Delta\delta_2^{(0)} = -0.0687 \text{ rad} = -3.936^0$

$\Delta\delta_3^{(0)} = -0.0495 \text{ rad} = -2.837^0$

Similarly

$$\begin{bmatrix} \Delta Q_2^{(0)} \\ \Delta Q_3^{(0)} \end{bmatrix} = \begin{pmatrix} 50.97 & -31.98 \\ -31.98 & 60.47 \end{pmatrix} \begin{bmatrix} \Delta|V_2|^{(0)} \\ \Delta|V_3|^{(0)} \end{bmatrix}$$

$$\therefore \begin{bmatrix} \Delta|V_2|^{(0)} \\ \Delta|V_3|^{(0)} \end{bmatrix} = \begin{bmatrix} 50.97 & -31.98 \\ -31.98 & 60.47 \end{bmatrix}^{-1} \begin{bmatrix} -0.102 \\ 1.051 \end{bmatrix}$$

$\therefore \Delta|V_2|^{(0)} = 0.01332$

$\Delta|V_3|^{(0)} = 0.0244$

$\therefore \delta_2^{(1)} = \delta_2^{(0)} + \Delta\delta_2^{(0)} = 0 - 3.936^0 = -3.936^0$

$\delta_3^{(1)} = \delta_3 + \Delta\delta_3^{(0)} = 0 - 2.837^0 = -2.837^0$

$|V_2|^{(1)} = |V_2|^{(0)} + \Delta|V_2|^{(0)} = 1.0 + 0.01332 = 1.01332$

$|V_3|^{(1)} = |V_3|^{(0)} + \Delta|V_3|^{(0)} = 1.0 + 0.0244 = 1.0244$

After 1st Iteration

$\delta_2^{(1)} = -3.936^0$;	$|V_2|^{(1)} = 1.01332$
$\delta_3^{(1)} = -2.837^0$;	$|V_3|^{(1)} = 1.0244$

2nd Iteration :-

$P_{2(\text{Calculated})}^{(1)} = -2.62$; $P_{3(\text{Calculated})}^{(1)} = -0.96$

$Q_{2(\text{Calculated})}^{(1)} = 0.005$; $Q_{3(\text{Calculated})}^{(1)} = -0.16177$.

$\Delta P_2^{(1)} = -2.556 - (-2.62) = 0.064$

$\Delta P_3^{(1)} = -1.386 - (-0.96) = -0.426$

$\Delta Q_2^{(1)} = -1.102 - (0.005) = -1.107$

$\Delta Q_3^{(1)} = -0.452 - (-0.16177) = -0.29$

$$\therefore \begin{bmatrix} \Delta\delta_2^{(1)} \\ \Delta\delta_3^{(1)} \end{bmatrix} = \begin{bmatrix} 52.97 & -31.98 \\ -31.98 & 63.48 \end{bmatrix}^{-1} \begin{bmatrix} 0.064 \\ -0.426 \end{bmatrix}$$

$\therefore \Delta\delta_2^{(1)} = -0.004 \text{ rad} = -0.229^\circ$

$\Delta\delta_3^{(1)} = -0.0087 \text{ rad} = -0.5^\circ$

And

$$\begin{bmatrix} \Delta|V_2|^{(1)} \\ \Delta|V_3|^{(1)} \end{bmatrix} = \begin{bmatrix} 50.97 & -31.98 \\ -31.98 & 60.47 \end{bmatrix}^{-1} \begin{bmatrix} -1.107 \\ -0.29 \end{bmatrix}$$

$\therefore \Delta|V_2|^{(1)} = -0.037$

$\Delta|V_3|^{(1)} = -0.02436$

$\therefore \delta_2^{(2)} = \delta_2^{(1)} + \Delta\delta_2^{(1)}$

$= -3.936^\circ + (-0.229^\circ)$

$\therefore \delta_2^{(2)} = -4.165^\circ$

$$\therefore \delta_3^{(2)} = \delta_3^{(1)} + \Delta\delta_3^{(1)}$$

$$\therefore \delta_3^{(2)} = -2.837^0 + (-0.5^0)$$

$$\therefore \delta_3^{(2)} = -3.337^0$$

$$|V_2|^{(2)} = |V_2|^{(1)} + \Delta|V_2|^{(1)}$$

$$\therefore |V_2|^{(2)} = 1.01332 + (-0.037)$$

$$\therefore |V_2|^{(2)} = 0.9763$$

$$\therefore |V_3|^{(2)} = V_3^{(1)} + \Delta V_3^{(1)}$$

$$= 1.0244 + (-0.02436)$$

$$\therefore |V_3|^{(2)} = 1.0$$

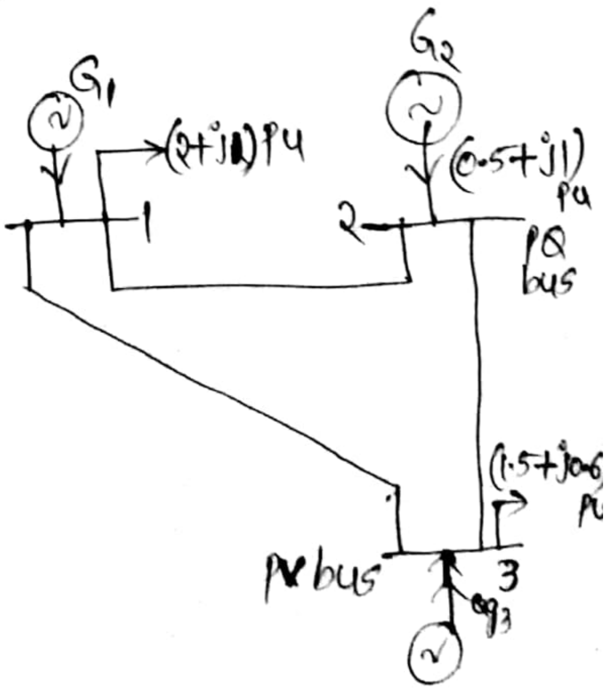
After 2nd Iteration

$$\delta_2^{(2)} = -4.165^0 \; ; \; \delta_3^{(2)} = -3.337^0$$

$$|V_2|^{(2)} = 0.9763 \; ; \; |V_3|^{(2)} = 1.0$$

Ex-5):-

$$Y_{Bus} = \begin{bmatrix} 26.925\angle{-68.2^0} & 11.18\angle 116.6^0 & 15.81\angle 108.4^0 \\ 11.18\angle 116.6^0 & 29.065\angle{-63.4^0} & 17.885\angle 116.6^0 \\ 15.81\angle 108.4^0 & 17.885\angle 116.6^0 & 33.615\angle{-67.3^0} \end{bmatrix}$$



Sol:

$V_1 = 1.0\angle 0^\circ$ = slack bus voltage

$|V_2|^{(0)} = 1.0$
$\delta_2^{(0)} = 0.0$ } ⇒ starting values [Bus 2 is PQ bus]

$|V_3| = 1.0$ ⇒ Bus 3 is PV bus

$\delta_3^{(0)} = 0.0$ ⇒ starting value

$$\begin{bmatrix} \Delta P_2 \\ \Delta P_3 \\ \Delta Q_2 \end{bmatrix}^{(P)} = \left[\begin{array}{cc|c} \frac{\partial P_2}{\partial \delta_2} & \frac{\partial P_2}{\partial \delta_3} & \frac{\partial P_2}{\partial |V_2|} \\ \frac{\partial P_3}{\partial \delta_2} & \frac{\partial P_3}{\partial \delta_3} & \frac{\partial P_3}{\partial |V_2|} \\ \hline \frac{\partial Q_2}{\partial \delta_2} & \frac{\partial Q_2}{\partial \delta_3} & \frac{\partial Q_2}{\partial |V_2|} \end{array}\right]^{(P)} \begin{bmatrix} \Delta \delta_2 \\ \Delta \delta_3 \\ \Delta |V_2| \end{bmatrix}^{(P)}$$

⇒ For decoupled load flow case, we can write,

$$\begin{bmatrix} \Delta P_2 \\ \Delta P_3 \end{bmatrix}^{(P)} = \begin{bmatrix} \frac{\partial P_2}{\partial \delta_2} & \frac{\partial P_2}{\partial \delta_3} \\ \frac{\partial P_3}{\partial \delta_2} & \frac{\partial P_3}{\partial \delta_3} \end{bmatrix}^{(P)} \begin{bmatrix} \Delta \delta_2 \\ \Delta \delta_3 \end{bmatrix}^{(P)} \longrightarrow (i)$$

, $$J_1^{(P)} = \begin{bmatrix} \frac{\partial P_2}{\partial \delta_2} & \frac{\partial P_2}{\partial \delta_3} \\ \frac{\partial P_3}{\partial \delta_2} & \frac{\partial P_3}{\partial \delta_3} \end{bmatrix}^{(P)}_{2\times 2}$$

and
$$\Delta Q_2^{(P)} = \left(\frac{\partial Q_2}{\partial |V_2|}\right)^{(P)} \cdot \Delta |V_2|^{(P)} \longrightarrow (ii)$$

, $$J_4^{(P)} = \left[\frac{\partial Q_2}{\partial |V_2|}\right]^{(P)}_{1\times 1}$$

Now,

$$\frac{\partial P_2}{\partial \delta_2} = |V_2||V_1||Y_{21}| \sin(\theta_{21} - \delta_2 + \delta_1) + |V_2||V_3||Y_{23}| \sin(\theta_{23} - \delta_2 + \delta_3)$$

$$\frac{\partial P_2}{\partial \delta_3} = -|V_2||V_3||Y_{23}| \sin(\theta_{23} - \delta_2 + \delta_3)$$

$$\frac{\partial P_3}{\partial \delta_2} = -|V_3||V_2||Y_{32}| \sin(\theta_{32} - \delta_3 + \delta_2)$$

$$\frac{\partial P_3}{\partial \delta_3} = |V_3||V_1||Y_{31}| \sin(\theta_{31} - \delta_3 + \delta_1) + |V_3||V_2||Y_{32}| \sin(\theta_{32} - \delta_3 + \delta_2)$$

$$\frac{\partial Q_2}{\partial |V_2|} = -|V_1||Y_{21}| \sin(\theta_{21} - \delta_2 + \delta_1) - 2|V_2||Y_{22}| \sin\theta_{22} - |V_3||Y_{23}| \sin(\theta_{23} - \delta_2 + \delta_3)$$

set $p = 0$

$$\frac{\partial P_2}{\partial \delta_2} = 11.18 \sin(116.6^0) + 17.885 \sin(116.6^0) \simeq 26$$

$$\frac{\partial P_2}{\partial \delta_3} = -17.885 \sin(116.6^0) = -16$$

$$\frac{\partial P_3}{\partial \delta_2} = -17.885 \sin(116.6^0) = -16$$

$$\frac{\partial P_3}{\partial \delta_3} = 15.81 \sin(108.4^0) + 17.885 \sin(116.6^0) = 31$$

$$\therefore J_1^{(0)} = \begin{bmatrix} 26 & -16 \\ -16 & 31 \end{bmatrix}_{2\times 2}$$

$$\frac{\partial Q_2}{\partial |V_2|} = -11.18 \sin(116.6^0) - 2 \times 29.065 \sin(-63.4^0) - 17.885 \sin(116.6^0)$$

$$= 26$$

$$\therefore J_4^{(0)} = [26]_{1\times 1}$$

$$P_2^{scheduled} = Pg_2 - PL_2 = 0.5 - 0.0 = 0.50\ pu$$

$$Q_2^{scheduled} = Qg_2 - QL_2 = 1.0 - 0.0 = 1.0\ pu$$

$$P_3^{scheduled} = Pg_3 - PL_3 = 0.0 - 1.50 = -1.50\ pu$$

$$P_2 = |V_2||V_1||Y_{21}|\cos(\theta_{21} - \delta_2 + \delta_1) + |V_2|^2|Y_{22}|\cos\theta_{22} + |V_2||V_3||Y_{23}|\cos(\theta_{23} - \delta_2 + \delta_3)$$

$$\therefore P_{2\,(Calculated)}^{(0)} = 1 \times 1 \times 11.18\cos(116.6^0) + (1)^2 \times 29.065\cos(-63.4^0) + 1 \times 1 \times 17.885\cos(116.6^0)$$

$$\therefore P_{2\,(Calculated)}^{(0)} \simeq 0.0$$

$$P_3 = |V_3||V_1||Y_{31}|\cos(\theta_{31} - \delta_3 + \delta_1) + |V_3||V_2||Y_{32}|\cos(\theta_{32} - \delta_3 + \delta_2) + |V_3|^2|Y_{33}|\cos\theta_{33}.$$

$$\therefore P_{3\,(Calculated)}^{(0)} = 1 \times 1 \times 15.81\cos(108.4^0) + 17.885\cos(116.6^0) + (1)^2 \times 33.615\cos(-67.2^0)$$

$$\therefore P_{3\,(Calculated)}^{(0)} \simeq 0.0$$

$$Q_2 = -|V_2||V_1||Y_{21}|\sin(\theta_{21} - \delta_2 + \delta_1) - |V_2|^2|Y_{22}|\sin\theta_{22} - |V_2||V_3||Y_{23}|\sin(\theta_{23} - \delta_2 + \delta_3)$$

$$\therefore Q_{2\,(Calculated)}^{(0)} = -11.18\sin(116.6^0) - 29.065\sin(-63.4^0) - 17.885\sin(116.6^0)$$

$$\therefore Q_{2\,(Calculated)}^{(0)} \simeq 0.0$$

$$\therefore \Delta P_2^{(0)} = P_2^{scheduled} - P_{2\,(Calculated)}^{(0)} = 0.50 - 0.0$$

$$\Delta P_2^{(0)} = 0.50$$

$$\Delta P_3^{(0)} = P_3^{scheduled} - P_{3\,(Calculated)}^{(0)} = -1.50 - 0.0$$

$$\therefore \Delta P_3^{(0)} = -1.50$$

$$\Delta Q_2^{(0)} = Q_2^{scheduled} - Q_{2\,(Calculated)}^{(0)} = 1.0 - 0.0$$

$$\therefore \Delta Q_2^{(0)} = 1.0$$

From eq (i)

$$\begin{bmatrix} \Delta\delta_2^{(0)} \\ \Delta\delta_3^{(0)} \end{bmatrix} = \begin{bmatrix} 26 & -16 \\ -16 & 31 \end{bmatrix}^{-1} \begin{bmatrix} 0.5 \\ -1.50 \end{bmatrix}$$

$$\therefore \Delta\delta_2^{(0)} = -0.015 \text{ rad} = -0.86^0; \quad \Delta\delta_3^{(0)} = -0.056 \text{ rad} = -3.2^0$$

From eq (ii)

$$\Delta|V_2|^{(0)} = \frac{\Delta Q_2^{(0)}}{\left(\frac{\partial Q_2}{\partial |V_2|}\right)} = \frac{1}{26} = 0.0384$$

$$\therefore \delta_2^{(1)} = \delta_2^{(0)} + \Delta\delta_2^{(0)} = 0 - 0.86^0 = -0.86^0$$

$$\delta_3^{(1)} = \delta_3^{(0)} + \Delta\delta_3^{(0)} = 0 - 3.2^0 = -3.2^0$$

$$|V_2|^{(1)} = |V_2|^{(0)} + \Delta|V_2|^{(0)} = 1 + 0.0384 = 1.0384$$

After 1st iteration

$$|V_2|^{(1)} = 1.0384; \quad \delta_2^{(1)} = -0.86^0$$

$$\delta_3^{(1)} = -3.2^0$$

Iteration-2 :-

set $p = 1$

$$P_{2\,(\text{Calculated})}^{(1)} = 1.0384 \times 11.18 \cos(116.6^\circ + 0.86^\circ - 0^\circ) + (1.0384)^2 \times 29.065 \cos(-63$$

$$+ 1.0384 * 17.885 \cos(116.6^\circ + 0.86^\circ - 3.2^\circ)$$

$$\therefore P_{2\,(\text{Calculated})}^{(1)} = 1.049$$

Similarly,

$$P_{3\,(\text{Calculated})}^{(1)} = -1.78 \; ; \quad Q_{2\,(\text{Calculated})}^{(1)} = 0.79$$

$$\Delta P_2^{(1)} = 0.5 - 1.049 = -0.549$$

$$\Delta P_3^{(1)} = -1.5 - (-1.78) = 0.28$$

$$\Delta Q_2^{(1)} = 1 - 0.79 = 0.21$$

$$\therefore \begin{bmatrix} \Delta\delta_2^{(1)} \\ \Delta\delta_3^{(1)} \end{bmatrix} = \begin{bmatrix} 26 & -16 \\ -16 & 31 \end{bmatrix}^{-1} \begin{bmatrix} -0.549 \\ 0.28 \end{bmatrix}$$

$$\therefore \Delta\delta_2^{(1)} = -0.028 \text{ rad} = -1.3^\circ$$

$$\therefore \Delta\delta_3^{(1)} = -0.0027 \text{ rad} = -0.15^\circ$$

$$\therefore \Delta|V_2|^{(1)} = \frac{0.21}{26} = 0.008$$

$$\therefore \delta_2^{(2)} = \delta_2^{(1)} + \Delta\delta_2^{(1)} = -0.86 - 1.3^\circ = -2.16^\circ$$

$$\delta_3^{(2)} = \delta_3^{(1)} + \Delta\delta_3^{(1)} = -3.2^\circ - 0.15 = -3.35^\circ$$

$$|V_2|^{(2)} = |V_2|^{(1)} + \Delta|V_2|^{(1)} = 1.0384 + 0.008 = 1.0464$$

After 2nd iteration:

$$|V_2|^{(2)} = 1.0464$$

$$\delta_2^{(2)} = -2.16$$

$$\delta_3^{(2)} = -3.35^\circ$$

Fast DeCoupled Load Flow

⇒ The diagonal elements of J_1 described by eq (57) may be written as:

$$\frac{\partial P_i}{\partial \delta_i} = \sum_{k=1}^{n} |V_i||V_k||Y_{ik}| \sin(\theta_{ik} - \delta_i + \delta_k) - |V_i|^2 |Y_{ii}| \sin\theta_{ii} \longrightarrow (65)$$

using eq (65) and (51), we get,

$$\frac{\partial P_i}{\partial \delta_i} = -Q_i - |V_i|^2 |Y_{ii}| \sin\theta_{ii}$$

$$\therefore \frac{\partial P_i}{\partial \delta_i} = -Q_i - |V_i|^2 B_{ii} \longrightarrow (66)$$

where $B_{ii} = |Y_{ii}| \sin\theta_{ii}$ ⇒ Imaginary part of the diagonal elements of the bus admittance matrix.

⇒ In a practical power system, $B_{ii} >> Q_i$ and hence we may neglect Q_i in eq (66)

⇒ Further simplification is obtained by assuming $|V_i|^2 \simeq |V_i|$, which gives,

$$\frac{\partial P_i}{\partial \delta_i} = -|V_i| B_{ii} \longrightarrow (67)$$

⇒ under normal operating conditions, $\delta_k - \delta_i$ is quite small.

Therefore, $\theta_{ik} - \delta_i + \delta_k \simeq \theta_{ik}$ and eq (58) reduces to

$$\frac{\partial P_i}{\partial \delta_k} = -|V_i||V_k| B_{ik}$$

Assuming, $|V_K| \simeq 1.0$

$$\frac{\partial P_i}{\partial \delta_K} = -|V_i| B_{iK} \longrightarrow (68)$$

Similarly, the diagonal elements of J_4 as given by Eq (59) may be written as:

$$\frac{\partial Q_i}{\partial |V_i|} = -|V_i||Y_{ii}| \sin\theta_{ii} - \sum_{K=1}^{n} |V_i||V_K||Y_{iK}| \sin(\theta_{iK} - \delta_i + \delta_K) \longrightarrow (69)$$

using Eqs (69) and (51), we get,

$$\frac{\partial Q_i}{\partial |V_i|} = -|V_i||Y_{ii}| \sin\theta_{ii} + Q_i$$

$$\therefore \frac{\partial Q_i}{\partial |V_i|} = -|V_i| B_{ii} + Q_i \longrightarrow (70)$$

Again, $B_{ii} >> Q_i$; Q_i may be neglected in Eq (70)

$$\therefore \frac{\partial Q_i}{\partial |V_i|} = -|V_i| B_{ii} \longrightarrow (71)$$

Assuming $\theta_{iK} - \delta_i + \delta_K \simeq \theta_{iK}$; Eq (60) can be written as

$$\frac{\partial Q_i}{\partial |V_K|} = -|V_i| B_{iK} \longrightarrow (72)$$

Therefore, Eqs (55) and (56) take the following form:

$$\frac{\Delta P}{|V_i|} = -B' \Delta\delta \longrightarrow (73)$$

$$\frac{\Delta Q}{|V_i|} = -B'' \Delta|V| \longrightarrow (74)$$

B' and B'' are the imaginary part of the bus admittance matrix Y_{BUS}.

⇒ B' and B'' are constant matrices and they need to be inverted once.

⇒ The decoupled and fast decoupled power flow solutions require more iterations than the coupled NR method but require less computing time per iteration.

Tap Changing Transformer:-

⇒ When the tap ratio is at the nominal value ($a=1$), the transformer is represented by a series admittance y_{pq}. When tap ratio is off-nominal, the admittance is different from both sides of the transformer.

⇒ Fig.9 shows a transformer with admittance y_{pq} in series with an ideal transformer representing the off-nominal tap ratio $1:a$. t is a fictitious bus between the ratio and admittance of the transformer.

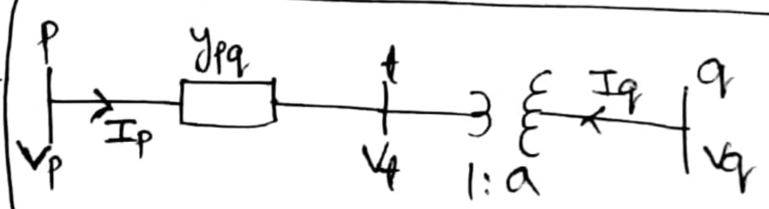


Fig.9: Equivalent Circuit.

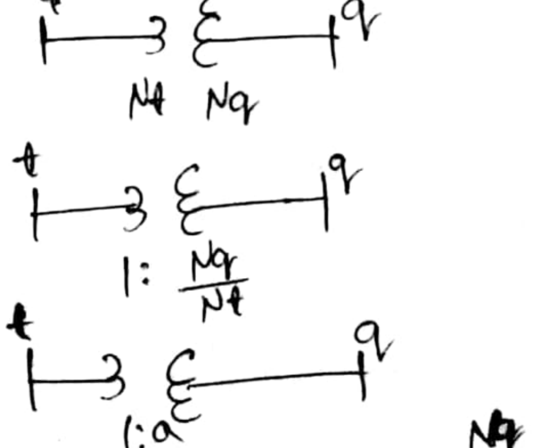
From Fig.9,

$$\frac{V_q}{V_t} = \frac{N_q}{N_t} = a$$

$$\therefore V_t = \frac{V_q}{a} \longrightarrow (75)$$

and

$$N_t I_p = -N_q I_q$$



$$\therefore a = \frac{N_q}{N_t}$$

$$\therefore I_p = -\frac{N_q}{N_p} I_q$$

$$\therefore I_p = -a I_q \longrightarrow (76)$$

The current I_p is given by

$$I_p = y_{pq}(V_p - V_t) \longrightarrow (77)$$

using Eqs (77) and (75), we get,

$$I_p = y_{pq} V_p - \frac{y_{pq}}{a} V_q \longrightarrow (78)$$

From Eq (76),

$$I_q = -\frac{I_p}{a} \longrightarrow (79)$$

From Eqs (79) and (78), we have,

$$\therefore I_q = \frac{-1}{a}\left(y_{pq} V_p - \frac{y_{pq}}{a} V_q\right)$$

$$\therefore I_q = \frac{-y_{pq}}{a} V_p + \frac{y_{pq}}{a^2} \cdot V_q \longrightarrow (80)$$

writing Eqs (78) and (80) in matrix form,

$$\begin{bmatrix} I_p \\ I_q \end{bmatrix} = \begin{bmatrix} y_{pq} & \frac{-y_{pq}}{a} \\ \frac{-y_{pq}}{a} & \frac{y_{pq}}{a^2} \end{bmatrix} \begin{bmatrix} V_p \\ V_q \end{bmatrix} \longrightarrow (81)$$

Now can equivalent π-model can be obtained for a tap changing transformer.

In eq (81),

$$y_{pp} = y_{pq} = y_{pq} - \frac{y_{pq}}{a} + \frac{y_{pq}}{a}$$

$$\therefore y_{pp} = \frac{y_{pq}}{a} + \frac{(a-1)}{a} y_{pq} \longrightarrow (82)$$

and

$$y_{qq} = \frac{y_{pq}}{a^2} = \frac{y_{pq}}{a^2} + \frac{y_{pq}}{a} - \frac{y_{pq}}{a}$$

$$y_{qq} = \frac{y_{pq}}{a} + \frac{(1-a)}{a^2} y_{pq} \longrightarrow (83)$$

⇒ Fig.10 shows the equivalent π-Model.

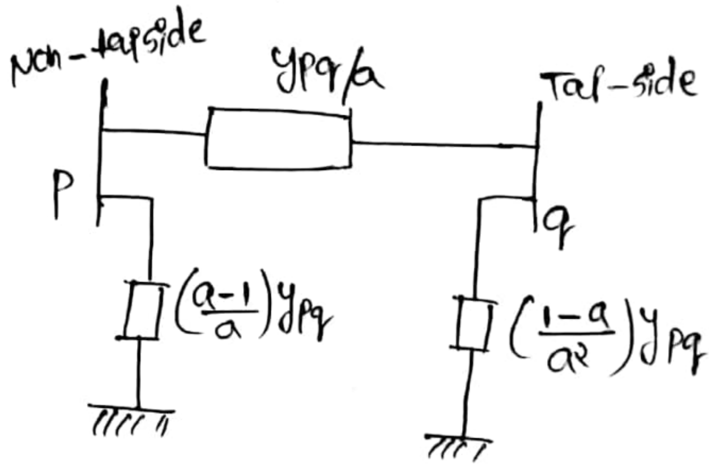


Fig.10: Equivalent π-Model for a tap changing Transformer.

~~Introduction~~ <u>Incorporation of P and PQV Buses in the load Flow Algorithm:-</u>

⇒ With the introduction of P and PQV buses, the Jacobian matrix gets modified.

⇒ A P bus is basically a generation bus with no reactive power specified.

⇒ On the other hand, a PQV bus is a remotely voltage controlled bus whose real power, reactive power and the voltage magnitude are specified.

⇒ The voltage magnitude of the PQV bus is controlled by the P bus

⇒ In Fig.11, suppose bus 2 is a P bus, bus 3 is assumed to be PQ bus and bus 4 is treated as the PQV bus. Bus 1 is slack Bus.

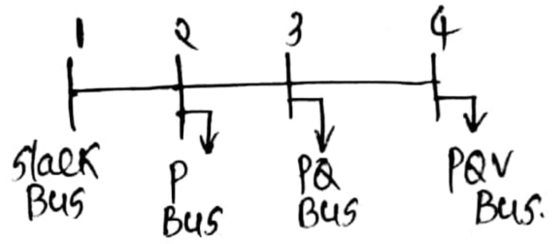


Fig.11: 4 bus network with P and PQV Bus.

⇒ For this system having a 'P' bus (bus-2) controlling the voltage of PQV bus (bus-4), the augmented set of equations takes the form given by eqs (84) and (85)

$$\Delta V = \begin{bmatrix} \Delta V_2 \\ \Delta V_3 \end{bmatrix} \longrightarrow (84)$$

and

$$\Delta Q = \begin{bmatrix} \Delta Q_3 \\ \Delta Q_4 \end{bmatrix} \longrightarrow (85)$$

2 – P Bus
3 – PQ Bus
4 – PQV Bus.

⇒ Then the equation relating the changes in power to the changes in phase angles and voltage magnitude for the N-R Method is:

$$\begin{bmatrix} \Delta P_2 \\ \Delta P_3 \\ \Delta P_4 \\ \Delta Q_3 \\ \Delta Q_4 \end{bmatrix} = \begin{bmatrix} \partial P_2/\partial \delta_2 & \partial P_2/\partial \delta_3 & \partial P_2/\partial \delta_4 & \partial P_2/\partial V_2 & \partial P_2/\partial V_3 \\ \partial P_3/\partial \delta_2 & \partial P_3/\partial \delta_3 & \partial P_3/\partial \delta_4 & \partial P_3/\partial V_2 & \partial P_3/\partial V_3 \\ \partial P_4/\partial \delta_2 & \partial P_4/\partial \delta_3 & \partial P_4/\partial \delta_4 & \partial P_4/\partial V_2 & \partial P_4/\partial V_3 \\ \partial Q_3/\partial \delta_2 & \partial Q_3/\partial \delta_3 & \partial Q_3/\partial \delta_4 & \partial Q_3/\partial V_2 & \partial Q_3/\partial V_3 \\ \partial Q_4/\partial \delta_2 & \partial Q_4/\partial \delta_3 & \partial Q_4/\partial \delta_4 & \partial Q_4/\partial V_2 & \partial Q_4/\partial V_3 \end{bmatrix}_{5\times 5} \begin{bmatrix} \Delta \delta_2 \\ \Delta \delta_3 \\ \Delta \delta_4 \\ \Delta V_2 \\ \Delta V_3 \end{bmatrix} \longrightarrow (86)$$

⇒ After this, the N-R load flow method is used to solve the network. 'Q_2' at bus 2 (i.e at P bus) is then obtained.

⇒ voltage at PQV bus may be Controlled by using shunt Capacitor.

⇒ In Fig.12, suppose QC_2 is the reactive power injected by shunt Capacitor at bus 2 to maintain the voltage magnitude at bus 4 (PQV Bus).

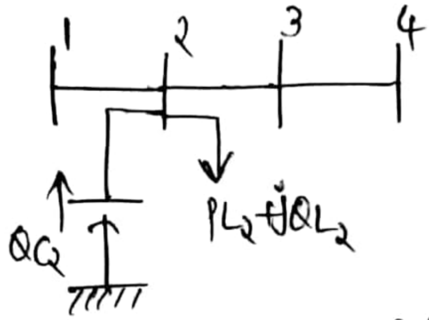


Fig.12: Reactive power injected by the shunt Capacitor at P Bus (Bus-2)

⇒ For this System, the amount of reactive power required at bus-2 (P Bus) to Control the voltage magnitude at bus-4 (PQV Bus) is given by QC_2. which can be Computed using the expression that follows in eqs (88).

$$Q_2 = QC_2 - QL_2 \longrightarrow (87)$$

where,

Q_2 = net reactive power injected at bus 2

QC_2 = reactive power injected by shunt Capacitor

QL_2 = reactive power load at bus-2.

$$\therefore QC_2 = Q_2 + QL_2 \longrightarrow (88).$$

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Symmetrical Three-Phase Fault

⇒ This type of fault can be defined as the simultaneous short circuit across all the three phases.

⇒ This type of fault occurs infrequently,

For example:

⇒ when a mechanical excavator cuts quickly through a whole cable.

⇒ when a line, which has been made safe for maintenance by clamping all the three phases to earth is accidentally made alive.

⇒ when due to slow fault clearance, an earth fault spreads across to the other two phases.

⇒ This type of fault generally leads to most severe fault current flow against which the system must be protected.

⇒ Fault studies form an important part of power system analysis and the problem consists of determining bus voltage and line current during faults.

⇒ The three phase fault information is used to select and set phase relays.

⇒ Fault studies are used for proper choice of circuit breakers and protective relaying.

⇒ A power system network comprises synchronous generators, transformer, transmission lines and loads.

⇒ During fault, loads current can be neglected because voltages dip very low so that current drawn by loads can be neglected in comparison to fault currents.

⇒ The magnitude of the fault currents depend on the internal impedance of the synchronous generator and the impedance of the intervening circuit.

⇒ Generator behaviour can be divided into three different periods:

1) The subtransient period, lasting only for the first few cycles.
2) The transient period, covering a relatively longer time.
3) steady state period.

⇒ Another important point is that the circuit breakers rated MVA breaking capacity is based on three phase fault MVA.

⇒ For three phase-fault calculation, following assumptions are made:

1) The emfs of all generators are $1\angle 0°$ pu, this assumption simplify the problem and it means that the voltage is at its nominal value and the system is operating at no load at the time of fault. Since all emfs are equal and in phase, all the generators can be replaced by a single generator.

2). charging capacitances of the transmission line are ignored.

3). shunt elements in the transformer model are neglected.

Ex-1):- A 4 bus sample power system is shown in Fig.1. Perform the short circuit analysis for a three phase solid fault on bus 4.

Data are given below:

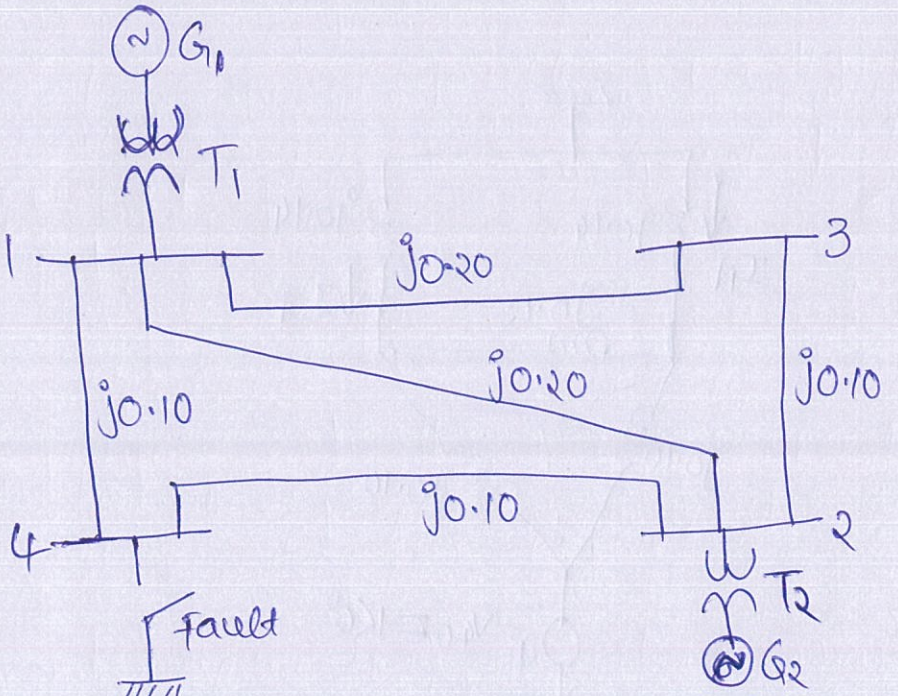
G1: 11.2 KV, 100 MVA, $x'_{g_1} = 0.08$ PU

G2: 11.2 KV, 100 MVA, $x'_{g_2} = 0.08$ PU.

T1: 11/110 KV, 100 MVA, $x_{T_1} = 0.06$ PU

T2: 11/110 KV, 100 MVA, $x_{T_2} = 0.06$ PU

Assume prefault voltages 1.0 PU and prefault currents to be zero



~~Assume prefault~~

Fig.1: 4-bus power system

10c

Circuit Model for Fault Calculation is shown in Fig. 1(a)

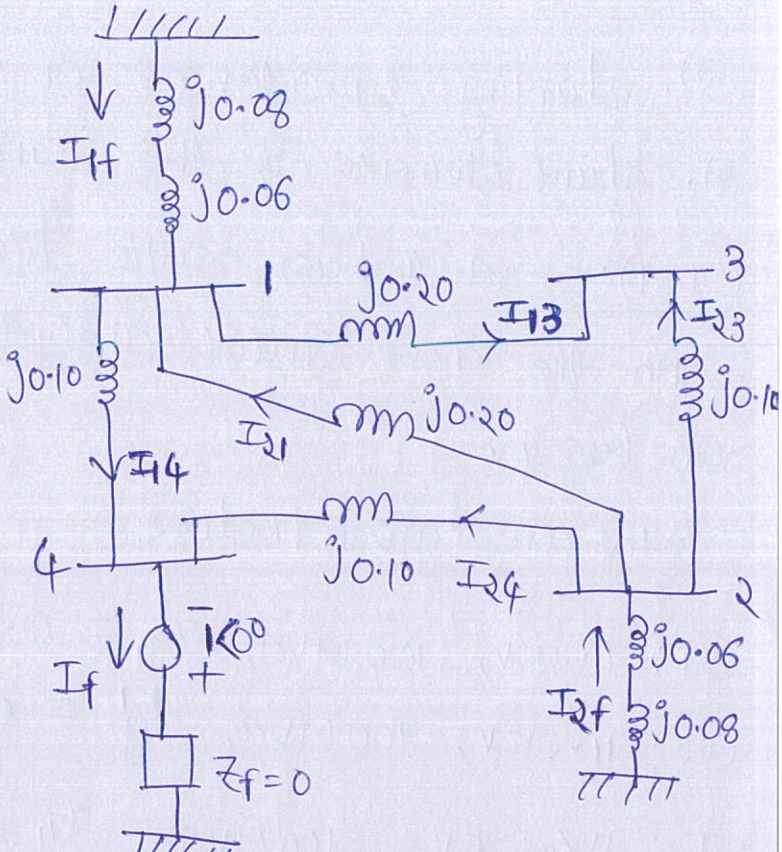


Fig. 1(a)

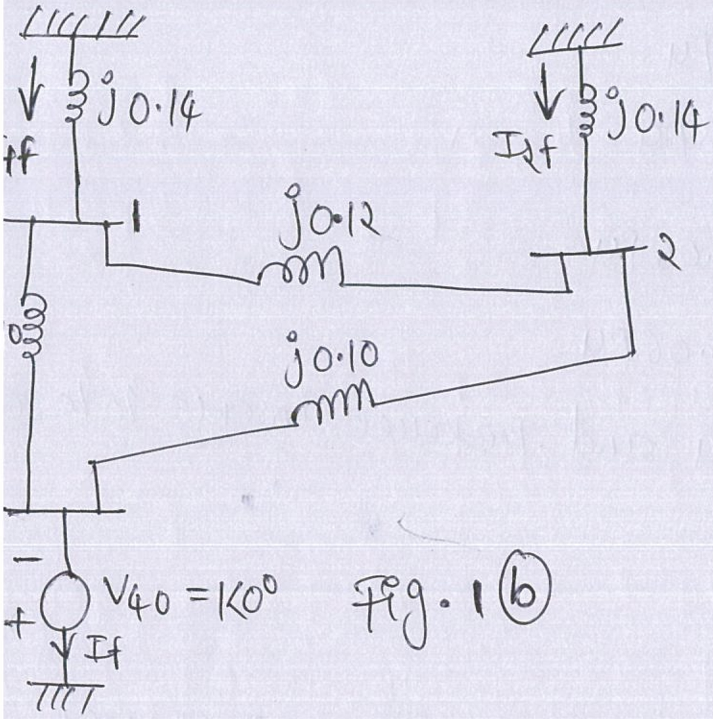


Fig. 1(b)

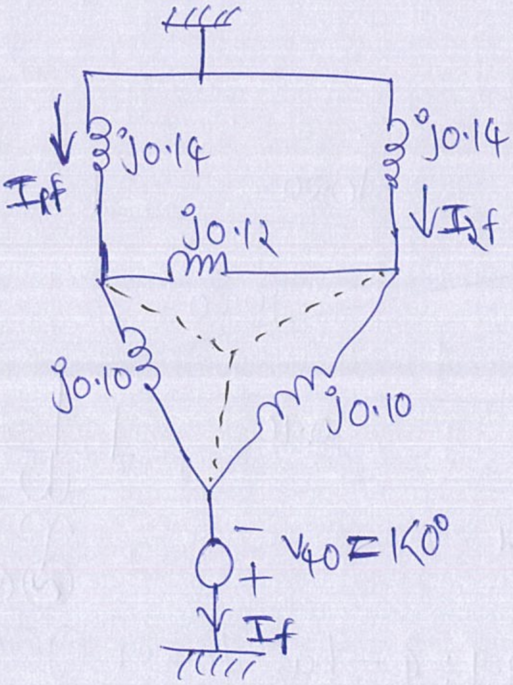


Fig. 1(c)

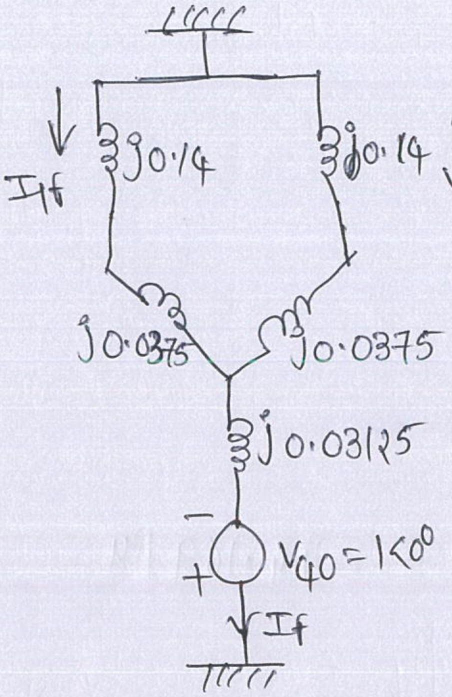
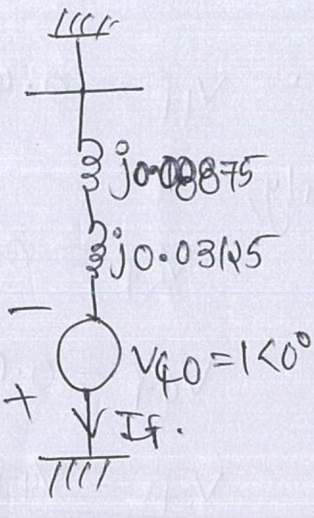
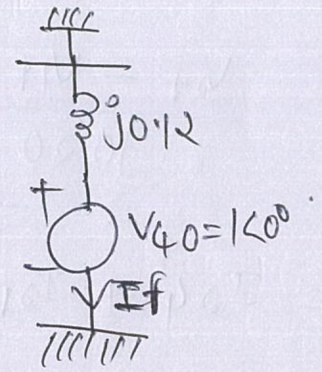


Fig. 1 (d)

$\Rightarrow$



$\Downarrow$



$$I_f = \frac{V_{40}}{Z} = \frac{1\angle 0^\circ}{j0.12}$$

$$\therefore I_f = -j8.33 \text{ pu.}$$

~~$V_{4f} = 0.0$~~

~~$I_{24} = \frac{V_{4f} - V_{4f}}{j0.10} = \frac{0.4169}{j0.10} = -j4.169 \text{ pu}$~~

$$I_{1f} = I_{2f} = -j8.33 \times \frac{j0.1775}{j0.1775 + j0.1775}$$

$$= -j4.165 \text{ pu}$$

Now $\frac{E_{g1}^0 - V_{1f}}{j0.14} = I_{1f} = -j4.165$

$E_{g1}^{0} = 1\angle 0^{\circ}$,

$\therefore V_{1f} = 0.4169 \text{ pu}$

Similarly,

$V_{2f} = 0.4169 \text{ pu}$

$V_{4f} = 0.0$

$$I_{24} = \frac{V_{2f} - V_{4f}}{j0.10} = \frac{0.4619}{j0.10} = -j4.169 \text{ pu}$$

$$I_{21} = \frac{V_{2f} - V_{1f}}{j0.20} = \frac{0.4169 - 0.4169}{j0.20} = 0.0 \text{ pu}$$

$$I_{2f} = I_{24} + I_{21} + I_{23}$$

$$= -j4.169 + 0.0 + I_{23}$$

$$-j4.165 = -j4.169 + I_{23}.$$

$$\therefore I_{23} = j0.004 \text{ pu}.$$

Now

$$\frac{V_{2f} - V_{3f}}{j0.10} = I_{23} = j0.004$$

$$\therefore V_{3f} = V_{2f} - j0.004 \times j0.10 = 0.4169 + 0.0004$$

$$\therefore V_{3f} = 0.4173 \text{ pu}$$

$$\therefore I_{13} = \frac{V_{1f} - V_{3f}}{Z_{13}} = \frac{0.4169 - 0.4173}{j0.20} = -j0.002 \text{ pu}$$

Short circuit MVA at bus 4

$= |I_f| \times (MVA)_B$

$= 8.33 \times 100 = 833$ MVA.

Short Circuit Analysis for Large Systems:-

⇒ Fig.2 shows schematic diagram of an n-bus power system.

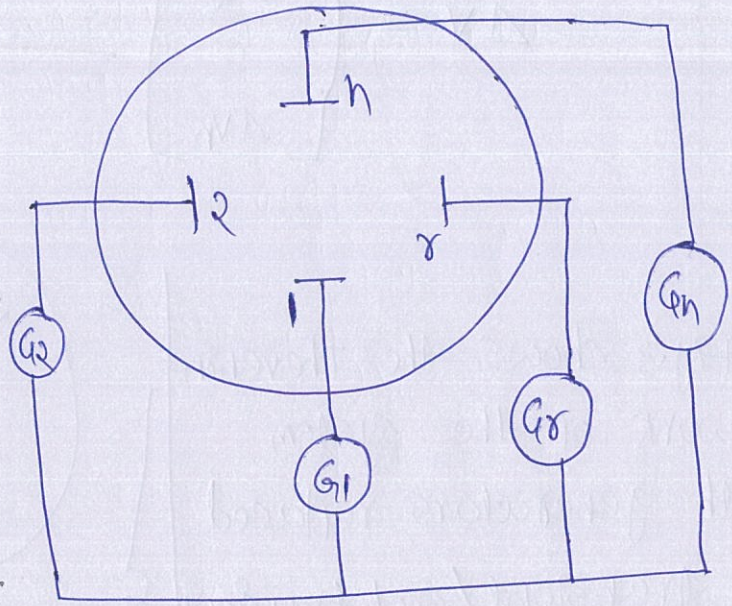


Fig.2: n bus power system.

⇒ First step in short circuit study is to obtain prefault bus voltage and line currents using load flow study.

⇒ prefault bus voltages can be defined as:

$$V_{Bus}^0 = \begin{bmatrix} V_1^0 \\ V_2^0 \\ \vdots \\ V_r^0 \\ \vdots \\ V_n^0 \end{bmatrix} \longrightarrow (1)$$

where $V_1^0, V_2^0, \ldots, V_n^0$ are the prefault bus voltages.

⇒ Let bus 'r' is faulted bus and Z_f is the fault impedance

⇒ The Post fault bus voltage vector is given by

$$V_{Bus}^{f} = V_{Bus}^{0} + \Delta V \longrightarrow ②$$

where ΔV (vector) is changes in bus voltages caused by the fault and is given by

$$\Delta V = \begin{bmatrix} \Delta V_1 \\ \Delta V_2 \\ \vdots \\ \Delta V_n \end{bmatrix} \longrightarrow 2ⓐ$$

⇒ Fig.3 shows the Thevenin network of the system with generators replaced by transient/subtransient reactances with their emfs shorted.

⇒ In Fig.3, we excite the passive Thevenin network with $-V_r^0$ is in series with Z_f.

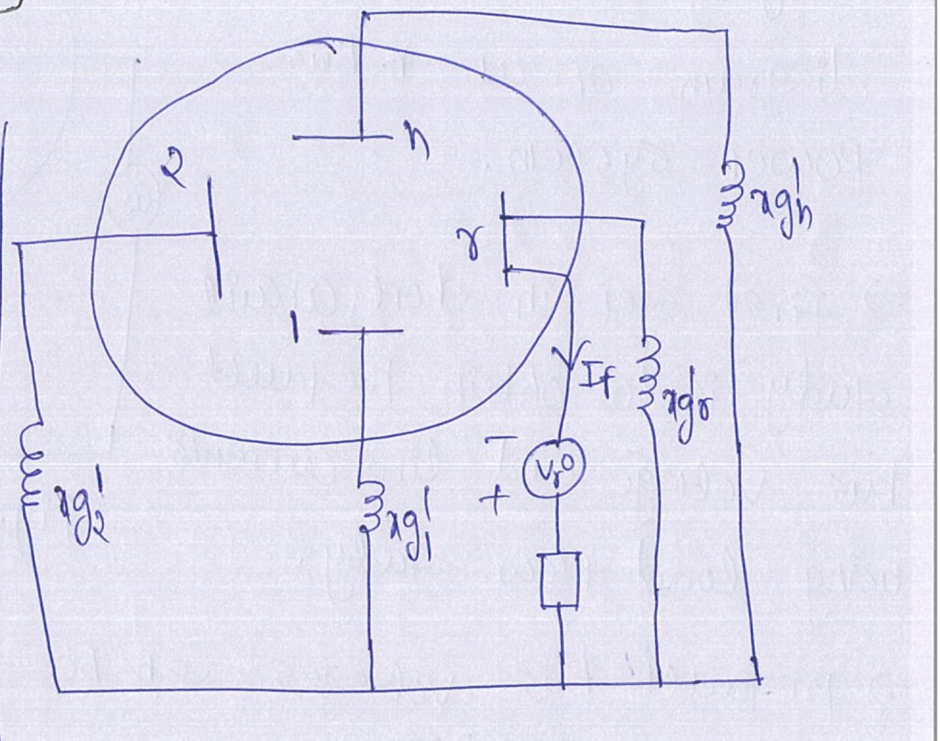


Fig. 3: Thevenin network of Fig.2 with $-V_r^0$ is in series with Z_f.

Now

$$\Delta V = Z_{BUS} I_f \longrightarrow 2ⓑ$$

where Z_{BUS} is the bus impedance matrix of the Passive Thevenin network and is given by

$$Z_{Bus} = \begin{bmatrix} Z_{11} & Z_{12} & \cdots & Z_{1n} \\ Z_{21} & Z_{22} & \cdots & Z_{2n} \\ \vdots & \vdots & & \vdots \\ Z_{n1} & Z_{n2} & \cdots & Z_{nn} \end{bmatrix} \longrightarrow (3)$$

and C_f is bus current injection vector. The network is injected with current $-I_f$ only at the r-th bus, we have,

$$C_f = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ I_{rf} = -I_f \\ \vdots \\ 0 \end{bmatrix} \longrightarrow (4)$$

From Eqs (2)(6) and (4), we obtain

$$\Delta V_r = -Z_{rr} I_f \longrightarrow (5)$$

$$\Delta V = Z_{Bus} \cdot C_f$$

$$\begin{bmatrix} \Delta V_1 \\ \Delta V_2 \\ \vdots \\ \Delta V_r \\ \vdots \\ \Delta V_n \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} & \cdots & & Z_{1n} \\ Z_{21} & Z_{22} & \cdots & & Z_{2n} \\ \vdots & \vdots & & & \\ Z_{r1} & Z_{r2} & \cdots & Z_{rr} \cdots & Z_{rn} \\ \vdots & & & & \\ Z_{n1} & Z_{n2} & \cdots & \cdots & Z_{nn} \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ \vdots \\ I_{rf} = -I_f \\ \vdots \\ 0 \end{bmatrix}$$

⇒ explanation of above eq.

$$\therefore \Delta V_r = -Z_{rr} \cdot I_f$$

⇒ The voltage at the r-th bus under fault is

$$V_{rf} = V_r^0 + \Delta V_r = V_r^0 - Z_{rr} I_f \longrightarrow (6)$$

[∵ From eq (5) $\Delta V_r = -Z_{rr} I_f$].

Also,

$$V_{rf} = Z_f I_f \longrightarrow (7)$$

From eqs (6) and (7), we get

$$Z_f I_f = V_r^0 - Z_{rr} I_f$$

$$\therefore I_f = \frac{V_r^0}{(Z_{rr} + Z_f)} \longrightarrow (8)$$

using eq (5); at the i-th bus (r = i),

$$\Delta V_i = -Z_{ir} \cdot I_f \longrightarrow (9)$$

Therefore, using eq (6), at i-th bus (r = i),

$$V_{if} = V_i^0 - Z_{ir} I_f \longrightarrow (10)$$

From eqs (10) and (8), we obtain,

$$V_{if} = V_i^0 - \frac{Z_{ir}}{(Z_{rr} + Z_f)} V_r^0 \longrightarrow (11)$$

For i = r, eq (11) becomes

$$\therefore V_{rf} = V_r^0 - \frac{Z_{rr}}{(Z_{rr} + Z_f)} V_r^0$$

$$\therefore V_{rf} = \frac{Z_f}{(Z_{rr} + Z_f)} \cdot V_r^0 \longrightarrow (12)$$

⇒ Note that V_i^0's are prefault bus voltages and can be obtained from load flow study. Z_{BUS} matrix for short circuit study can be obtained by inverting Y_{BUS} matrix.

⇒ Also note that synchronous motors must be included in Z_{Bus} formulation for the short circuit study. However, in formulating short circuit study network, load impedances are ignored, because these are very much larger than the impedances of generators and transmission lines.

⇒ Fault current flowing from bus i to bus j is given by

$$I_{f,ij} = y_{ij}\left(V_{if} - V_{jf}\right) \longrightarrow (13)$$

Post fault generator current for i-th generator is given by

$$I_{f,gi} = \frac{\left(V'_{gi} - V_{if}\right)}{j x'_{gi}} \longrightarrow (14)$$

Ex-2) :— A sample power system is shown in Fig. 4. Obtain the short circuit solution for a solid three phase fault at bus 4.

Sol: Assuming prefault bus voltages are 1.0 pu and prefault currents are zero.

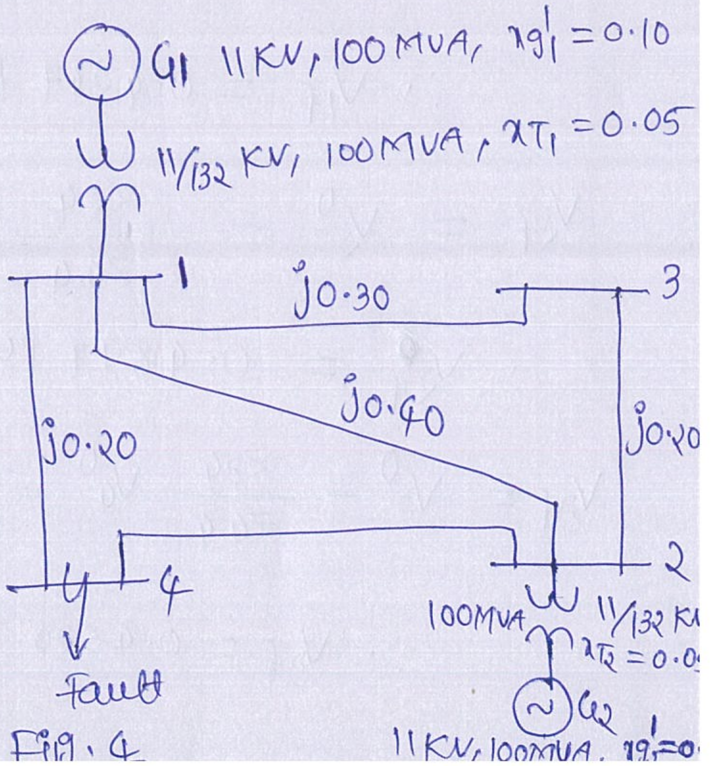


Fig. 4

$$Z_{Bus} = \begin{bmatrix} j0.1806 & j0.1194 & j0.1438 & j0.1560 \\ j0.1194 & j0.1806 & j0.1560 & j0.1438 \\ j0.1438 & j0.1560 & j0.2712 & j0.1486 \\ j0.1560 & j0.1438 & j0.1486 & j0.2712 \end{bmatrix}$$

$$\boxed{Z_{Bus} = Y_{Bus}^{-1}}$$

using eq (11),

$$V_{if} = V_i^0 - \frac{Z_{ir}}{(Z_{rr} + Z_f)} V_r^0$$

Prefault condition, $V_1^0 = V_2^0 = V_3^0 = V_4^0 = 1.0\ pu$

Bus 4 is faulted bus, i.e; $r = 4$

$$Z_f = 0$$

$$V_{1f} = V_1^0 - \frac{Z_{14}}{Z_{44}} V_4^0 = 1.0 - \frac{j0.1560}{j0.2712} \times 1.0$$

$$\therefore V_{1f} = 0.4247\ pu$$

$$V_{2f} = V_2^0 - \frac{Z_{24}}{Z_{44}} V_4^0 = 1.0 - \frac{j0.1438}{j0.2712} \times 1.0$$

$$\therefore V_{2f} = 0.4697\ pu$$

$$V_{3f} = V_3^0 - \frac{Z_{34}}{Z_{44}} V_4^0 = 1.0 - \frac{j0.1486}{j0.2712} \times 1.0$$

$$\therefore V_{3f} = 0.4520\ pu$$

$$V_{4f} = 0.0$$

Fault Current can be Computed using eq (13)

$$I_{f,ij} = y_{ij}(V_{if} - V_{jf})$$

$$I_{f,12} = y_{12}(V_{1f} - V_{2f}) = \frac{1}{z_{12}}(V_{1f} - V_{2f})$$

$$\therefore I_{f,12} = \frac{0.4247 - 0.4697}{j0.4} = j0.1125 \text{ pu}$$

Similarly,

$$I_{f,13} = j0.091 \text{ pu}$$

$$I_{f,14} = -j2.1235 \text{ pu}$$

$$I_{f,24} = -j1.5656 \text{ pu}$$

$$I_{f,23} = -j0.0885 \text{ pu}.$$

Formulation of ZBUS Matrix:-

We know that

$$C_{BUS} = Y_{BUS} \cdot V_{BUS}.$$

$$\therefore V_{BUS} = Y_{BUS}^{-1} \cdot C_{BUS} = Z_{BUS} \cdot C_{BUS} \longrightarrow (15)$$

where

$$Z_{BUS} = Y_{BUS}^{-1} \longrightarrow (16)$$

ZBUS Formulation by Current Injection Technique:-

eq (15) Can be written in expanded form:

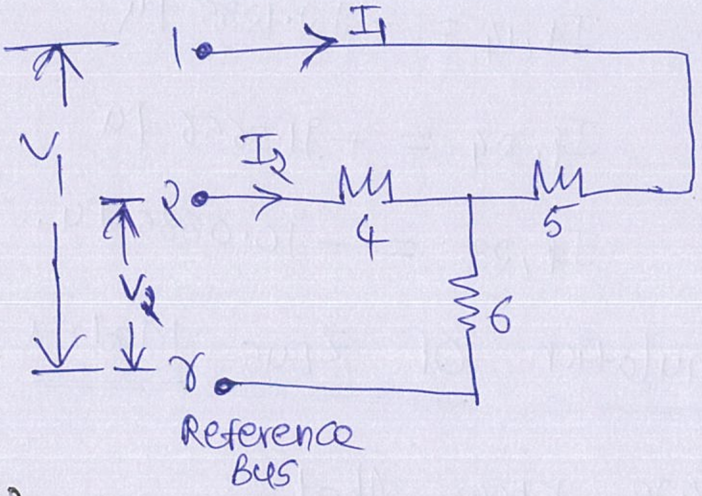
$$V_1 = Z_{11} I_1 + Z_{12} I_2 + \dots\dots + Z_{1n} I_n$$

$$V_2 = Z_{21} I_1 + Z_{22} I_2 + \cdots + Z_{2n} I_n$$
$$\vdots$$
$$V_n = Z_{n1} I_1 + Z_{n2} I_2 + \cdots + Z_{nn} I_n \quad \longrightarrow (17)$$

From eq (17), we get,

$$Z_{ij} = \frac{V_i}{I_j} \Bigg|_{\substack{I_1 = I_2 = \cdots = I_n = 0 \\ I_j \neq 0}} \longrightarrow (18)$$

<u>Ex-3)</u>:— A sample network is shown in Fig. 5. Determine ZBus matrix.



<u>Fig. 5</u>

<u>Sol</u>

Inject unit current at bus 1 and keeping bus 2 open circuited as shown in Fig. 5 (a).

$I_1 = 1.0$ pu, $I_2 = 0.0$

Calculating voltages at bus 1 and bus 2

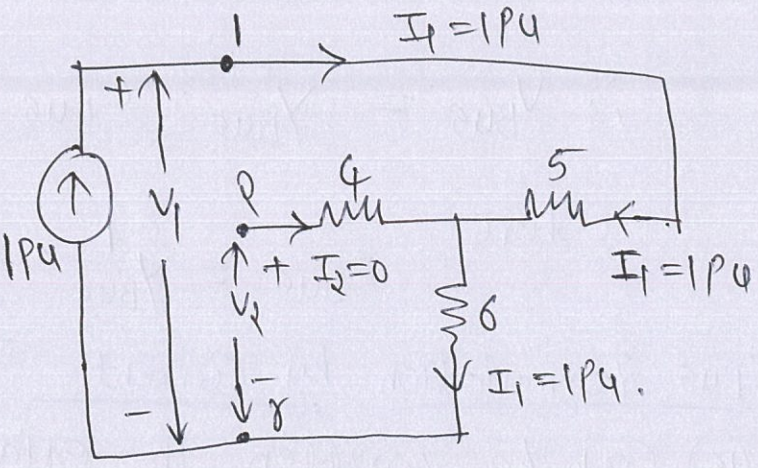


Fig. 5 (a)

$5 \times I_1 + 6 \times I_2 = V_1$

$\therefore \frac{V_1}{I_1} = Z_{11} = 11$

$\therefore Z_{11} = \frac{V_1}{1} = 11$

$\therefore Z_{11} = V_1 = 11$

Fig 5(a)

$I_2 \times 4 + I_1 \times 6 = V_2$

$0 \times 4 + I_1 \times 6 = V_2$

$\frac{V_2}{I_1} = Z_{21} = 6$

$\frac{V_2}{1} = Z_{21} = 6$

$\therefore V_2 = Z_{21} = 6$

we have,

$Z_{11} = V_1 = 11.0$

$Z_{21} = V_2 = 6.0$

From Fig. 5(b) we have,

$Z_{22} = V_2 = 10.0$

$Z_{12} = V_1 = 6.0$

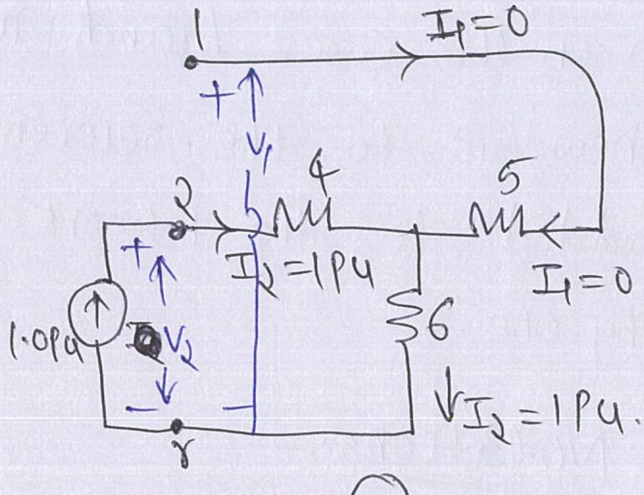


Fig. 5(b)

There fore,

$$Z_{Bus} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} = \begin{bmatrix} 11.0 & 6.0 \\ 6.0 & 10.0 \end{bmatrix}$$

⇒ the ZBus matrix also referred to as the 'Open circuit impedance matrix'.

Algorithm For Building ZBus matrix:—

⇒ ZBus building algorithm is a step by step procedure which proceeds branch by branch.

⇒ Main advantage of this method is that, any modification of the network elements does not require complete rebuilding of ZBus matrix. Details of ZBus Formulation is given below:

Type-1 Modification:—

⇒ In this Case, branch impedance Z_b is added from a new bus to the reference bus, that is a new bus is added to the network and dimension of ZBus goes up by one.

Notations:—

i, j ⟶ old buses

r ⟶ Reference bus

K ⟶ New bus

⇒ Fig. 6 shows a passive linear n-bus power system network.

⇒ In fig. 6, an impedance Z_b is added between new bus K and the reference bus r.

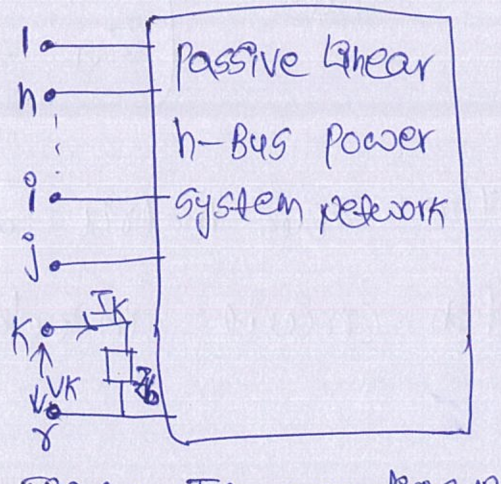


Fig6: Type-1 Modification

From Fig. 6;

$$V_K = Z_b I_K \quad \text{or} \quad V_K = Z_{KK} I_K$$

$$Z_{Ki} = Z_{iK} = 0 \; ; \; \text{for } i = 1, 2, \cdots, n$$

$$Z_{KK} = Z_b.$$

Therefore,

$$Z_{Bus}^{new} = \left[\begin{array}{c|c} Z_{Bus}^{old} & \begin{matrix} 0 \\ \vdots \\ 0 \end{matrix} \\ \hline 0 \cdots\cdots 0 & Z_b \end{array}\right] \longrightarrow (19)$$

where

Z_{Bus}^{old} is bus impedance matrix before adding a new branch.

Type-2 Modification:-

From Fig. 7, we have,

$$V_K = V_j + Z_b I_K$$

⇒ In this case branch impedance Z_b is added from a news bus K to the old bus j.

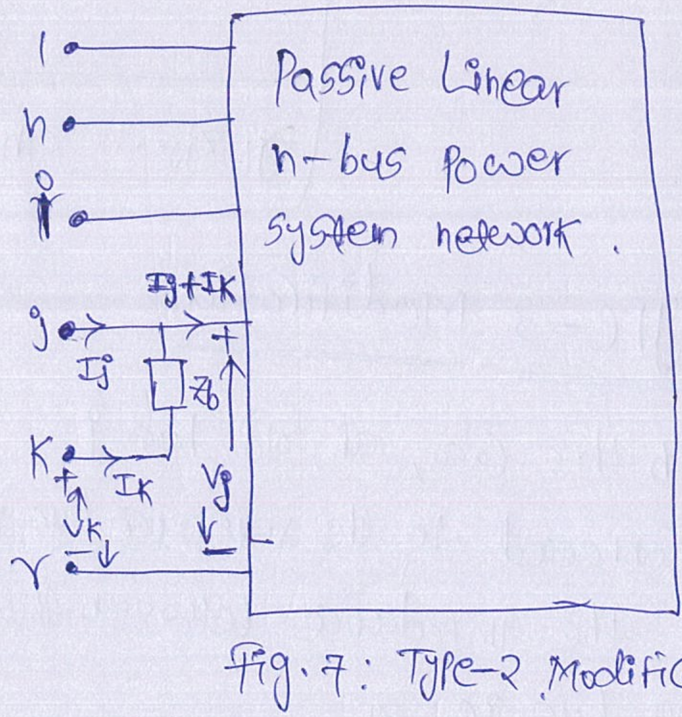


Fig. 7: Type-2 Modification.

$$\therefore \begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_n \\ \hline V_K \end{bmatrix} = \left[\begin{array}{c|c} Z_{Bus}^{old} & \begin{matrix} Z_{1j} \\ Z_{2j} \\ \vdots \\ Z_{nj} \end{matrix} \\ \hline Z_{j1}\, Z_{j2} \cdots Z_{jn} & (Z_{jj} + Z_b) \end{array}\right] \begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_n \\ \hline I_K \end{bmatrix} \longrightarrow (20)(a)$$

$$\therefore V_K = \left[Z_{j1} I_1 + Z_{j2} I_2 + \cdots + Z_{jj} (I_j + I_K) + \cdots \cdots + Z_{jn} I_n \right] + Z_b \cdot I_K$$

$$\therefore V_K = \left[Z_{j1} I_1 + Z_{j2} I_2 + \cdots + Z_{jj} I_j + \cdots + Z_{jn} I_n \right] + (Z_{jj} + Z_b) I_K \longrightarrow (20)$$

$$\therefore Z_{Bus}^{new} = \left[\begin{array}{c|c} Z_{Bus}^{old} & \begin{matrix} Z_{1j} \\ Z_{2j} \\ \vdots \\ Z_{nj} \end{matrix} \\ \hline Z_{j1}\, Z_{j2} \cdots Z_{jn} & (Z_{jj} + Z_b) \end{array}\right] \longrightarrow (21)$$

Type-3 Modification

⇒ In this case, an old bus-j is connected to the reference bus-r and the impedance between this two bus is Z_b.

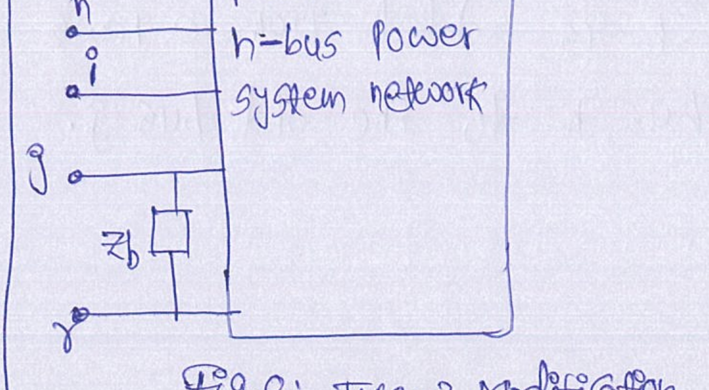


Fig.8: Type-3 Modification.

⇒ Referring to Fig. 7, if bus K is connected to reference bus r, $V_K = 0$

Thus, eq 20 ⓐ is modified as:

$$\begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_n \\ \hline 0 \end{bmatrix} = \left[\begin{array}{c|c} Z_{Bus}^{old} & \begin{matrix} Z_{1j} \\ Z_{2j} \\ \vdots \\ Z_{nj} \end{matrix} \\ \hline Z_{j1} \; Z_{j2} \cdots Z_{jn} & (Z_{jj} + Z_b) \end{array}\right] \begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_n \\ \hline I_K \end{bmatrix} \longrightarrow (22)$$

From eq (22), we get,

$$0 = Z_{j1} I_1 + Z_{j2} I_2 + \cdots\cdots + Z_{jn} I_n + (Z_{jj} + Z_b) I_K$$

$$\therefore I_K = \frac{-1}{(Z_{jj} + Z_b)} \left[Z_{j1} I_1 + j Z_2 I_2 + \cdots\cdots + Z_{jn} I_n \right] \longrightarrow (23)$$

Expression of voltage for i-th bus can be written as:

$$V_i = Z_{i1} I_1 + Z_{i2} I_2 + \cdots\cdots + Z_{in} I_n + Z_{ij} I_K \longrightarrow (24)$$

From eqs (24) and (23), we get,

$$V_i = \left[Z_{i1} - \frac{Z_{ij} Z_{j1}}{Z_{jj} + Z_b} \right] I_1 + \left[Z_{i2} - \frac{Z_{ij} \cdot Z_{j2}}{Z_{jj} + Z_b} \right] I_2 + \cdots$$

$$\cdots\cdots + \left[Z_{in} - \frac{Z_{ij} \cdot Z_{jn}}{Z_{jj} + Z_b} \right] I_n \longrightarrow (25)$$

⇒ By inspection, Z_{Bus}^{new} can easily be written

From eq (25), i.e;

$$Z_{Bus}^{new} = Z_{Bus}^{old} - \frac{1}{(Z_{jj} + Z_b)} \begin{bmatrix} Z_{1j} \\ Z_{2j} \\ \vdots \\ Z_{ij} \\ \vdots \\ Z_{nj} \end{bmatrix} \begin{bmatrix} Z_{j1} & Z_{j2} & \cdots & Z_{jn} \end{bmatrix} \longrightarrow (26)$$

Type-4 Modification:-

⇒ In this case, two old buses are connected and impedance between these buses is Z_b.

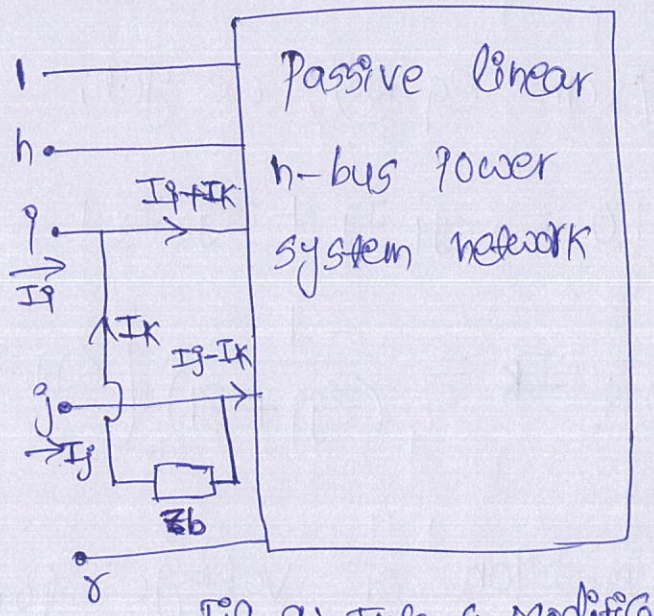


Fig-9: Type-4 Modification.

From Fig. 9, we can write,

$$V_i = Z_{i1} I_1 + Z_{i2} I_2 + \cdots + Z_{ii}(I_i + I_k) + Z_{ij}(I_j - I_k) + \cdots + Z_{in} I_n \longrightarrow (27)$$

Also

$$V_j = Z_b I_k + V_i \longrightarrow (28)$$

$$V_j = Z_{j1} I_1 + Z_{j2} I_2 + \cdots + Z_{ji}(I_i + I_k) + Z_{jj}(I_j - I_k) + \cdots + Z_{jn} I_n \longrightarrow (29)$$

From eqs (28), (27) and (29), we get,

$$Z_{j1} I_1 + Z_{j2} I_2 + \cdots\cdots + Z_{ji}(I_i + I_K) + Z_{jj}(I_j - I_K) + \cdots$$
$$\cdots\cdots + Z_{jn} I_n = Z_b I_K + Z_{i1} I_1 + Z_{i2} I_2 + \cdots\cdots$$
$$\cdots + Z_{ii}(I_i + I_K) + Z_{ij}(I_j - I_K) + \cdots\cdots + Z_{in} I_n$$

$$\therefore 0 = (Z_{i1} - Z_{j1}) I_1 + (Z_{i2} - Z_{j2}) I_2 + \cdots\cdots + (Z_{ii} - Z_{ji}) I_i$$
$$+ (Z_{ij} - Z_{jj}) I_j + \cdots\cdots + (Z_{in} - Z_{jn}) I_n$$
$$+ (Z_b + Z_{ii} + Z_{jj} - Z_{ij} - Z_{ji}) I_K \longrightarrow (30)$$

Note that $Z_{ij} = Z_{ji}$

and coefficient of I_K is $(Z_b + Z_{ii} + Z_{jj} - 2Z_{ij})$

OR,

$$\begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_n \\ \hline 0 \end{bmatrix} = \left[\begin{array}{c|c} Z_{Bus}^{old} & \begin{matrix} Z_{1i} - Z_{1j} \\ Z_{2i} - Z_{2j} \\ \vdots \\ Z_{ni} - Z_{nj} \end{matrix} \\ \hline (Z_{i1} - Z_{j1}) \cdots\cdots (Z_{in} - Z_{jn}) & (Z_b + Z_{ii} + Z_{jj} - 2Z_{ij}) \end{array}\right] \begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_n \\ \hline I_K \end{bmatrix} \longrightarrow (31)$$

Eliminating I_K in Eq (31) and following the same procedure for type-3 modification, we get,

$$Z_{Bus}^{new} = Z_{Bus}^{old} - \frac{1}{(z_b + Z_{ii} + Z_{jj} - 2Z_{ij})} \begin{bmatrix} (Z_{1i} - Z_{1j}) \\ (Z_{2j} - Z_{2j}) \\ \vdots \\ (Z_{ni} - Z_{nj}) \end{bmatrix} \left[(Z_{i1} - Z_{j1}) \; (Z_{i2} - Z_{j2}) \cdots (Z_{in} - Z_{jn}) \right] \longrightarrow (32)$$

⇒ With the use of above mentioned four modifications bus impedance matrix can be formulated by a step by step technique considering one branch at a time.

Ex-4):- Fig.10 shows a three bus network obtain impedance matrix Z_{Bus}.

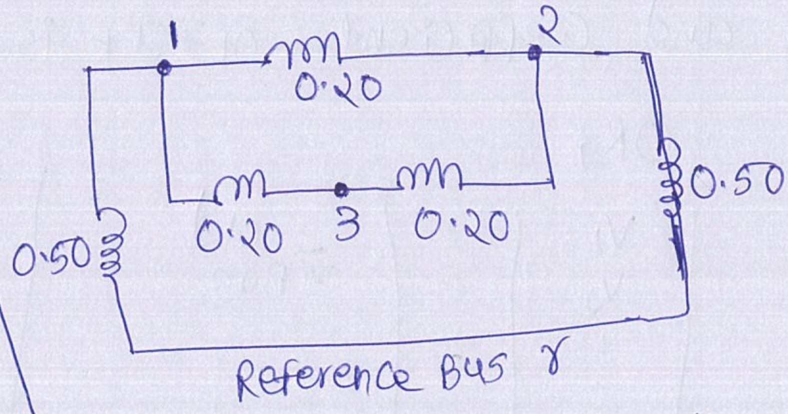


Fig.10: Three bus network.

Sol:

Step-1:-

Add branch $Z_{1r} = 0.50$ [From new bus-1 to reference bus-r ⇒ Type-1 Modification].

$$\therefore Z_{Bus} = [0.50] \longrightarrow (i)$$

Step-2:- Type-2 Modification :- That is add branch $Z_{21} = 2.0$ [From new bus-2 to add bus-1], $j=1$, $K=2$

$$\therefore Z_{Bus} = \begin{bmatrix} 0.50 & 0.50 \\ 0.50 & 0.70 \end{bmatrix} \longrightarrow (ii)$$

Step-3 :— Add branch $Z_{13} = 0.20$ from new bus-3 to old bus-1. This is Type-2 modification $[K=3;\ j=1]$

$Z_b = Z_{31} = 0.2$; $Z_{jj} = Z_{11} = 0.50$

$\therefore Z_b + Z_{jj} = Z_b + Z_{11} = (0.2 + 0.50) = 0.70$.

$$\therefore Z_{Bus} = \left[\begin{array}{cc|c} 0.50 & 0.50 & 0.50 \\ 0.50 & 0.70 & 0.50 \\ \hline 0.50 & 0.50 & 0.70 \end{array}\right] \longrightarrow (iii)$$

Step-4 :— Add branch Z_{2r} from old bus-2 to reference bus-r. This is Type-3 modification.

old bus $j=2$; $n=3$; $Z_b = Z_{2r} = 0.50$

From eq (26).

$$\therefore Z_{Bus}^{new} = Z_{Bus}^{old} - \frac{1}{(Z_{22}+Z_b)} \begin{bmatrix} Z_{12} \\ Z_{22} \\ Z_{32} \end{bmatrix} \begin{bmatrix} Z_{21} & Z_{22} & Z_{23} \end{bmatrix}$$

$$\therefore Z_{Bus}^{new} = \begin{bmatrix} 0.50 & 0.50 & 0.50 \\ 0.50 & 0.70 & 0.50 \\ 0.50 & 0.50 & 0.70 \end{bmatrix} - \frac{1}{(0.7+0.5)} \begin{bmatrix} 0.50 \\ 0.70 \\ 0.50 \end{bmatrix} \begin{bmatrix} 0.50 & 0.70 & 0.50 \end{bmatrix}$$

$$\therefore Z_{Bus} = \begin{bmatrix} 0.2916 & 0.2084 & 0.2916 \\ 0.2084 & 0.2916 & 0.2084 \\ 0.2916 & 0.2084 & 0.4916 \end{bmatrix} \longrightarrow \text{(iv)}$$

Step-5:— Add branch $Z_{23} = 0.20$ from old bus-2 to old bus-3. This is Type-4 modification.

$n=3$; $i=2$; $j=3$; $Z_b = Z_{23} = 0.20$

From eq. (32)

$$Z_{Bus}^{new} = Z_{Bus}^{old} - \frac{1}{(Z_b + Z_{22} + Z_{33} - 2Z_{23})} \begin{bmatrix} (Z_{12} - Z_{13}) \\ (Z_{22} - Z_{23}) \\ (Z_{32} - Z_{33}) \end{bmatrix} \begin{bmatrix} (Z_{21} - Z_{31}) & (Z_{22} - Z_{32}) & (Z_{23} - Z_{33}) \end{bmatrix}$$

$$Z_{Bus} = \begin{bmatrix} 0.2916 & 0.2084 & 0.2916 \\ 0.2084 & 0.2916 & 0.2084 \\ 0.2916 & 0.2084 & 0.4916 \end{bmatrix} - \frac{1}{(0.20 + 0.2916 + 0.4916 - 2 \times 0.2084)} \begin{bmatrix} -0.0832 \\ 0.0832 \\ -0.2832 \end{bmatrix} \begin{bmatrix} -0.0832 & 0.0832 & -0.2832 \end{bmatrix}$$

$$\therefore Z_{Bus} = j \begin{bmatrix} 0.2793 & 0.2206 & 0.2500 \\ 0.2206 & 0.2793 & 0.2500 \\ 0.2500 & 0.2500 & 0.3500 \end{bmatrix}$$

Ex-5) :- Fig. 11 shows a sample power system network. For a solid three phase fault at bus-3, determine (a) Fault current (b) V_{1f} and V_{2f} (c) fault currents in lines 1-2, 1-3 and 2-3. (d) $I_{g1,f}$ and $I_{g2,f}$.

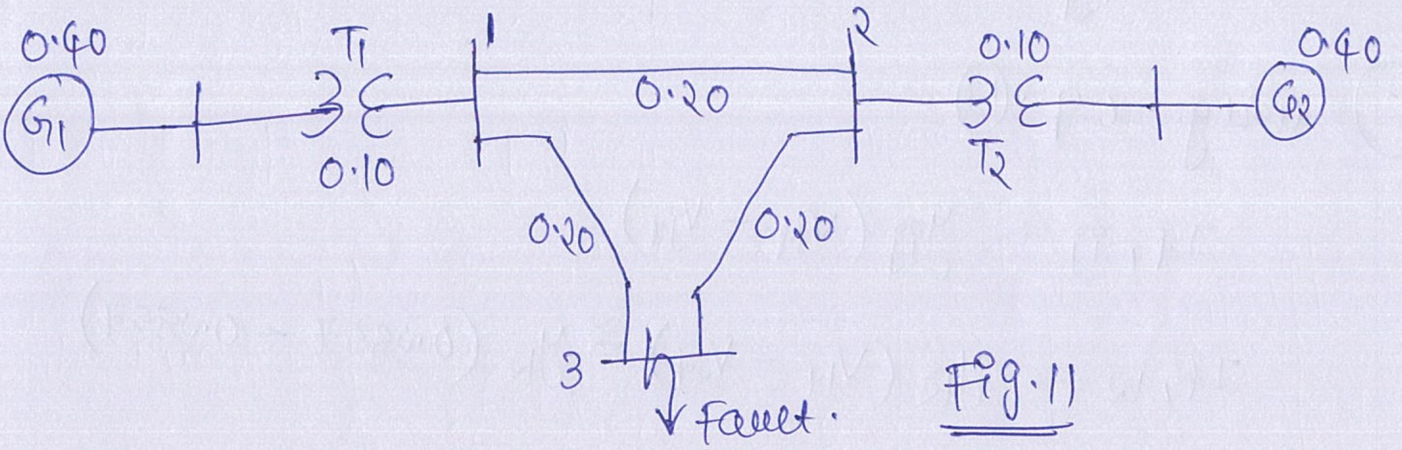


Fig. 11

Sol: (a) using Eq (8),

$$I_f = \frac{V_r^0}{(Z_{rr} + Z_f)}$$

⇒ Thevenin passive network for this system is shown in Fig. 10 and Z_{BUS} matrix for this system is alredy formulated. For this case $Z_f = 0.0$ and $Z_{33} = j0.35$

r = 3

$$\therefore I_f = \frac{V_r^0}{(Z_{rr} + Z_f)} = \frac{V_3^0}{(Z_{33} + 0.0)} = \frac{1.0}{j0.35} = -j2.85 \text{ pu.}$$

(b) using Eq (11),

$$V_{if} = V_i^0 - \frac{Z_{ir}}{(Z_{rr} + Z_f)} \cdot V_r^0$$

when $i=1$

$$V_{1f} = V_1^0 - \frac{Z_{13}}{Z_{33}} \cdot V_3^0 = \left(1 - \frac{j0.25}{j0.35}\right)$$

$\therefore V_{1f} = 0.2857$ pu

similarly,

$V_{2f} = 0.2857$ pu and $V_{3f} = 0.0$ pu

(c) using eq. (13)

$$I_{f,ij} = y_{ij}(V_{if} - V_{jf})$$

$$I_{f,12} = y_{12}(V_{1f} - V_{2f}) = y_{12}(0.2857 - 0.2857)$$

$$\therefore I_{f,12} = 0.0$$

$$I_{f,13} = y_{13}(V_{1f} - V_{3f}) = \frac{1}{j0.20}(0.2857 - 0)$$

$$\therefore I_{f,13} = -j1.4285 \text{ pu}$$

similarly,

$$I_{f,23} = -j1.4285 \text{ pu}$$

(d) using eq (14), we can write,

$$I_{f,gi} = \frac{V_{gi}' - V_{if}}{(jx_{gi}' + jx_{Ti})}$$

Note that transformer reactance is also included in above equation.

$V_{g1}' = 1.0$ pu [pre-fault no load voltage].

$V_{1f} = 0.2857\ pu$; $x_{g1}' = 0.40\ pu$; $x_{T_1} = 0.10\ pu$

$$\therefore I_{f,g1} = \frac{(1-0.2857)}{j(0.4+0.1)} = -j1.4286\ pu$$

similarly, $I_{f,g2} = -j1.4286\ pu$.

Symmetrical Components:-

⇒ In a balanced system, analysis can be done on a single phase basis. The knowledge of voltage and current in one phase is sufficient to determine the voltage and current in other two phases. Real and Reactive powers are three times the corresponding per phase values.

⇒ when the system is unbalanced, the voltages, currents and the phase impedances are in general unequal.

⇒ unbalanced operation can result when loads are unbalanced

⇒ unbalanced system operation can result due to unsymmetrical fault, e.g., line to line fault, double line to ground fault, or single line to ground fault.

⇒ such an unbalanced operation can be analyzed through symmetrical components where the unbalanced three phase voltages and currents are transformed into three sets of balanced voltages and currents called symmetrical components.

Symmetrical Components of an unbalanced Three phase system:—

⇒ The unbalanced phasors of a three-phase system can be resolved into following three component sets of balanced phasors which possess certain symmetry.

1). A set of three phasors equal in magnitude, displaced from each other by 120° in phase, and having the same phase sequence as the original unbalanced phasors. The set of balanced phasor is called positive sequence component.

2). A set of three phasors equal in magnitude, displaced from each other by 120° in phase, and having the phase sequence opposite to that of the original phasors. This set of balanced phasors is called negative sequence components.

3). A set of three phasors equal in magnitude with zero phase ~~phase~~ displacement from each other. This set is called zero sequence components. The components of this set are all identical.

⇒ These three sets of balanced phasors are called symmetrical components of the original unbalanced phasors.

⇒ Assume that the three phases are represented a, b and c such that phase sequence abc (positive sequence)

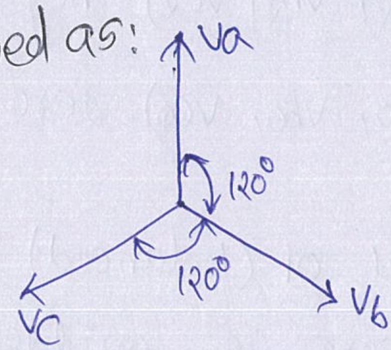
⇒ say V_a, V_b and V_c are balanced voltages (phasors) characterized by equal magnitudes and interphase difference of 120°, then the set is said to have a phase sequence abc (positive sequence).

⇒ If V_b lags V_a by 120° and V_c lags V_b by 120°.

⇒ Assume V_a is reference phasor,

$$\therefore V_a = V_a \;;\quad V_b = \beta^2 V_a \;;\quad V_c = \beta V_a$$

where the complex operator β is defined as:



$$\beta = e^{j120^\circ}$$

β has the following properties:

$$\therefore \beta^2 = e^{j240^\circ} = e^{-j120^\circ} = \beta^*$$

$$(\beta^2)^* = \beta$$

$$\beta^3 = 1$$

$$1 + \beta + \beta^2 = 0$$

$\longrightarrow$ (1)

⇒ If the phase sequence is acb (negative sequence) then

$$V_a = V_a \;;\quad V_b = \beta V_a \;;\quad V_c = \beta^2 V_a$$

$$V_b = V_a \angle -120^\circ$$

$$\therefore V_b = V_a e^{-j120^\circ}$$

$$\therefore V_b = \beta^2 V_a$$

$$V_c = V_a \angle -240^\circ$$

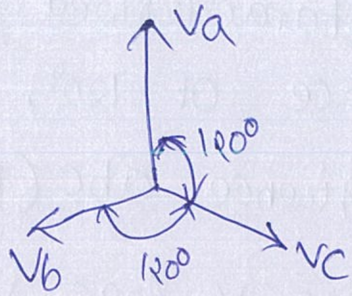
$$\therefore V_c = V_a \angle 120^\circ$$

$$= V_a e^{j120^\circ}$$

$$\therefore V_c = \beta V_a .$$

⇒ Assume that the subscript 1, 2, 0 refer to positive sequence, negative sequence and zero sequence respectively.

⇒ If V_a, V_b and V_c represent an unbalanced set of voltage phasors, the three balanced sets are written as:



$V_b = V_a \angle -240^\circ$
$= V_a \angle 120^\circ$
$V_b = V_a e^{j120^\circ}$
$\therefore V_b = \beta V_a$
$V_c = V_a \angle -120^\circ$
$= V_a e^{-j120^\circ}$
$\therefore V_c = \beta^2 V_a$.

(V_{a1}, V_{b1}, V_{c1}) positive sequence set

(V_{a2}, V_{b2}, V_{c2}) negative sequence set

(V_{a0}, V_{b0}, V_{c0}) zero sequence set.

A set of (balanced) positive sequence phasors is written as:

$V_{a1}, \; V_{b1} = \beta^2 V_{a1} \; ; \; V_{c1} = \beta V_{a1}$ ⟶ (2)

A set of (balanced) negative sequence phasors is written as:

$V_{a2}, \; V_{b2} = \beta V_{a2} \; ; \; V_{c2} = \beta^2 V_{a2}$ ⟶ (3)

A set of zero sequence phasors is written as:

$V_{a0}, \; V_{b0} = V_{a0} \; ; \; V_{c0} = V_{a0}$ ⟶ (4)

⇒ The three phasors (V_a, V_b, V_c) can be expressed as the sum of positive, negative and zero sequence phasors defined above.

Thus we can write,

$$V_a = V_{a1} + V_{a2} + V_{a0} \longrightarrow (5)$$

$$V_b = V_{b1} + V_{b2} + V_{b0} \longrightarrow (6)$$

$$V_c = V_{c1} + V_{c2} + V_{c0} \longrightarrow (7)$$

Fig.1 shows symmetrical components of the unbalanced phasors

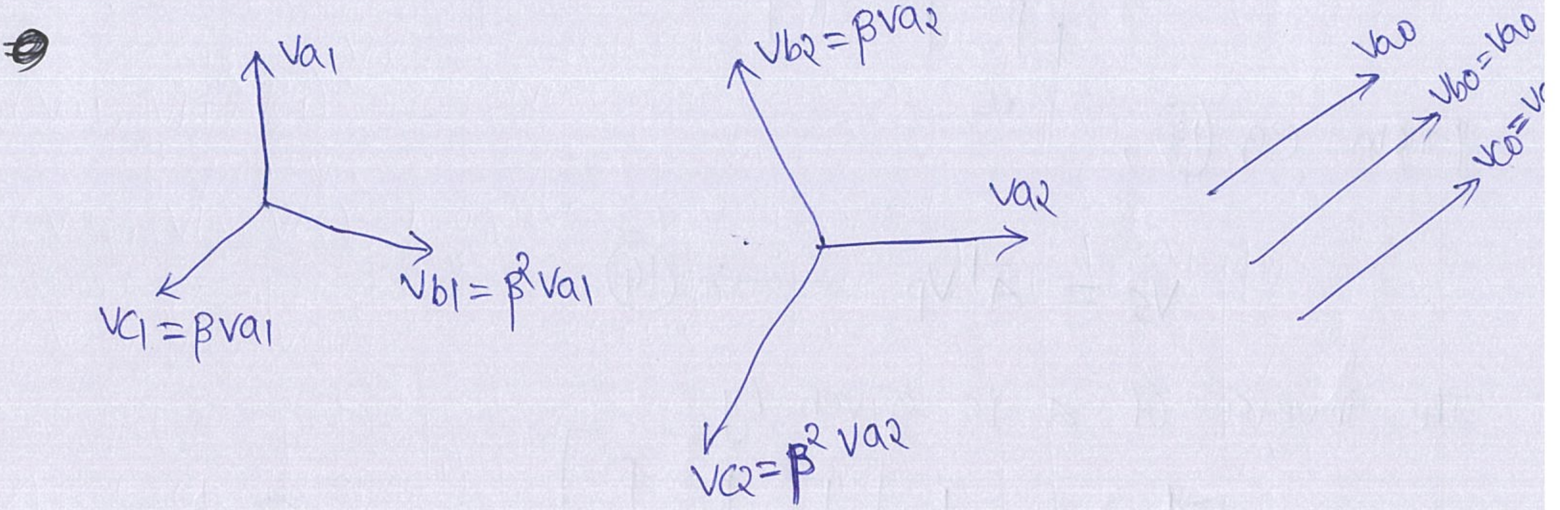


Fig.1: Symmetrical Components of unbalanced voltage phasors.

Let us express eqs (5), (6) and (7) in terms of reference phasors V_{a1}, V_{a2}, V_{a0}. Thus,

$$V_a = V_{a1} + V_{a2} + V_{a0} \longrightarrow (8)$$

$$V_b = \beta^2 V_{a1} + \beta V_{a2} + V_{a0} \longrightarrow (9)$$

$$V_c = \beta V_{a1} + \beta^2 V_{a2} + V_{a0} \longrightarrow (10)$$

Eqs (8), (9) and (10) can be written in matrix form:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ \beta^2 & \beta & 1 \\ \beta & \beta^2 & 1 \end{bmatrix} \begin{bmatrix} V_{a1} \\ V_{a2} \\ V_{a0} \end{bmatrix} \longrightarrow (11)$$

or

$$V_p = A V_s \longrightarrow (12)$$

where

$$V_p = [V_a \ \ V_b \ \ V_c]^T$$

$$V_s = [V_{a1} \ \ V_{a2} \ \ V_{a0}]^T$$

$$A = \begin{bmatrix} 1 & 1 & 1 \\ \beta^2 & \beta & 1 \\ \beta & \beta^2 & 1 \end{bmatrix} \longrightarrow (13)$$

From eq (12),

$$V_s = A^{-1} V_p \longrightarrow (14)$$

The inverse of A is given by

$$A^{-1} = \frac{1}{3} \begin{bmatrix} 1 & \beta & \beta^2 \\ 1 & \beta^2 & \beta \\ 1 & 1 & 1 \end{bmatrix} \longrightarrow (15)$$

Complex conjugate of eq (13) can be given as

$$A^* = \begin{bmatrix} 1 & 1 & 1 \\ (\beta^2)^* & \beta^* & 1 \\ \beta^* & (\beta^2)^* & 1 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ \beta & \beta^2 & 1 \\ \beta^2 & \beta & 1 \end{bmatrix}$$

(or) $$(A^*)^T = \begin{bmatrix} 1 & \beta & \beta^2 \\ 1 & \beta^2 & \beta \\ 1 & 1 & 1 \end{bmatrix} \longrightarrow (16)$$

using eqs (15) and (16), we get

$$A^{-1} = \frac{1}{3}(A^*)^T \longrightarrow (17)$$

using eqs (14) and (15), we get

$$V_{a1} = \frac{1}{3}(V_a + \beta V_b + \beta^2 V_c) \longrightarrow (18)$$

$$V_{a2} = \frac{1}{3}(V_a + \beta^2 V_b + \beta V_c) \longrightarrow (19)$$

$$V_{a0} = \frac{1}{3}(V_a + V_b + V_c) \longrightarrow (20)$$

⇒ The symmetrical components transformation given above for voltages can also be applied automatically for a set of currents. Thus,

$$I_a = I_{a1} + I_{a2} + I_{a0} \longrightarrow (21)$$

$$I_b = \beta^2 I_{a1} + \beta I_{a2} + I_{a0} \longrightarrow (22)$$

$$I_c = \beta I_{a1} + \beta^2 I_{a2} + I_{a0} \longrightarrow (23)$$

Also,

$$I_{a1} = \frac{1}{3}(I_a + \beta I_b + \beta^2 I_c) \longrightarrow (24)$$

$$I_{a2} = \frac{1}{3}(I_a + \beta^2 I_b + \beta I_c) \longrightarrow (25)$$

$$I_{a0} = \frac{1}{3}(I_a + I_b + I_c) \longrightarrow (26)$$

Power Invariance :—

⇒ The complex power in a three-phase system is given by

$$S = V_p^T I_p^* = \begin{bmatrix} V_a & V_b & V_c \end{bmatrix} \begin{bmatrix} I_a^* \\ I_b^* \\ I_c^* \end{bmatrix}$$

$$\therefore S = V_a I_a^* + V_b I_b^* + V_c I_c^* \longrightarrow (27)$$

Also

$$S = V_p^T I_p^* = [A V_s]^T [A I_s]^*$$

$$S = V_s^T A^T A^* I_s^* \longrightarrow (28)$$

Now

$$A^T A^* = 3 \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\therefore S = 3 V_s^T I_s^* = 3 V_{a1} I_{a1}^* + 3 V_{a2} I_{a2}^* + 3 V_{a0} I_{a0}^* \longrightarrow (29)$$

= sum of symmetrical component powers.

Sequence Impedances & Transmission Lines :—

⇒ Transmission line is a static device and hence the phase sequence has no effect on the impedance because currents and voltage encounter the same geometry of the line.

⇒ Therefore, positive and negative sequence impedance of transmission lines are equal i.e; $Z_1 = Z_2$.

⇒ As mentioned earlier, zero sequence currents are in phase and flow through the phases (a, b, c conductors), to return through the grounded neutral.

⇒ The ground or any shielding wire are in the path of zero sequence and zero-sequence impedance (Z_0), which includes the effect of the return path through the ground, is different from Z_1 and Z_2.

⇒ To get an idea of Z_0 of transmission line, consider 1-mt length of a three phase line as shown in Fig.2.

⇒ The ground surface is approximated to an equivalent fictitious conductor located at the average distance D_n from each of the three phases.

⇒ The phase conductors carry zero-sequence currents with return paths through a grounded neutral.

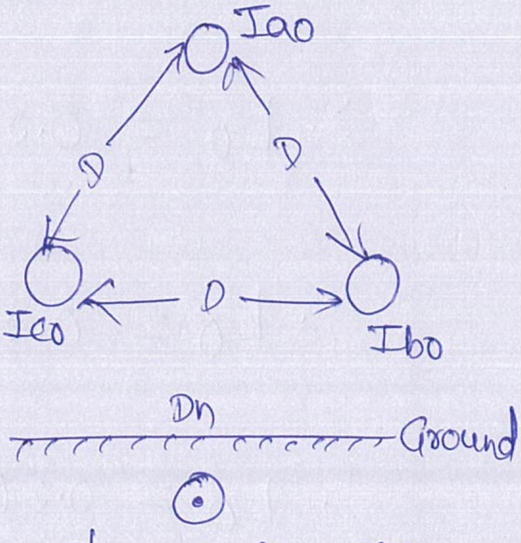


Fig.2: Flow of zero sequence current with earth return

we can write

$$I_{a0} + I_{b0} + I_{c0} + I_n = 0 \longrightarrow (30)$$

since,

$$I_{a0} = I_{b0} = I_{c0}, \text{ we get}$$

$$I_n = -3 I_{a0} \longrightarrow (31)$$

we can write, [Inductance chapter, Eqn (46)].

$$\lambda_{a0} = 2\times10^{-7}\left[I_{a0} \ln\frac{1}{r'} + I_{b0}\ln\frac{1}{D} + I_{c0}\ln\frac{1}{D} + I_n \ln\frac{1}{D_n}\right]$$

$$\longrightarrow (32)$$

since, $I_{a0} = I_{b0} = I_{c0}$ and $I_n = -3 I_{a0}$, we have

$$\lambda_{a0} = 2\times10^{-7} I_{a0} \ln\left(\frac{D_n^3}{r' D^2}\right) \text{ wb-T/mt} \longrightarrow (33)$$

since,

$$L_0 = \frac{\lambda_{a0}}{I_{a0}} = 0.2 \ln\left(\frac{D_n^3}{r' D^2}\right) \text{ mH/Km}$$

$$\therefore L_0 = 0.2 \ln\left(\frac{D}{r'} \times \frac{D_n^3}{D^3}\right) \text{ mH/Km}.$$

$$\therefore L_0 = 0.2 \ln\left(\frac{D}{r'}\right) + 0.2 \ln\left\{\left(\frac{D_n}{D}\right)^3\right\} \text{ mH/Km}.$$

$$\therefore L_0 = 0.2 \ln\left(\frac{D}{r'}\right) + 3\left\{0.2 \ln\left(\frac{D_n}{D}\right)\right\} \text{ mH/Km}$$

$$\longrightarrow (34)$$

First term in eq (34) is positive sequence inductance

Therefore,

$$X_0 = X_1 + 3X_n \longrightarrow (35)$$

Sequence Impedances of synchronous machine:-

⇒ Synchronous machine is designed with symmetrical windings and it induces emfs of positive sequence only.

⇒ The positive sequence generator impedance is the value found when positive sequence current flows due to an imposed positive-sequence set of voltages.

⇒ Neglecting the armature resistance, the positive sequence impedance of the machine is:

$$Z_1 = jX_d'' \text{ (if subtransient is of interest)} \longrightarrow (36)$$

$$Z_1 = jX_d' \text{ (if transient is of interest)} \longrightarrow (37)$$

$$Z_1 = jX_d \text{ (if steady-state value is of interest)} \longrightarrow (38)$$

⇒ With the flow of negative sequence currents in the stator, the net flux in the air gap rotates at opposite direction to that of the rotor.

⇒ Therefore, the net flux rotates twice the synchronous speed of the rotor.

⇒ In this case, field winding has no influence because field voltage is associated with the positive-sequence variables and only the damper winding produces an effect in the quadrature axis.

⇒ Therefore, the negative sequence impedance is close to the positive sequence subtransient impedance, i.e.

$$Z_2 \simeq jX_d'' \longrightarrow (39)$$

⇒ In a synchronous machine, no zero sequence voltage is induced. zero sequence impedance of the machine is due to the flow of zero-sequence current. The flow of zero sequence currents creates three mmfs which are in time phase but are distributed in space phase by 120°

⇒ Therefore, resultant airgap flux would be zero and there is no reactance due to armature reaction.

⇒ Hence, machine offers a very small reactance due to the leakage flux. Therefore, the rotor windings present leakage reactance only to the flow of zero sequence currents; i.e.

$$Z_0 = jx_l \longrightarrow (40)$$

Sequence Networks of a Loaded Synchronous Machine:-

⇒ Fig.3 shows a synchronous machine with neutral grounded through an impedance Z_n. The machine is supplying balanced three-phase load.

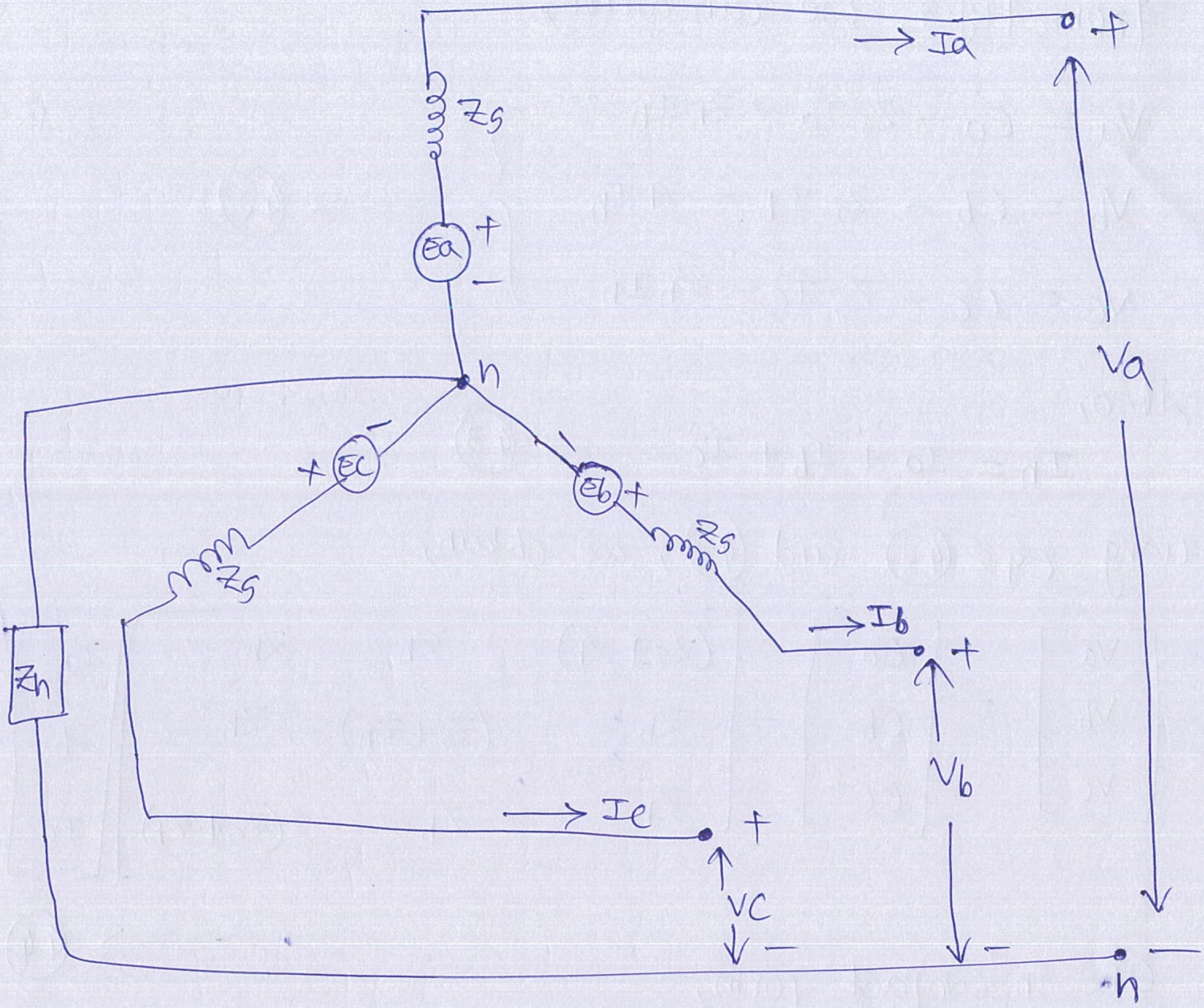


Fig.3: Three phase synchronous machine supplying balanced three phase load.

⇒ Balanced three phase of synchronous machine is represented as a positive-sequence set of phasors, i.e.

$$E_a = E_a \; ; \quad E_b = \beta E_a \; ; \quad E_c = \beta^2 E_a$$

$$\therefore \begin{bmatrix} E_a \\ E_b \\ E_c \end{bmatrix} = \begin{bmatrix} 1 \\ \beta \\ \beta^2 \end{bmatrix} E_a \longrightarrow (41)$$

From Fig. 3, we can write,

$$\left.\begin{aligned} V_a &= E_a - Z_s I_a - Z_n I_n \\ V_b &= E_b - Z_s I_b - Z_n I_n \\ V_c &= E_c - Z_s I_c - Z_n I_n \end{aligned}\right\} \longrightarrow (42)$$

Also,

$$I_n = I_a + I_b + I_c \longrightarrow (43)$$

using eqs (42) and (43), we obtain,

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} E_a \\ E_b \\ E_c \end{bmatrix} - \begin{bmatrix} (Z_s + Z_n) & Z_n & Z_n \\ Z_n & (Z_s + Z_n) & Z_n \\ Z_n & Z_n & (Z_s + Z_n) \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \longrightarrow (44)$$

or in compact form,

$$V_p = E_p - Z_p I_p \longrightarrow (45)$$

where,

$$V_p = \begin{bmatrix} V_a & V_b & V_c \end{bmatrix}^T$$

$$I_p = \begin{bmatrix} I_a & I_b & I_c \end{bmatrix}^T$$

$$E_p = \begin{bmatrix} E_a & E_b & E_c \end{bmatrix}^T$$

$$Z_p = \begin{bmatrix} (Z_s + Z_n) & Z_n & Z_n \\ Z_n & (Z_s + Z_n) & Z_n \\ Z_n & Z_n & (Z_s + Z_n) \end{bmatrix}$$

using eq (12), we can write,

$$V_p = A V_S \longrightarrow (46)$$

$$E_p = A E_S \longrightarrow (47)$$

similarly,

$$I_p = A I_S \longrightarrow (48)$$

where,

$$V_S = [V_{a1} \; V_{a2} \; V_{a0}]^T \; ; \; E_S = [E_{a1} \; E_{a2} \; E_{a0}]^T$$

$$I_S = [I_{a1} \; I_{a2} \; I_{a0}]^T$$

$$A = \begin{bmatrix} 1 & 1 & 1 \\ \beta^2 & \beta & 1 \\ \beta & \beta^2 & 1 \end{bmatrix}$$

Substituting expressions of V_p, E_p and I_p from eqs (46), (47) and (48) respectively into eqs (45), we get,

$$A V_S = A E_S - Z_p \cdot A I_S \longrightarrow (49)$$

Multiplying eq (49) by A^{-1}, we get

$$\therefore V_S = E_S - A^{-1} Z_p A I_S \longrightarrow (50)$$

$$\therefore V_S = E_S - Z_S' I_S \longrightarrow (51)$$

where, $Z_s' = A^{-1} Z_p A \longrightarrow (52)$

$$\therefore Z_s' = \frac{1}{3}\begin{bmatrix} 1 & \beta & \beta^2 \\ 1 & \beta^2 & \beta \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} (Z_s+Z_n) & Z_n & Z_n \\ Z_n & (Z_s+Z_n) & Z_n \\ Z_n & Z_n & (Z_s+Z_n) \end{bmatrix} \begin{bmatrix} 1 & 1 & 1 \\ \beta^2 & \beta & 1 \\ \beta & \beta^2 & 1 \end{bmatrix}$$

$$\therefore Z_s' = \begin{bmatrix} Z_s & 0 & 0 \\ 0 & Z_s & 0 \\ 0 & 0 & (Z_s+3Z_n) \end{bmatrix}$$

$$\therefore \begin{bmatrix} V_{a1} \\ V_{a2} \\ V_{a0} \end{bmatrix} = \begin{bmatrix} E_{a1} \\ E_{a2} \\ E_{a0} \end{bmatrix} - \begin{bmatrix} Z_s & 0 & 0 \\ 0 & Z_s & 0 \\ 0 & 0 & (Z_s+3Z_n) \end{bmatrix} \begin{bmatrix} I_{a1} \\ I_{a2} \\ I_{a0} \end{bmatrix} \longrightarrow (53)$$

Note that $E_{a1} = E_a$; $E_{a2} = E_{a0} = 0$

$$\therefore \begin{bmatrix} V_{a1} \\ V_{a2} \\ V_{a0} \end{bmatrix} = \begin{bmatrix} E_a \\ 0 \\ 0 \end{bmatrix} - \begin{bmatrix} Z_s & 0 & 0 \\ 0 & Z_s & 0 \\ 0 & 0 & (Z_s+3Z_n) \end{bmatrix} \begin{bmatrix} I_{a1} \\ I_{a2} \\ I_{a0} \end{bmatrix} \longrightarrow (54)$$

(or),

$$V_{a1} = E_a - Z_1 I_{a1} \longrightarrow (55)$$

$$V_{a2} = -Z_2 I_{a2} \longrightarrow (56)$$

$$V_{a0} = -Z_0 I_{a0} \longrightarrow (57)$$

where, $Z_1 = Z_s$; $Z_2 = Z_s$ and $Z_0 = (Z_s + 3Z_n)$

⇒ Positive, negative and zero sequence network of synchronous machine is shown in Fig. 4.

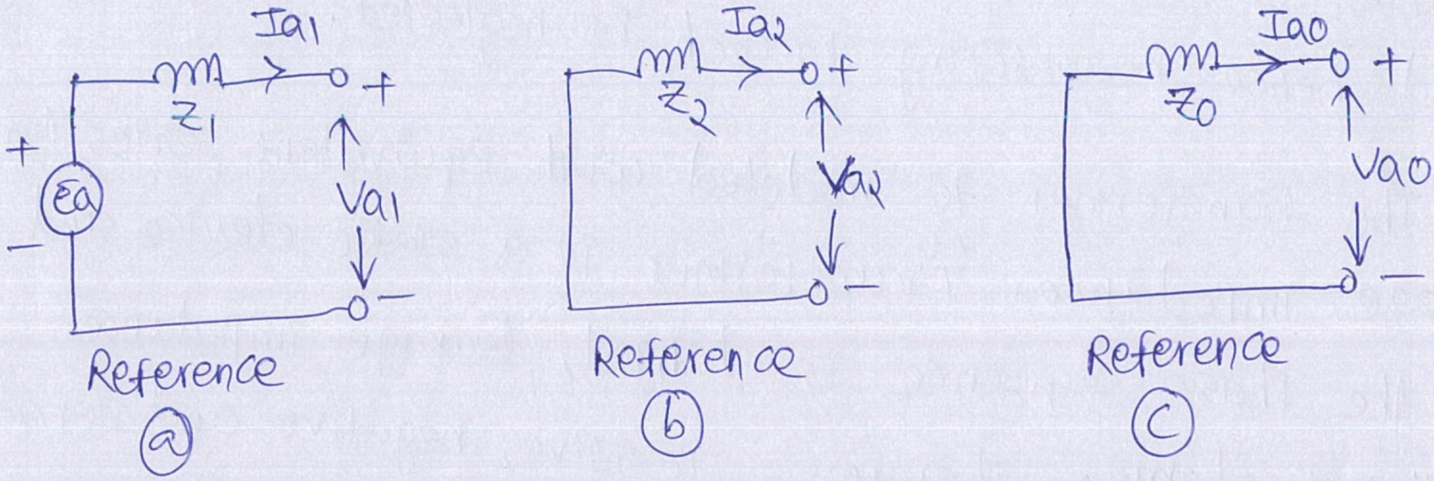


Fig. 4:- (a) Positive sequence network (b) negative sequence network (c) zero sequence network.

⇒ From the above derivations, following observations can be made:

1). The Three sequence networks are independent

2). The neutral of the system is the reference for positive and negative sequence networks but ground is the reference for the zero sequence network.

3). ~~Thee~~ There is no voltage source in the negative or zero-sequence networks. Only the positive sequence network has a voltage source.

4). The grounding impedance is reflected in the zero sequence network as $3Z_n$.

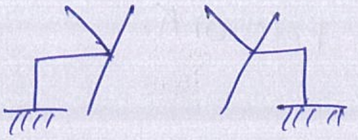
Sequence Impedances of Transformer :-

⇒ In power transformers, the core losses and the magnetizing current are on the order of 1% of rated value and hence magnetizing branch is neglected.

⇒ The transformer is modeled with equivalent series leakage impedance. Transformer is a static device and if the phase sequence is changed, leakage impedance will not change. Therefore, positive, negative and zero-sequence impedances are same and equal to leakage impedance of the transformer, i.e;

$$Z_1 = Z_2 = Z_0 = Z_l \longrightarrow (58)$$

⇒ The equivalent circuit for the zero-sequence impedance depends on the winding connection and also upon whether or not the neutrals are grounded.

(a)  - Connection :-

⇒ Both neutrals are grounded and there is a path for the zero sequence current to flow in the primary and secondary. Fig. 5 (a) gives the equivalent zero-sequence circuit connection.

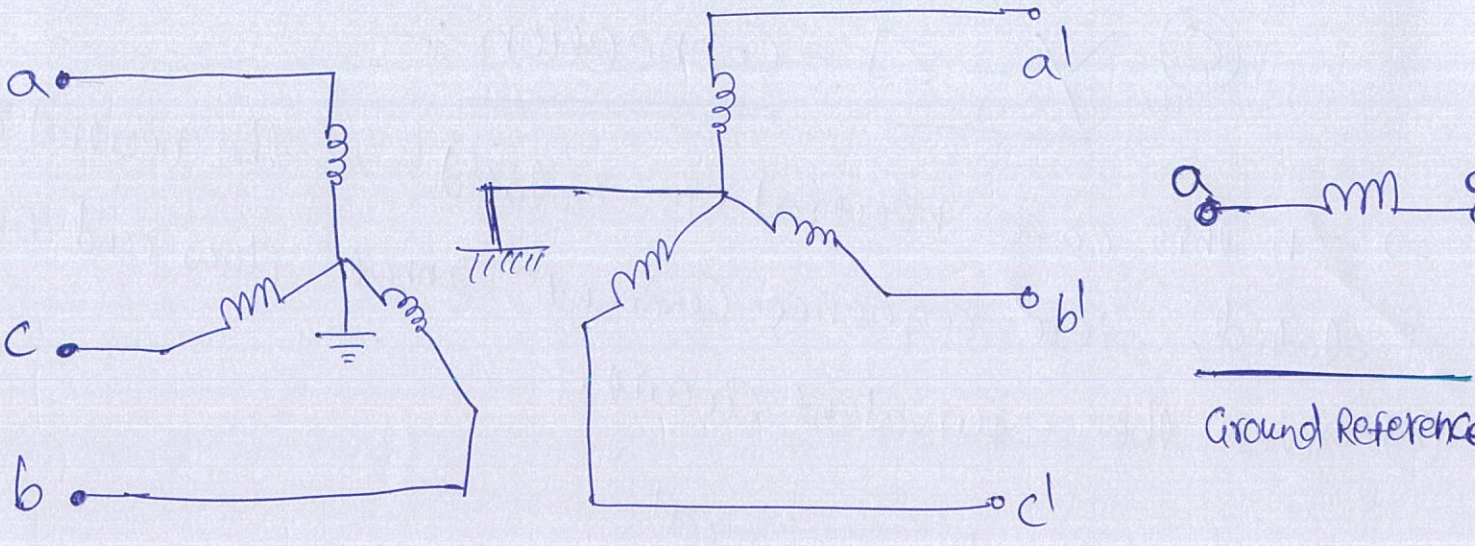


Fig. 5 (a)

(b) Y – Y – Connection :–

⇒ Primary neutral is grounded and secondary neutral is isolated. Zero sequence current in the secondary is zero. Consequently zero sequence current in the primary is zero. Fig. 5 (b) shows the equivalent zero-sequence circuit connection.

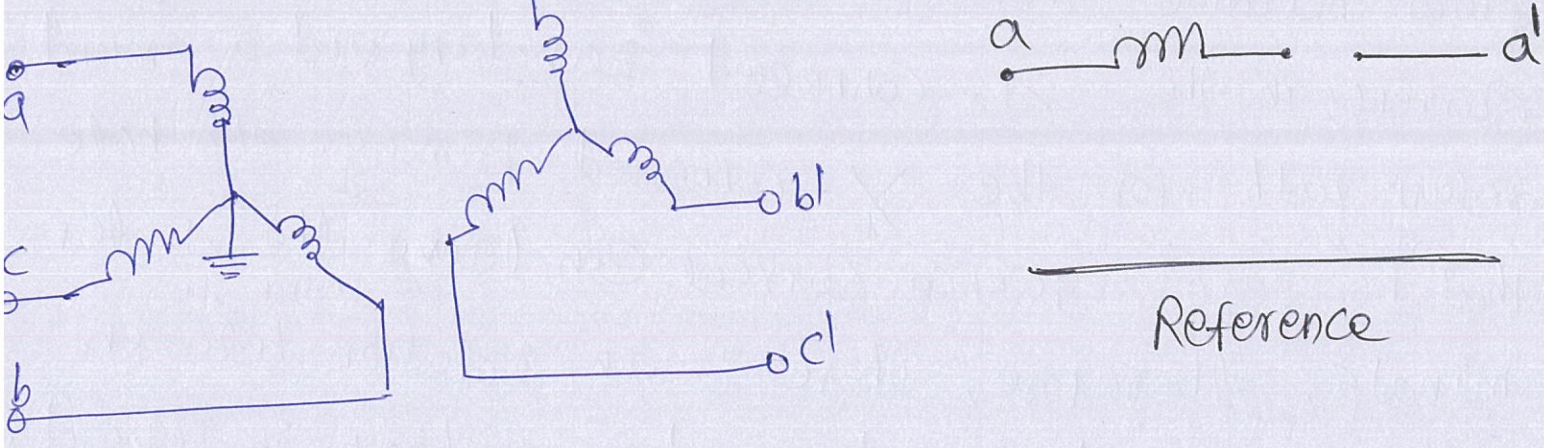


Fig. 5 (b)

(c) Y – Δ – Connection :–

⇒ In this case neutral is isolated. As the neutral is isolated, zero sequence current cannot flow and Fig. 5 (c) gives the equivalent circuit.

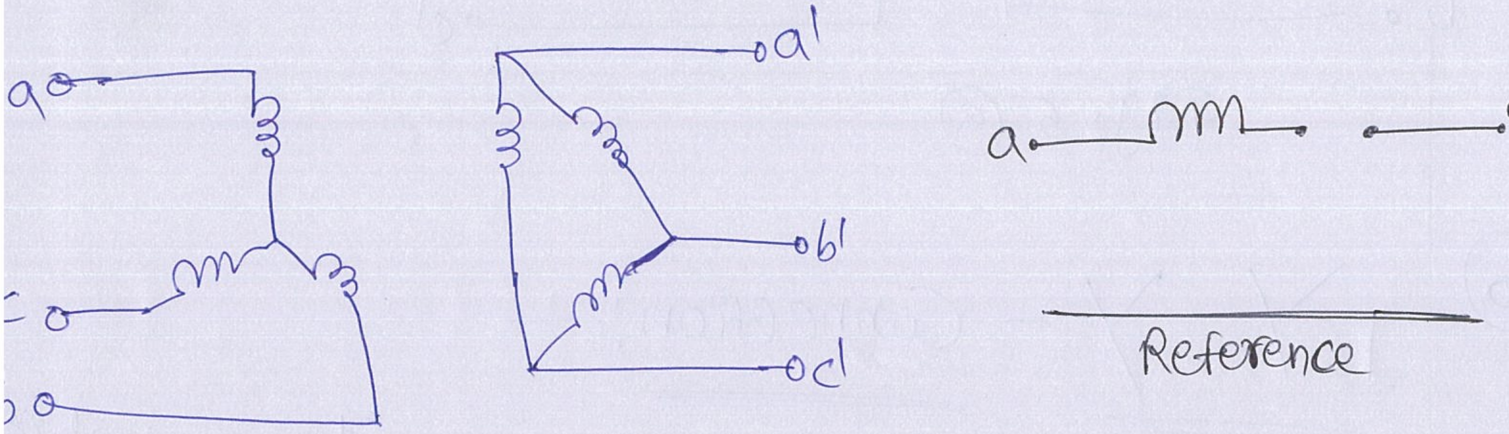
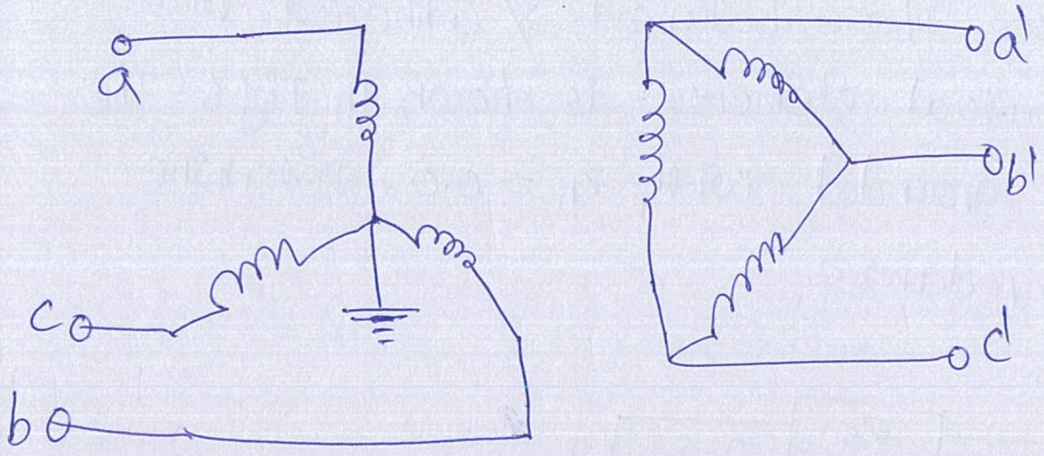
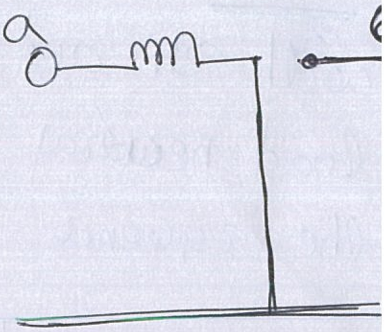


Fig. 5 (c)

(d) Y(grounded) – Δ – Connection :–

⇒ In this case neutral is grounded. Primary current can flow because there is zero sequence circulating current in the Δ – connected secondary and a ground return path for the Y – connected primary. Also note that no zero sequence current can leave the Δ – terminals, therefore, there is an isolation between the primary and secondary side as shown in Fig. 5 (d).



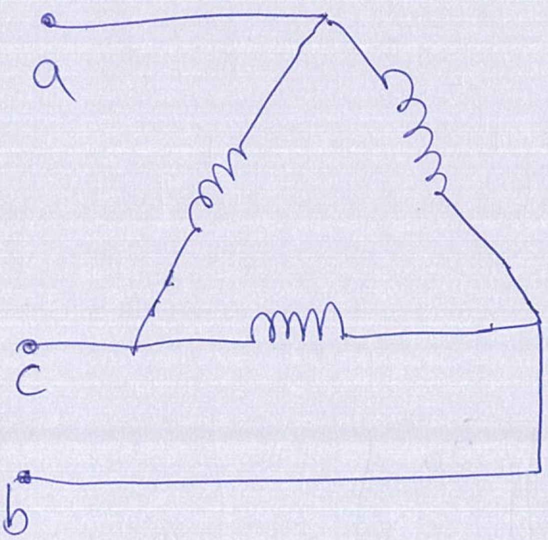


Reference.

Fig. 5 (d)

(e) Δ – Δ – Connection :-

⇒ In this case, zero sequence current circulate in the Δ-connected windings, but no current can leave the Δ-terminals and equivalent circuit is shown in Fig. 5 (e)



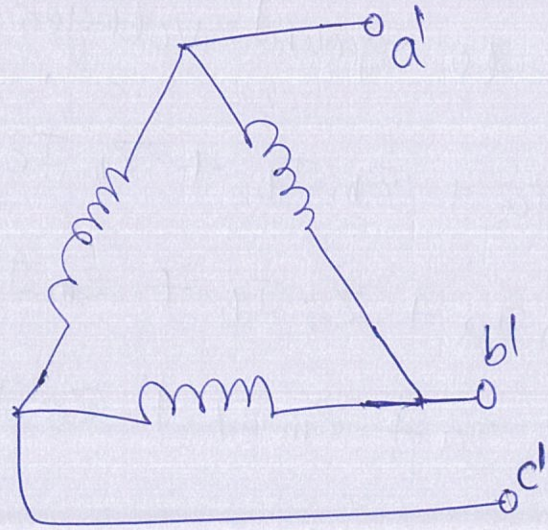
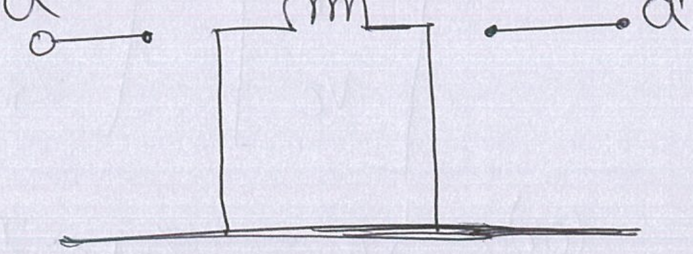


Fig. 5 (e)



Reference

Ex-1):- A Three phase balanced Y connected load with self and mutual elements is shown in Fig.6. The load neutral is grounded with $Z_n = 0.0$. Determine the sequence impedances.

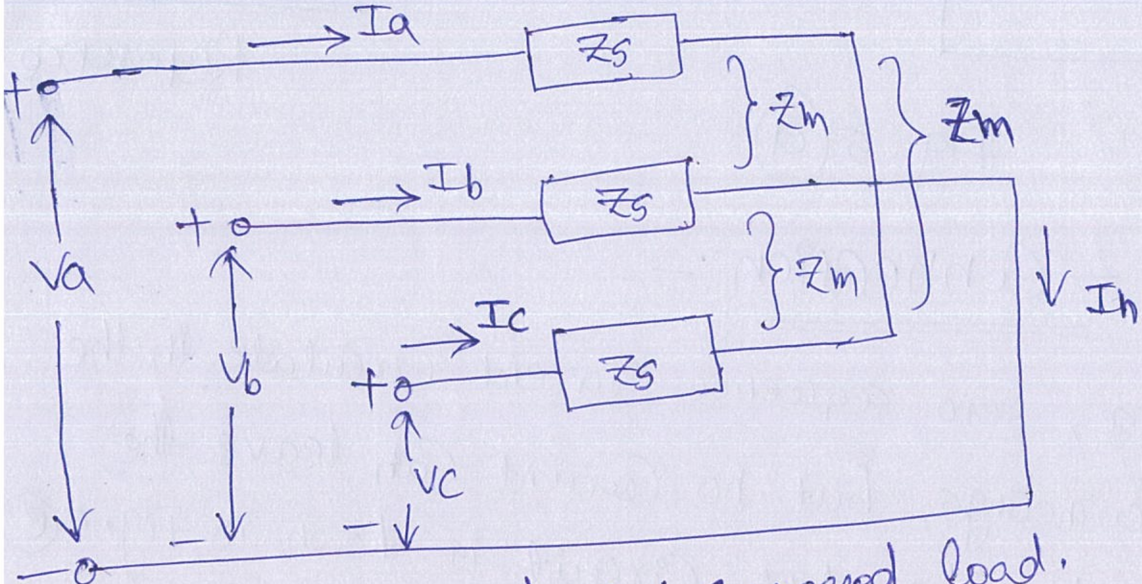


Fig.6: Balanced Y Connected load.

Sol: The line to ground voltages are:

$$V_a = Z_s I_a + Z_m I_b + Z_m I_c$$

$$V_b = Z_m I_a + Z_s I_b + Z_m I_c$$

$$V_c = Z_m I_a + Z_m I_b + Z_s I_c$$

(Or)

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} Z_s & Z_m & Z_m \\ Z_m & Z_s & Z_m \\ Z_m & Z_m & Z_s \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \longrightarrow (i)$$

(Or)

$$V_p = Z_{abc} \cdot I_p \longrightarrow (ii)$$

where,

$$V_p = [V_a \quad V_b \quad V_c]^T$$

$$I_p = [I_a \quad I_b \quad I_c]^T$$

$$Z_{abc} = \begin{bmatrix} Z_s & Z_m & Z_m \\ Z_m & Z_s & Z_m \\ Z_m & Z_m & Z_s \end{bmatrix}$$

using eq (12),

$$V_p = A V_s \longrightarrow \text{(iii)}$$

$$I_p = A I_s \longrightarrow \text{(iv)}$$

Substituting expressions of V_p and I_p in eq (ii)

$$A V_s = Z_{abc} A I_s \longrightarrow \text{(v)}$$

Multiplying eq (v) by A^{-1}, we get

$$\therefore V_s = A^{-1} Z_{abc} A I_s \longrightarrow \text{(vi)}$$

$$\therefore \begin{bmatrix} V_{a1} \\ V_{a2} \\ V_{a0} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & \beta & \beta^2 \\ 1 & \beta^2 & \beta \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} Z_s & Z_m & Z_m \\ Z_m & Z_s & Z_m \\ Z_m & Z_m & Z_s \end{bmatrix} \begin{bmatrix} 1 & 1 & 1 \\ \beta^2 & \beta & 1 \\ \beta & \beta^2 & 1 \end{bmatrix} \begin{bmatrix} I_{a1} \\ I_{a2} \\ I_{a0} \end{bmatrix}$$

$$\therefore \begin{bmatrix} V_{a1} \\ V_{a2} \\ V_{a0} \end{bmatrix} = \begin{bmatrix} Z_s - Z_m & 0 & 0 \\ 0 & Z_s - Z_m & 0 \\ 0 & 0 & Z_s + 2Z_m \end{bmatrix} \begin{bmatrix} I_{a1} \\ I_{a2} \\ I_{a0} \end{bmatrix} \longrightarrow \text{(vii)}$$

Therefore,

$$\left.\begin{aligned} Z_1 &= Z_s - Z_m \\ Z_2 &= Z_s - Z_m \\ Z_0 &= Z_s + 2Z_m \end{aligned}\right\}$$

Ex-2):— A delta connected resistive load is connected across an unbalanced three-phase supply as shown in Fig. 7. Find the symmetrical components of line currents. Also find the symmetrical components of delta currents.

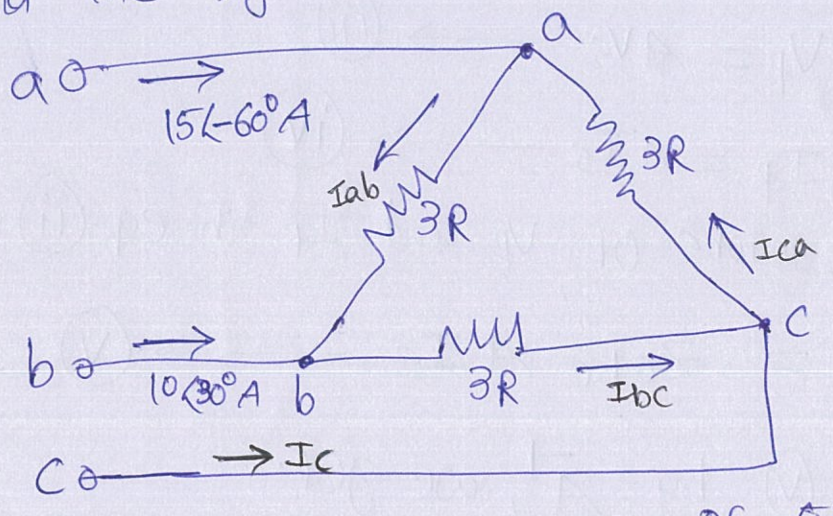


Fig. 7: Circuit connection of Example-2.

Sol^n $I_a + I_b + I_c = 0$

$I_a = 15\angle{-60^\circ}$ Amp ; $I_b = 10\angle 30^\circ$ Amp;

$\therefore 15\angle{-16^\circ} + 10\angle 30^\circ + I_c = 0$

$\therefore I_c = 18\angle 154^\circ$ Amp.

Using eq (24), (25) and (26), we get,

$$I_{a1} = \frac{1}{3}(I_a + \beta I_b + \beta^2 I_c)$$

$$\therefore I_{a1} = \frac{1}{3}\left(15\angle -16^\circ + 10\angle 120^\circ + 30^\circ + 18\angle 154^\circ + 240^\circ\right)$$

$$\therefore I_{a1} = 4.64\angle 8.5^\circ \text{ Amp}$$

$$I_{a2} = \frac{1}{3}\left(I_a + \beta^2 I_b + \beta I_c\right)$$

$$\therefore I_{a2} = \frac{1}{3}\left(15\angle -60^\circ + 10\angle 30^\circ + 240^\circ + 18\angle 154^\circ + 120^\circ\right)$$

$$\therefore I_{a2} = 13.96\angle -77.9^\circ \text{ Amp}$$

$$I_{a0} = \frac{1}{3}\left(I_a + I_b + I_c\right)$$

$$\therefore I_{a0} = 0 \text{ Amp.}$$

$$I_{b1} = \beta^2 I_{a1} = 4.64\angle 248.5^\circ \text{ Amp.}$$

$$I_{b2} = \beta I_{a2} = 13.96\angle 42.1^\circ \text{ Amp}$$

$$I_{b0} = I_{a0} = 0 \text{ Amp.}$$

$$I_{c1} = \beta I_{a1} = 4.64\angle 128.5^\circ \text{ Amp}$$

$$I_{c2} = \beta^2 I_{a2} = 13.96\angle 162.1^\circ \text{ Amp}$$

$$I_{c0} = I_{a0} = 0 \text{ Amp.}$$

Converting Δ-load into equivalent star [Fig. 7 ⓐ], we can write from Fig. 7ⓐ,

$$V_{ab} = R(I_a - I_b)$$

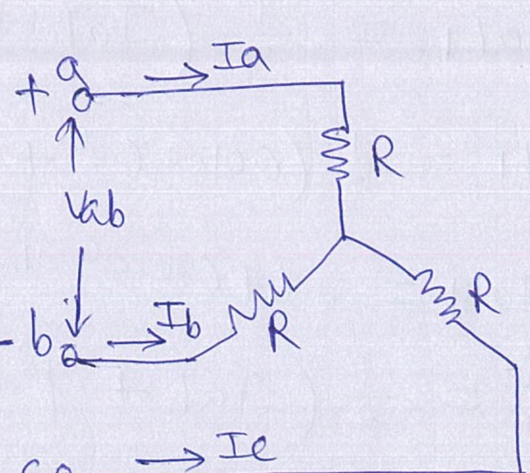


Fig. 7 ⓐ

$$I_{ab} = \frac{V_{ab}}{3R} \quad [\text{From Fig. 7}]$$

$$\therefore I_{ab} = \frac{R(I_a - I_b)}{3R}$$

$$\therefore I_{ab} = \frac{1}{3}(15\angle{-60^\circ} - 10\angle 30^\circ)$$

$$\therefore I_{ab} = 6.01\angle 266.3^\circ \text{ Amp.}$$

Similarly,

$$I_{bc} = \frac{1}{3}(I_b - I_c)$$

$$= \frac{1}{3}(10\angle 30^\circ - 18\angle 154^\circ)$$

$$\therefore I_{bc} = 8.33\angle{-6.64^\circ} \text{ Amp.}$$

$$I_{ca} = \frac{1}{3}(I_a - I_a)$$

$$= \frac{1}{3}(18\angle 154^\circ - 15\angle{-60^\circ})$$

$$\therefore I_{ca} = 10.52\angle 138.6^\circ \text{ Amp.}$$

Symmetrical components of delta currents are

$$I_{ab1} = \frac{1}{3}(I_{ab} + \beta I_{bc} + \beta^2 I_{ca})$$

$$\therefore I_{ab1} = \frac{1}{3}(6.01\angle 266.3^\circ + 8.33\angle 120^\circ - 6.64^\circ + 10.52\angle 378.6^\circ)$$

$$\therefore I_{ab1} = 2.67\angle 38.5^\circ \text{ Amp.}$$

$$I_{ab2} = \frac{1}{3}(I_{ab} + \beta^2 I_{bc} + \beta I_{ca})$$

$$\therefore I_{ab2} = 8.06\angle{-107.9^\circ} \text{ Amp.}$$

and

$$I_{ab0} = \frac{1}{3}\left(I_{ab} + I_{bc} + I_{ca}\right)$$

$$\therefore I_{ab0} = 0.0$$

Also note that $I_{ab1} = \frac{I_{a1}}{\sqrt{3}} \angle 30^0$

$$I_{ab2} = \frac{I_{a2}}{\sqrt{3}} \angle -30^0$$

Ex-3) :— A balanced Δ-Connected load is Connected to a three phase System and supplied to it is a Current of 15 Amp. If the fuse in One of the lines melts, Compute the symmetrical Components of the line Currents.

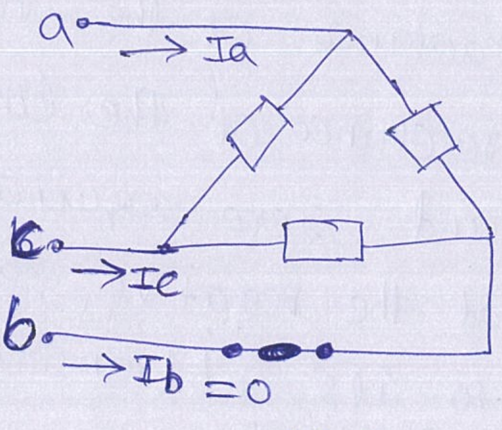


Fig. 8

Sol: $I_a = -I_c$; $I_b = 0$

$I_a = 15\angle 0^0$ Amp; $I_c = 15\angle 180^0$ Amp

$$\therefore I_{a1} = \frac{1}{3}\left(I_a + \beta I_c + \beta^2 I_b\right)$$

$$= \frac{1}{3}\left(15\angle 0^0 + 15\angle 180^0 + 120^0 + 0\right)$$

$$\therefore I_{a1} = (7.5 + j4.33) \text{ Amp.}$$

$$I_{a2} = \frac{1}{3}\left(I_a + \beta^2 I_c + \beta I_b\right)$$

$$\therefore I_{a2} = (7.5 - j4.33) \text{ Amp.}$$

$$I_{a0} = \frac{1}{3}(I_a + I_c + I_b)$$

$$\therefore I_{a0} = 0.0 \text{ Amp.}$$

Ex-4) :- A 50 MVA, 11KV, synchronous generator has a subtransient reactance of 20%. The generator supplies two motors over a transmission line with transformers at both ends as shown in Fig.9. The motors have rated inputs of 30 and 15 MVA, both 10KV, with 25% subtransient reactance. The three phase transformers are both rated 60MVA, 10.8/121 KV, with leakage reactance of 10% each. Assume zero-sequence reactances for the generator and motors of 6% each. Current limiting reactors of 2.5Ω each are connected in the neutral of the generator and motor No.2. The zero sequence reactance of the transmission line is 300Ω. The series reactance of the line is 100Ω. Draw the positive, negative and zero sequence networks.

Assume that the negative sequence reactance of each machine is equal to its subtransient reactance.

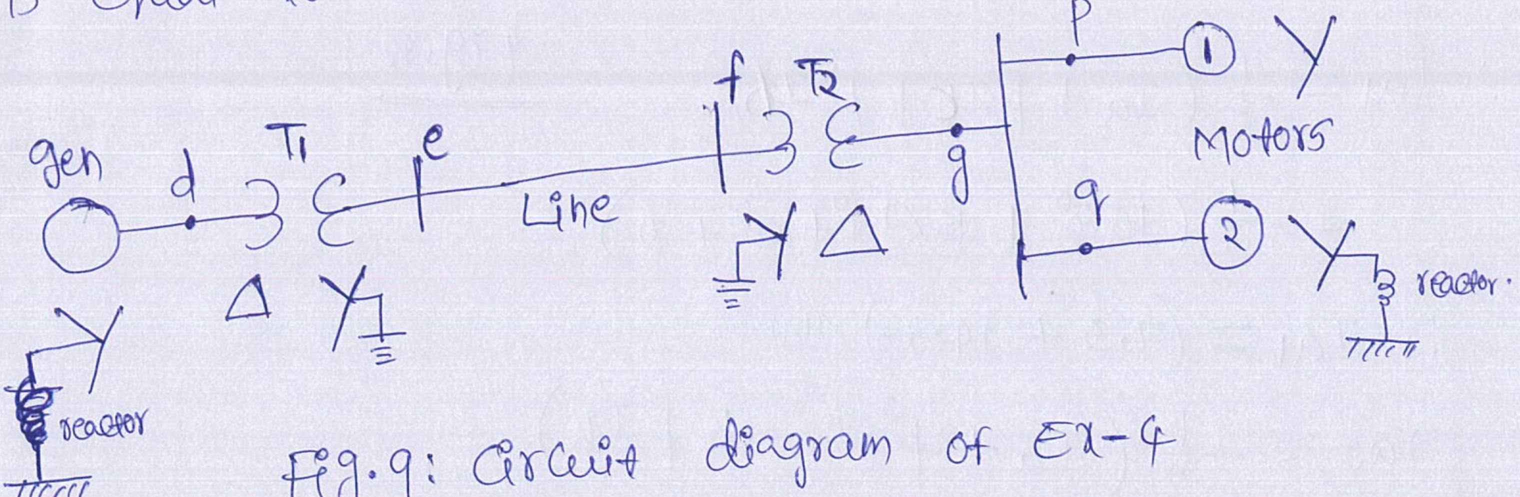


Fig.9: Circuit diagram of Ex-4

Sol: Assume Base power = 50 MVA, Base voltage = 11 KV.

Base voltage of transmission line = $11 \times \frac{121}{10.8} = 123.2$ KV

Motor base voltage $= 123.2 \times \frac{10.8}{121} = 11$ KV.

Transformer reactance

$$X_{T1} = X_{T2} = 0.10 \times \left(\frac{50}{60}\right) \times \left(\frac{10.8}{11}\right)^2 = 0.0805 \text{ pu}$$

Line reactance (positive and negative sequence)

$$= 100 \times \frac{50}{(123.2)^2} \text{ pu} = 0.33 \text{ pu}$$

Line reactance (zero sequence)

$$= \frac{300 \times 50}{(123.2)^2} = 0.99 \text{ pu}$$

Reactance of motor-1 (Positive and negative sequence)

$$= 0.25 \times \left(\frac{10}{11}\right)^2 \times \left(\frac{50}{30}\right) = 0.345 \text{ pu}$$

Zero-sequence reactance of motor-1

$$= 0.06 \times \left(\frac{10}{11}\right)^2 \times \left(\frac{50}{30}\right) = 0.082 \text{ pu}$$

Reactance of Motor-2 (positive and negative sequence)

$$= 0.25 \times \left(\frac{10}{11}\right)^2 \times \left(\frac{50}{15}\right) = 0.69 \text{ pu}$$

Zero sequence reactance of Motor-2

$$= 0.06 \times \left(\frac{10}{11}\right)^2 \times \left(\frac{50}{15}\right) = 0.164 \text{ pu}$$

Reactance Of reactors =

$$= 2.5 \times \frac{50}{(11)^2} = 1.033 \text{ pu.}$$

$$\left[3Z_n = 3 \times 1.033 = 3.10 \text{ pu} \right]$$

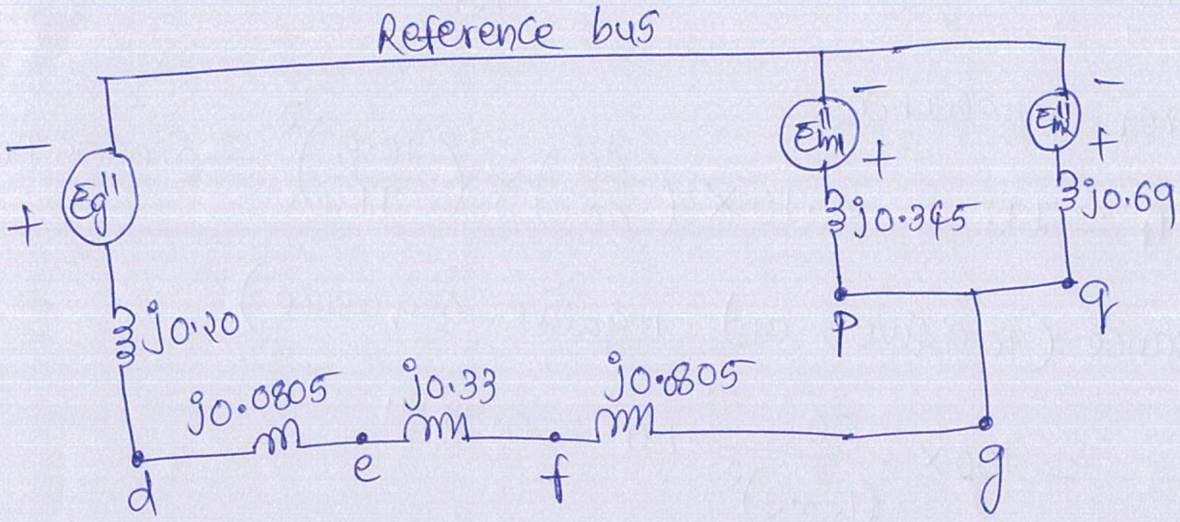


Fig. 10 ⓐ : positive sequence network.

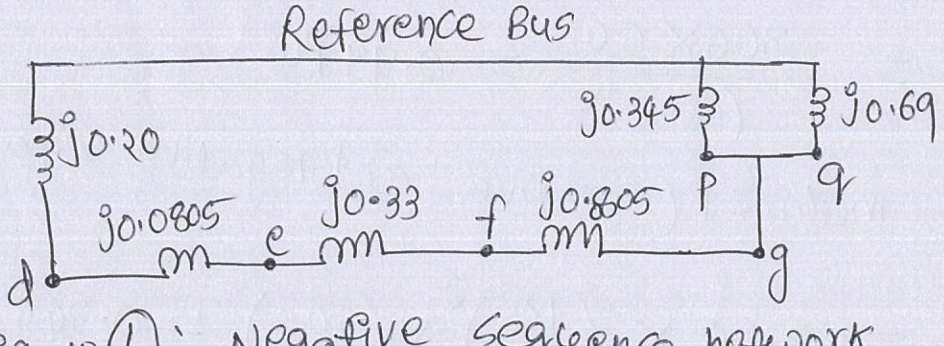


Fig. 10 ⓑ : Negative sequence network

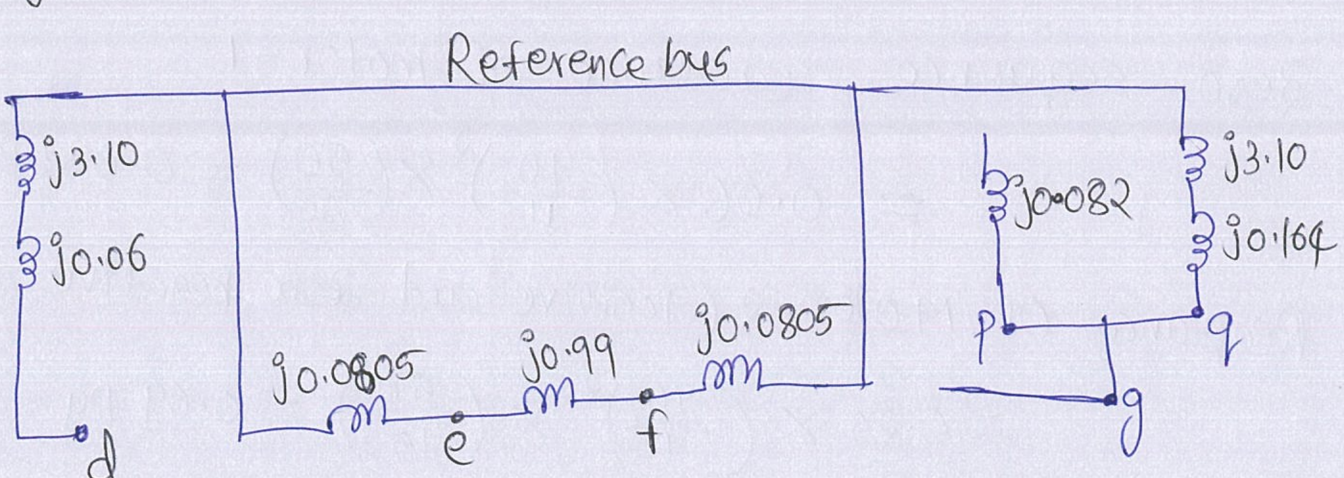


Fig. 10 ⓒ zero-sequence network

Ex-5):— Draw zero sequence network of the power system shown in Fig.11

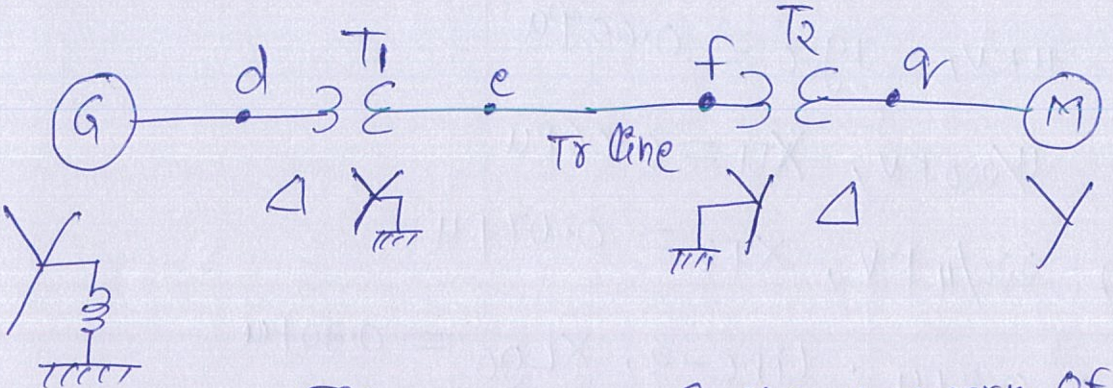


Fig.11 : Power System network of Ex-5

Sol:

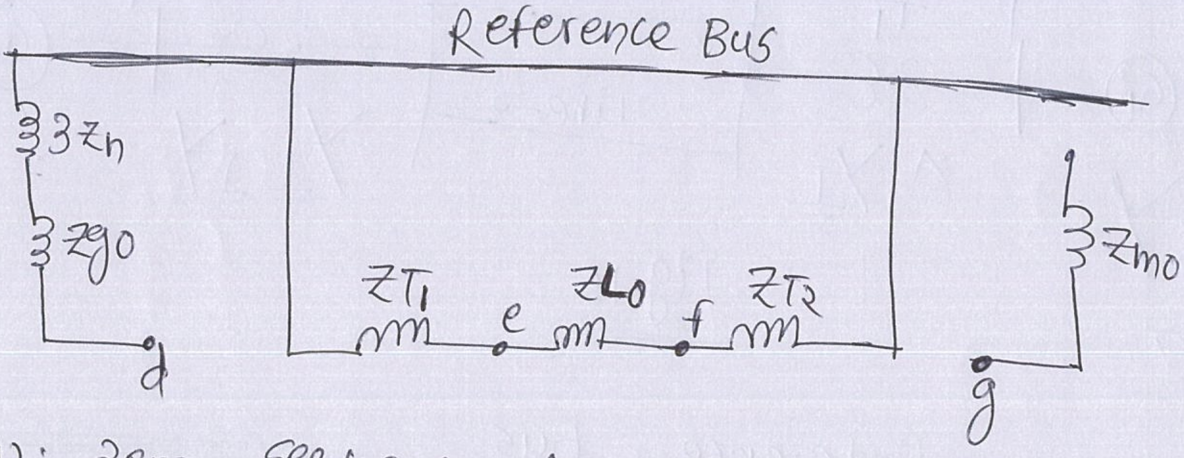


Fig.12: Zero sequence network of Ex-5.

Ex-6):— Draw the zero sequence network of the system shown in Fig.13.

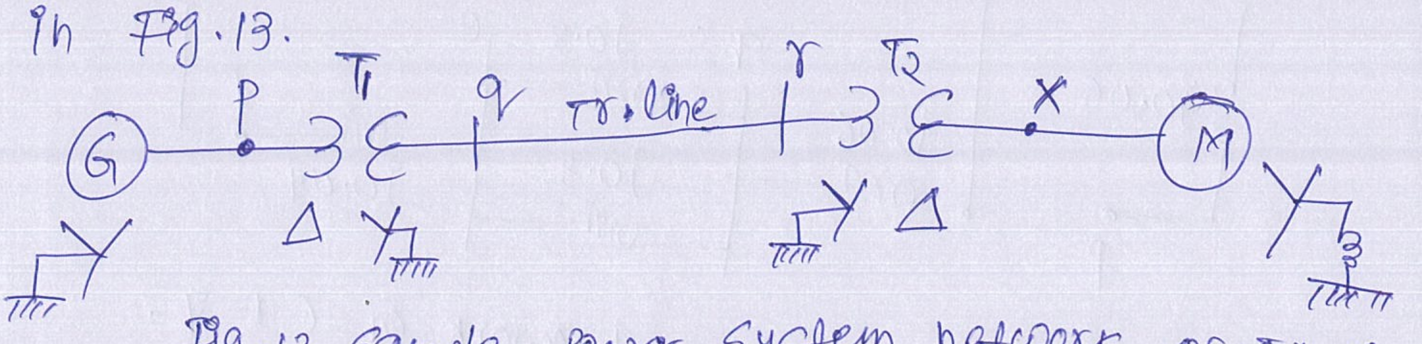


Fig.13 Sample power system network of Ex-6.

Sol:

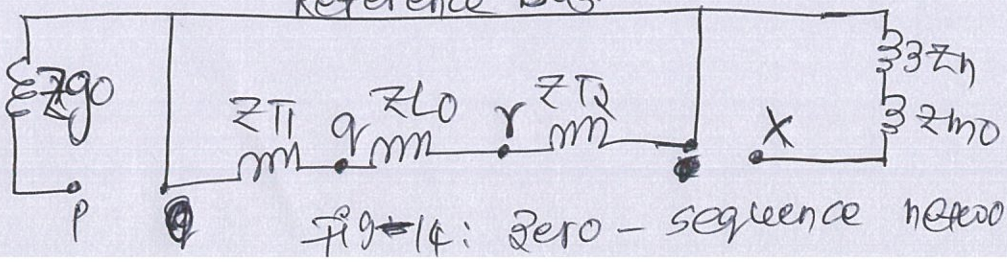


Fig-14: Zero-sequence network of Ex-6.

Ex-7):— Fig. 15 shows a sample power system network. Draw zero sequence network. Data are given below.

G1: 100 MVA, 11 KV, $x_{g10} = 0.05$ pu

G2: 100 MVA, 11 KV, $x_{g20} = 0.05$ pu

T1: 100 MVA, 11/220 KV, $X_{T1} = 0.06$ pu

T2: 100 MVA, 220/11 KV, $X_{T2} = 0.07$ pu

Line-1: $X_{L10} = 0.3$ pu; Line-2, $X_{L20} = 0.30$ pu

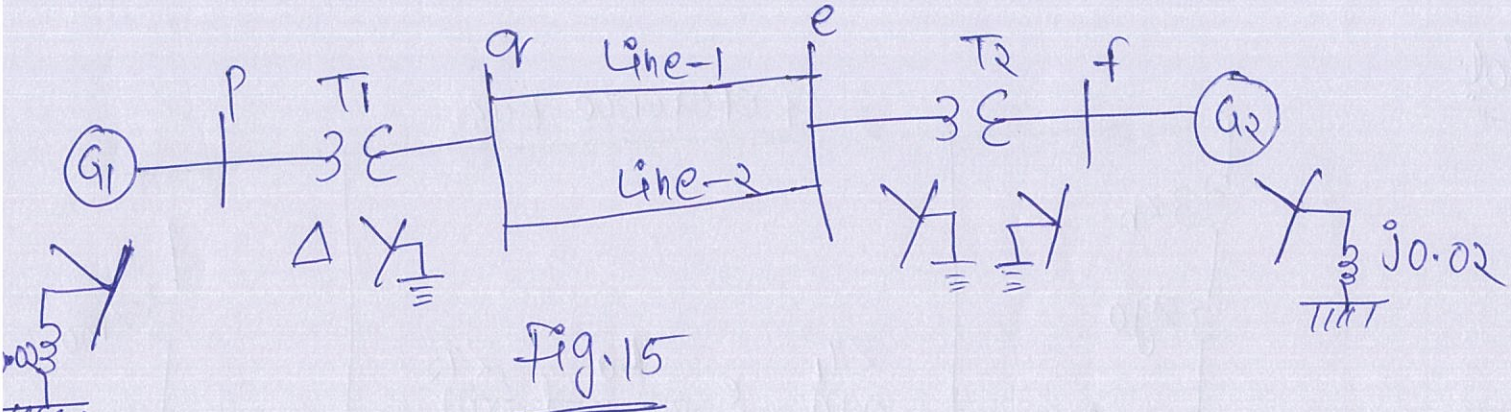


Fig. 15

Sol:

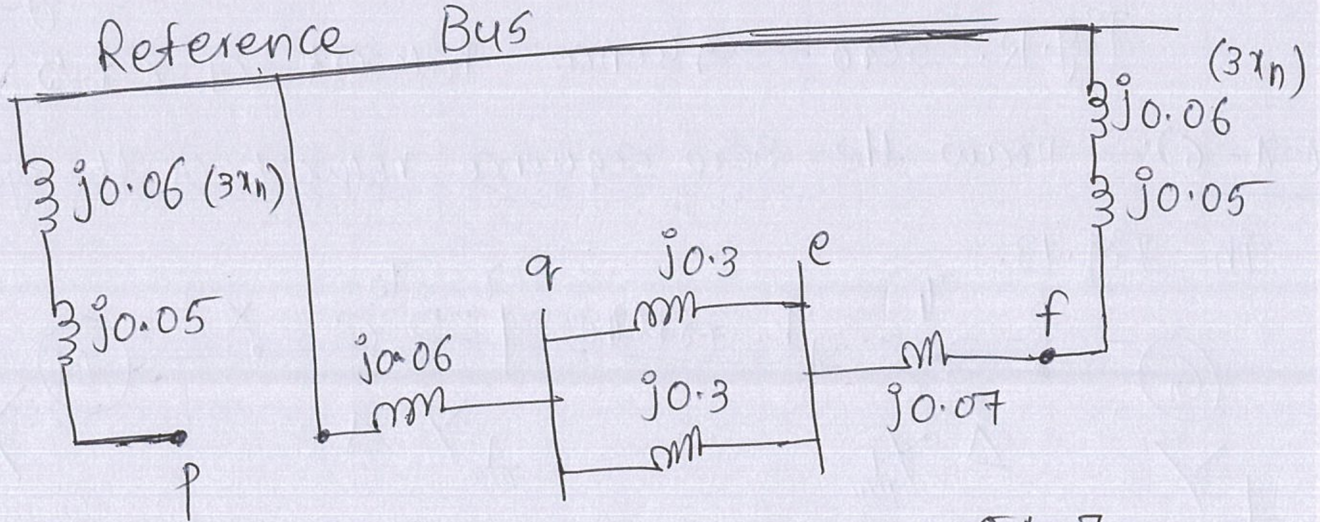


Fig. 16: Zero-sequence network of Ex-7.

Ex-8):— Draw the zero-sequence network of the sample power system shown in Fig. 17. Data are given below.

G : $x_{g0} = 0.05$ pu ; M : $x_{m0} = 0.03$ pu ; T_1 : $x_{T_1} = 0.12$ pu ;

T_2 : $x_{T_2} = 0.10$ pu ; Line-1 : $x_{L10} = x_{L20}$ & Line 2 : $= 0.70$ pu.

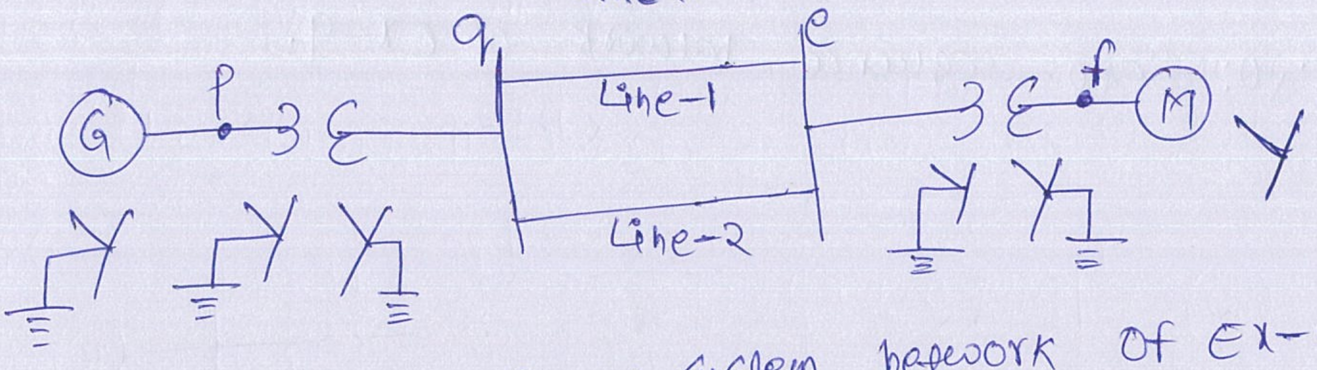


Fig. 17 : Sample power system network of Ex-8.

Soln

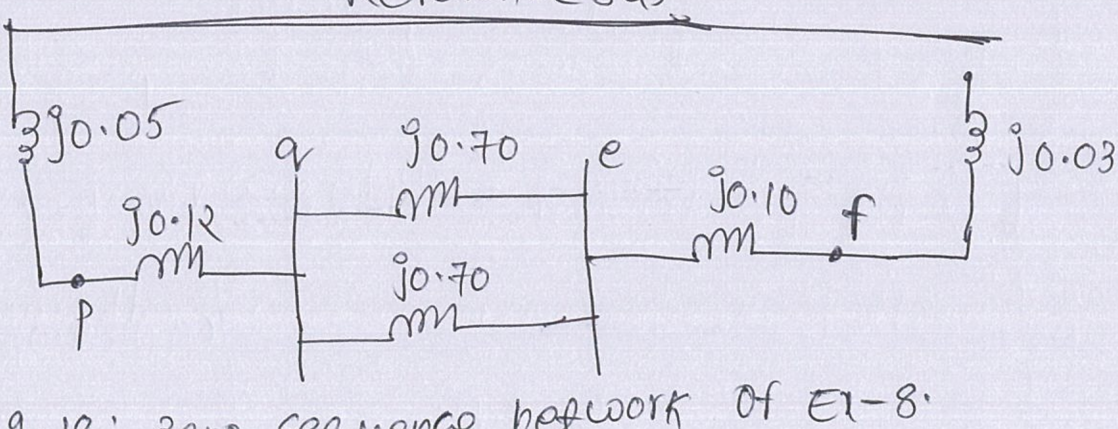


Fig. 18 : Zero sequence network of Ex-8.

Ex-9):— Draw the zero sequence network of the sample power system shown in Fig. 19.

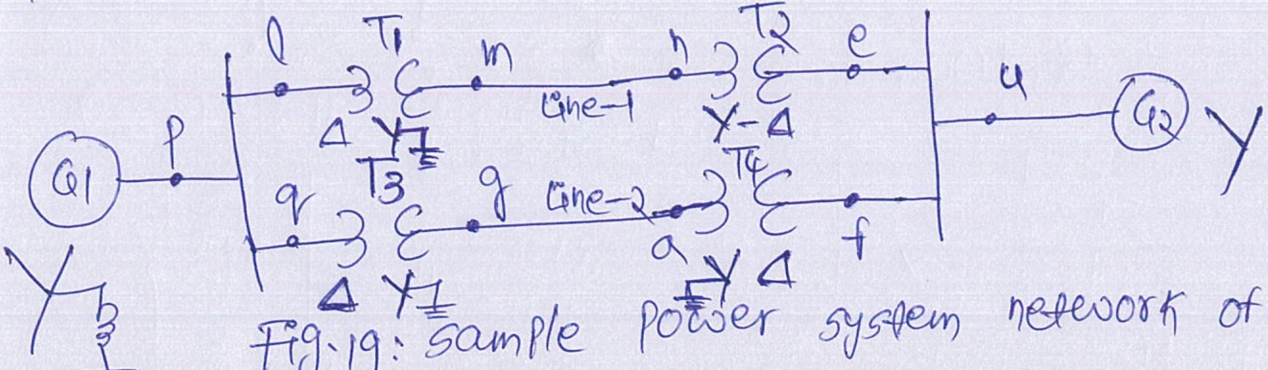


Fig. 19 : Sample power system network of Ex-9

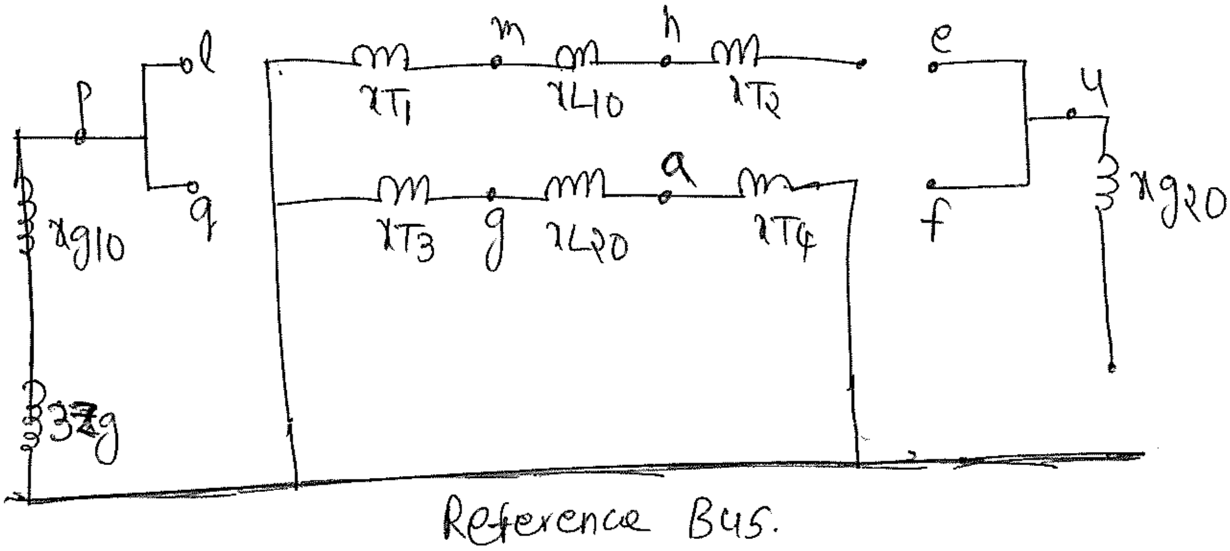


Fig. 20: zero-sequence network of Ex-9.

Unsymmetrical Faults

⇒ Different types of unbalanced faults that occur in a power system are:

ⓐ shunt type faults ⓑ series type faults.

Shunt Faults are of three types:

1) Single Line to ground (L-G) fault.

2) Line to Line (L-L) fault.

3) Double Line to Ground (L-L-G) fault.

Example of series type of fault is open conductor fault

⇒ unbalanced fault analysis is very important for relay setting, single phase switch and system stability studies.

Single Line To Ground Fault :-

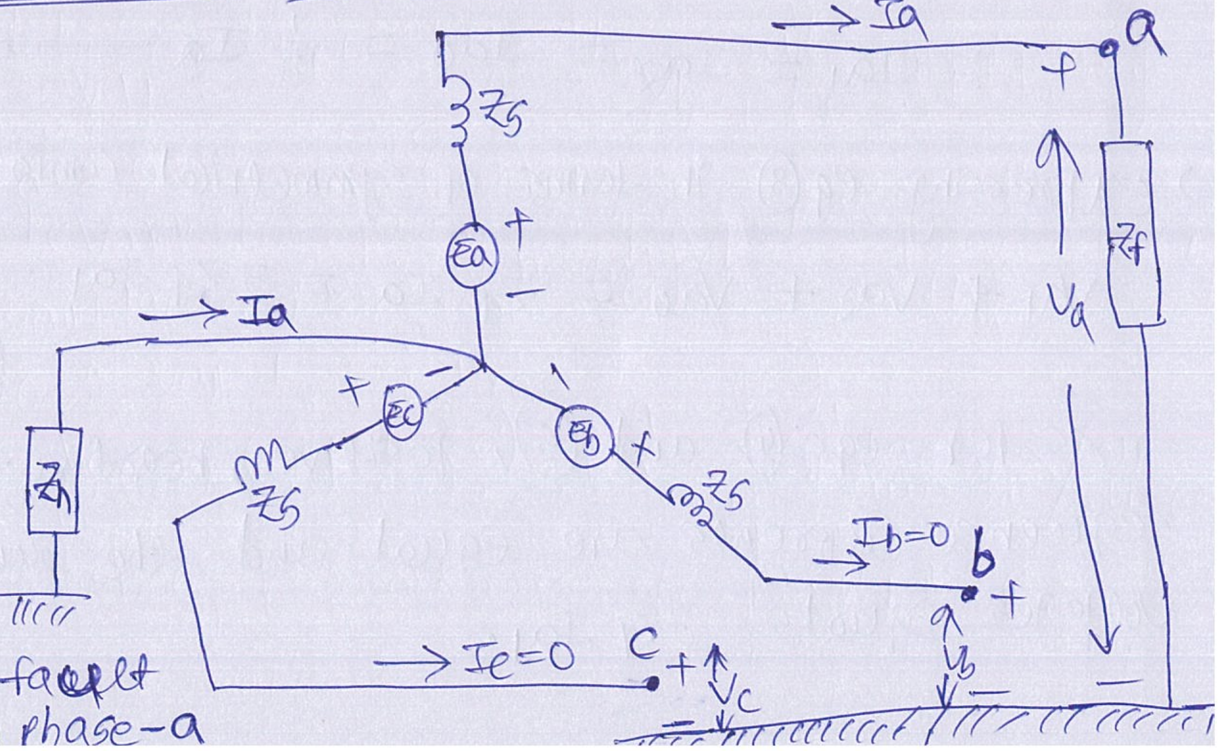


Fig.1: L-G fault on phase-a

⇒ Fig.1 shows a three phase generator with neutral grounded through impedance Z_n.

⇒ Assume that the fault occurs on phase "a" through impedance Z_f.

⇒ Also assuming that the generator is initially on no load and the boundary conditions at the fault point are:

$$I_b = 0 \longrightarrow (1)$$

$$I_c = 0 \longrightarrow (2)$$

$$V_a = Z_f I_a \longrightarrow (3)$$

The symmetrical components of the fault current are:

$$\begin{bmatrix} I_{a1} \\ I_{a2} \\ I_{a0} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & \beta & \beta^2 \\ 1 & \beta^2 & \beta \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} I_a \\ 0 \\ 0 \end{bmatrix}$$

$$\therefore I_{a1} = I_{a2} = I_{a0} = \frac{1}{3} I_a \longrightarrow (4)$$

⇒ Expressing eq (3) in terms of symmetrical component, we get,

$$V_{a1} + V_{a2} + V_{a0} = Z_f I_a = 3 Z_f I_{a1} \longrightarrow (5)$$

$$\left[\because I_{a0} = \frac{1}{3} I_{a1}\right]$$

⇒ As per eqs (4) and (5), positive, negative and zero sequence currents are equal and the sum of sequence voltages equals $3 Z_f I_{a1}$.

⇒ These equations suggest a series connection of sequence networks through an impedance $3Z_f$.

⇒ In many practical applications, the positive and negative sequence impedances are found to be equal, if the generator is solidly grounded $Z_n = 0$ and for bolted faults $Z_f = 0$.

⇒ Fig.2 shows the equivalent circuit connection.

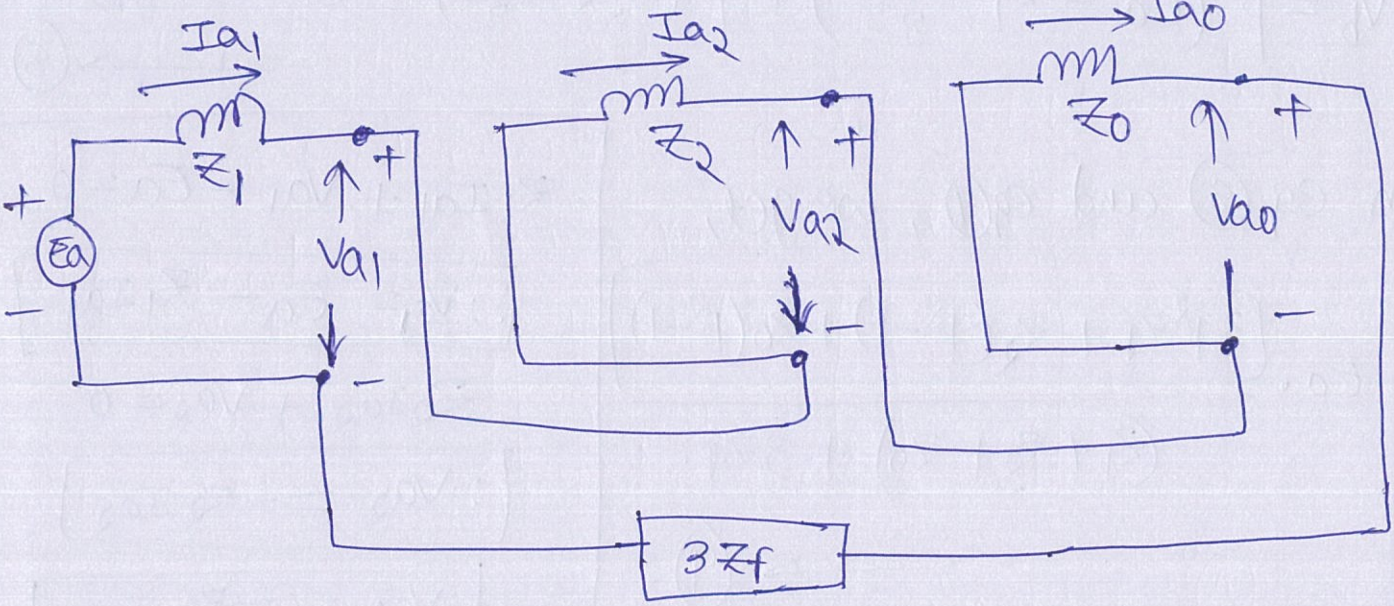


Fig.2: sequence network connection for single line to ground (L−G) fault.

From Fig.2: we can write,

$$I_{a1} = \frac{E_a}{(Z_1 + Z_2 + Z_0) + 3Z_f} \longrightarrow (6)$$

Fault Currents I_a is then given by

$$I_a = 3I_{a1} = \frac{3E_a}{(Z_1+Z_2+Z_0)+3Z_f} \longrightarrow (7)$$

under L-G Fault condition, the voltage of line b to ground is

$$V_b = \beta^2 V_{a1} + \beta V_{a2} + V_{a0}$$

$$\therefore V_b = \beta^2(E_a - Z_1 I_{a1}) + \beta(-Z_2 I_{a2}) + (-Z_0 I_{a0})$$

$$\therefore V_b = \beta^2\left(E_a - Z_1 \cdot \frac{I_a}{3}\right) + \beta\left(-Z_2 \cdot \frac{I_a}{3}\right) + \left(-Z_0 \cdot \frac{I_a}{3}\right) \longrightarrow (8)$$

$$Z_1 I_{a1} + V_{a1} - E_a = 0$$

$$\therefore V_{a1} = E_a - Z_1 I_{a1}$$

$$Z_2 I_{a2} + V_{a2} = 0$$

$$\therefore V_{a2} = -Z_2 I_{a2}$$

$$\therefore V_{a0} = -Z_0 I_{a0}$$

From eq (8) and eq (7), we get,

$$V_b = E_a \cdot \frac{\left[3\beta^2 Z_f + Z_2(\beta^2-\beta) + Z_0(\beta^2-1)\right]}{(Z_1+Z_2+Z_0)+3Z_f} \longrightarrow (9)$$

similarly,

$$V_c = \beta V_{a1} + \beta^2 V_{a2} + V_{a0}$$

$$\therefore V_c = \beta\left(E_a - Z_1 \cdot \frac{I_a}{3}\right) + \beta^2\left(-Z_2 \cdot \frac{I_a}{3}\right) + \left(-Z_0 \cdot \frac{I_a}{3}\right) \longrightarrow (10)$$

using eqs (7) and (10), we get,

$$\therefore V_c = E_a \cdot \frac{\left[3\beta Z_f + Z_2(\beta-\beta^2) + Z_0(\beta-1)\right]}{(Z_1+Z_2+Z_0)+3Z_f} \longrightarrow (11)$$

Line to Line (L-L) Fault:-

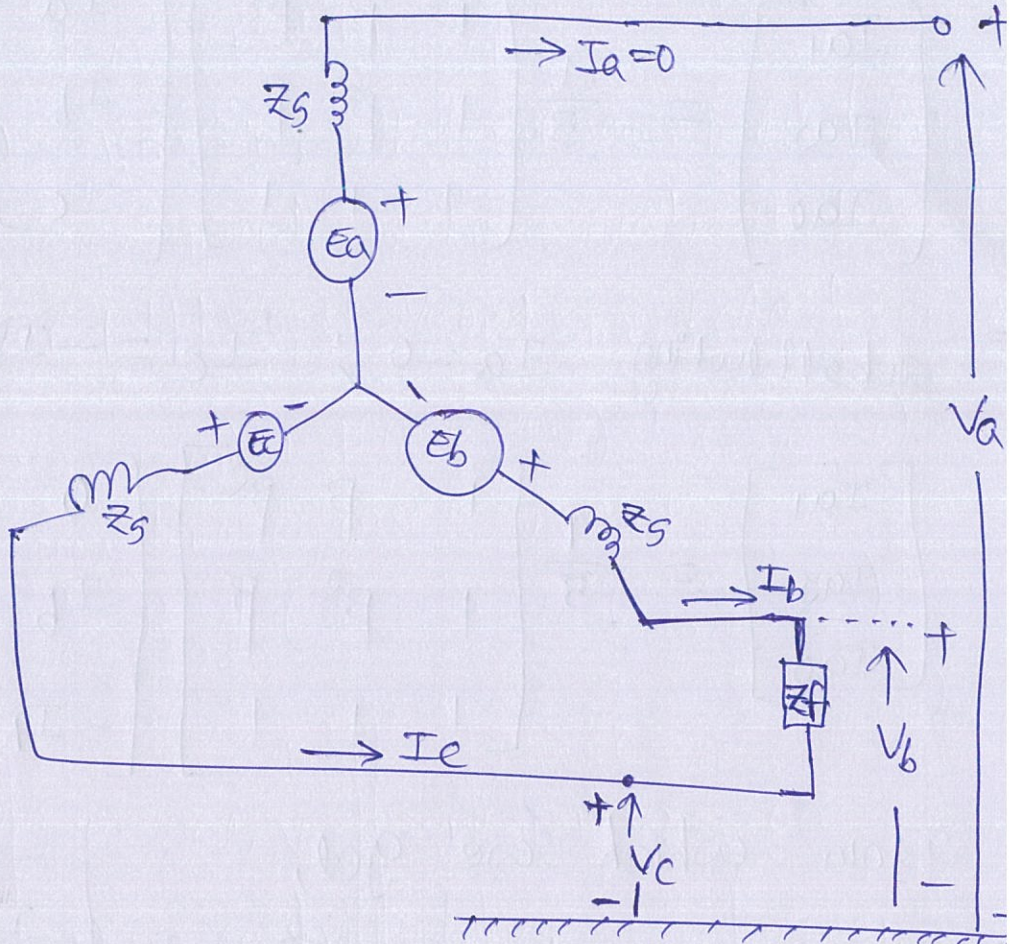


Fig.3: Line to Line Fault Between Phase b and c.

⇒ Fig.3 shows a three synchronous generator with a fault through an impedance Z_f between phase b and c.

It is assumed that the generator is initially on no load condition.

⇒ The boundary conditions at the fault point are:

$$V_b - V_c = Z_f I_b \longrightarrow (12)$$

$$I_b + I_c = 0 \longrightarrow (13)$$

$$I_a = 0 \longrightarrow (14)$$

⇒ The symmetrical components of the fault current are:

$$\begin{bmatrix} I_{a1} \\ I_{a2} \\ I_{a0} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & \beta & \beta^2 \\ 1 & \beta^2 & \beta \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \longrightarrow (15)$$

substituting $I_a = 0$; $I_c = -I_b$ in eq (15), we get

$$\begin{bmatrix} I_{a1} \\ I_{a2} \\ I_{a0} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & \beta & \beta^2 \\ 1 & \beta^2 & \beta \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} 0 \\ I_b \\ -I_b \end{bmatrix} \longrightarrow (16)$$

From which we get,

$$I_{a1} = \frac{1}{3}(\beta - \beta^2) I_b$$

$$I_{a2} = \frac{1}{3}(\beta^2 - \beta) I_b$$

$$\therefore I_{a2} = -\frac{1}{3}(\beta - \beta^2) = -I_{a1}$$

$$I_{a2} = -I_{a1} \longrightarrow (17)$$

$$I_{a0} = 0 \longrightarrow (18)$$

⇒ The symmetrical components of voltages under fault are:

$$\begin{bmatrix} V_{a1} \\ V_{a2} \\ V_{a0} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & \beta & \beta^2 \\ 1 & \beta^2 & \beta \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \longrightarrow (19)$$

substituting $V_c = V_b - Z_f I_b$ in eq (19), we get.

$$\begin{bmatrix} V_{a1} \\ V_{a2} \\ V_{a0} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & \beta & \beta^2 \\ 1 & \beta^2 & \beta \\ 1 & 1 & 1 \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_b - Z_f I_b \end{bmatrix} \longrightarrow (20)$$

From eq (20), we get,

$$3V_{a1} = V_a + (\beta + \beta^2) V_b - \beta^2 Z_f I_b \longrightarrow (21)$$

$$3V_{a2} = V_a + (\beta + \beta^2) V_b - \beta Z_f I_b \longrightarrow (22)$$

Subtracting eq (22) from eq (21), we get,

$$3(V_{a1} - V_{a2}) = (\beta - \beta^2) Z_f I_b \longrightarrow (23)$$

$$\therefore 3(V_{a1} - V_{a2}) = j\sqrt{3}\, Z_f I_b \longrightarrow (24) \quad [\because \beta - \beta^2 = j\sqrt{3}]$$

From eq (16),

$$I_{a1} = \frac{1}{3}(\beta I_b - \beta^2 I_b) = \frac{1}{3}(\beta - \beta^2) I_b$$

$$\therefore I_{a1} = \frac{1}{3} \times j\sqrt{3}\, I_b = \frac{j}{\sqrt{3}} I_b$$

$$\therefore I_b = \frac{\sqrt{3}}{j} I_{a1}$$

$$\therefore I_b = -j\sqrt{3}\, I_{a1} \longrightarrow (25)$$

Using eq (24) and (25), we get,

$$V_{a1} - V_{a2} = Z_f I_{a1} \longrightarrow (26)$$

Eqs (17) and (26) can be represented by connecting the positive and negative sequence networks in opposition and the equivalent circuit is shown in Fig.4.

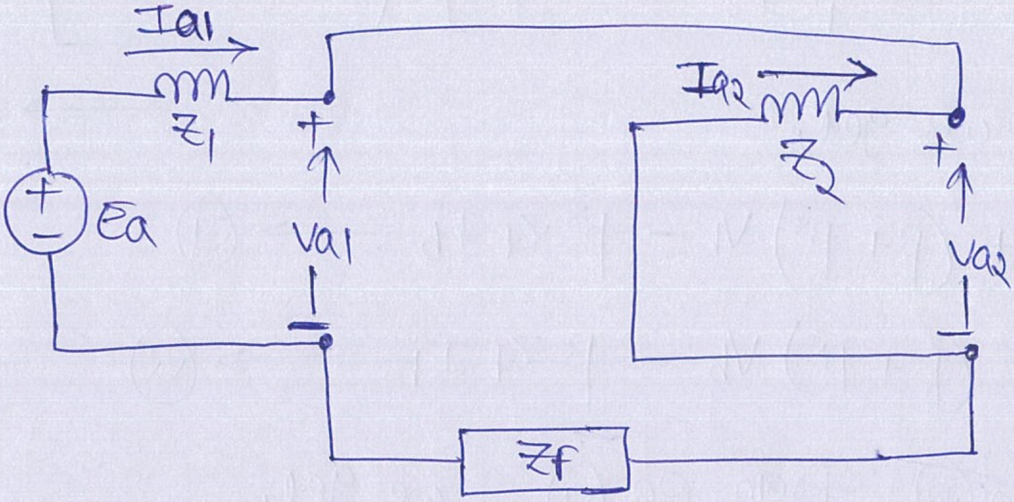


Fig.4: Sequence network connection for L-L fault.

From Fig.4;

$$I_{a1} = \frac{E_a}{(Z_1 + Z_2 + Z_f)} \longrightarrow (27)$$

Also

$$I_b = -I_c = \frac{-j\sqrt{3}\,E_a}{(Z_1 + Z_2 + Z_f)} \longrightarrow (28)$$

Double Line to Ground Fault:-

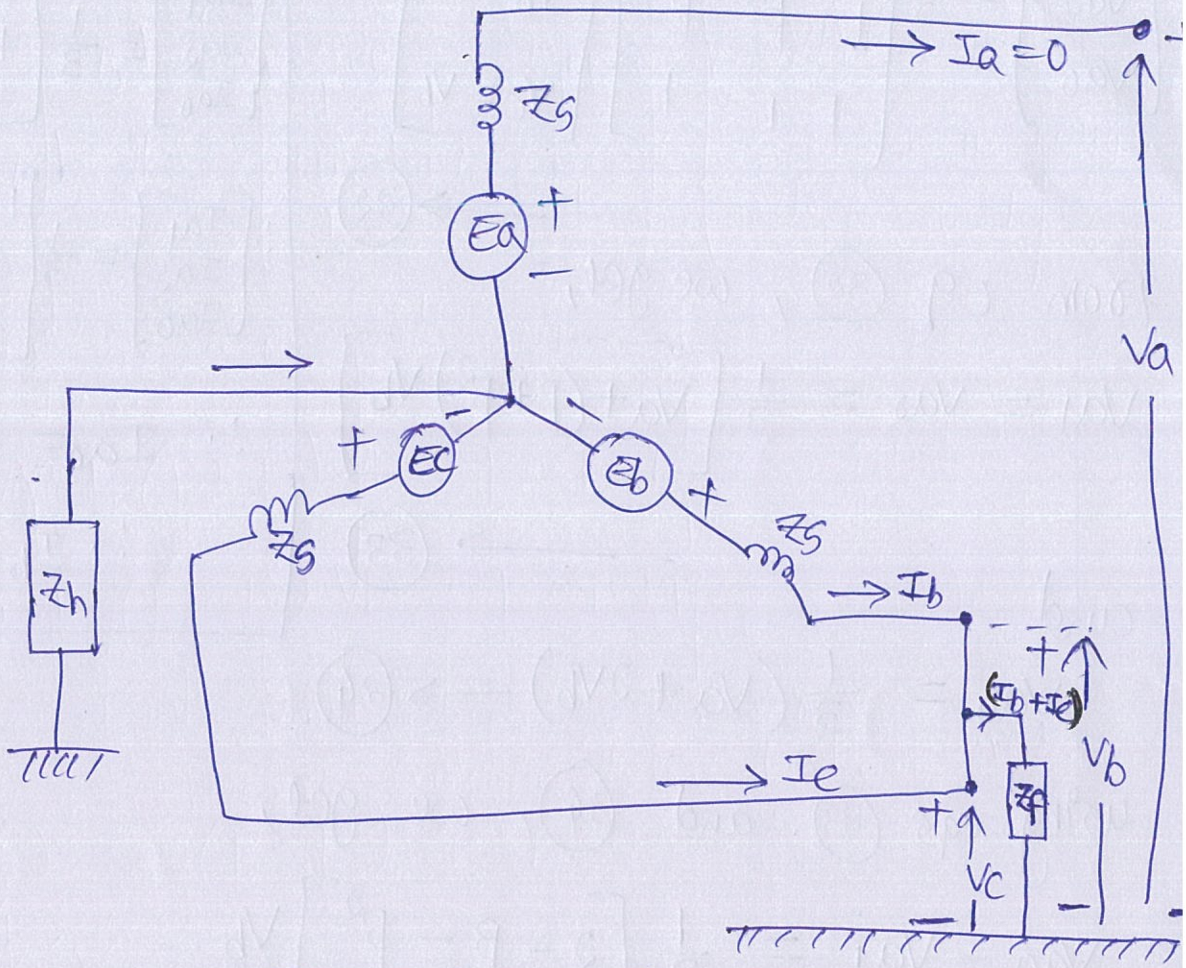


Fig.5: L-L-G Fault

⇒ Fig.5 shows a double line to ground fault.

⇒ The boundary conditions at the fault point are:

$$I_a = 0 \longrightarrow (29)$$

$$\therefore I_{a1} + I_{a2} + I_{a0} = 0 \longrightarrow (30)$$

and

$$V_b = V_c = (I_b + I_c) Z_f = 3 Z_f I_{a0} \longrightarrow (31)$$

The symmetrical components of voltages are given by

$[\therefore I_b + I_c = 3 I_{a0}]$

$$\begin{bmatrix} V_{a1} \\ V_{a2} \\ V_{a0} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & \beta & \beta^2 \\ 1 & \beta^2 & \beta \\ 1 & 1 & 1 \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c = V_b \end{bmatrix} \longrightarrow (32)$$

$$\begin{bmatrix} I_{a1} \\ I_{a2} \\ I_{a0} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & \beta & \beta^2 \\ 1 & \beta^2 & \beta \\ 1 & 1 & 1 \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

$$\therefore \begin{bmatrix} I_{a1} \\ I_{a2} \\ I_{a0} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & \beta & \beta^2 \\ 1 & \beta^2 & \beta \\ 1 & 1 & 1 \end{bmatrix}\begin{bmatrix} 0 \\ I_b \\ I_c \end{bmatrix}$$

$$\therefore I_{a0} = \frac{1}{3}(I_b + I_c)$$

$$\therefore I_b + I_c = 3 I_{a0}$$

From eq (32), we get,

$$V_{a1} = V_{a2} = \frac{1}{3}\left[V_a + (\beta + \beta^2) V_b\right] \longrightarrow (33)$$

and

$$V_{a0} = \frac{1}{3}(V_a + 2V_b) \longrightarrow (34)$$

using eqs (33) and (34), we get,

$$V_{a0} - V_{a1} = \frac{1}{3}\left[2 - \beta - \beta^2\right] V_b$$

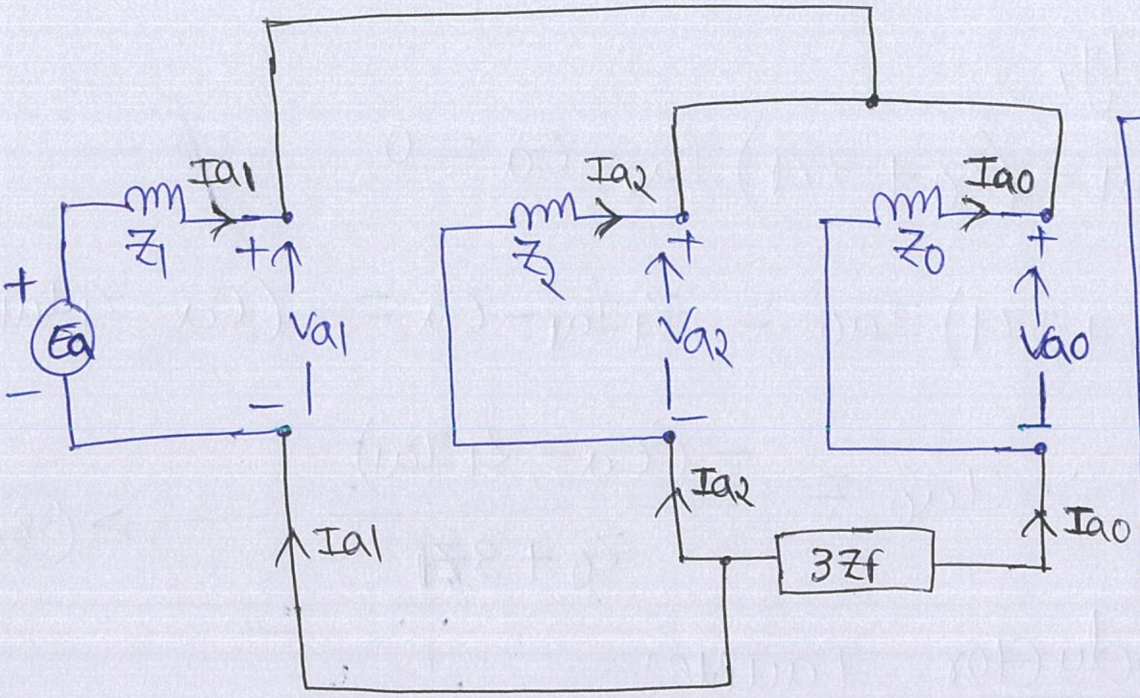
$$\therefore V_{a0} - V_{a1} = \frac{1}{3}\left[3 - (1 + \beta + \beta^2)\right] V_b$$

$$\therefore V_{a0} - V_{a1} = \frac{1}{3} \times 3 V_b = V_b \qquad [\because 1 + \beta + \beta^2 = 0]$$

$$\therefore V_{a0} - V_{a1} = 3 Z_f I_{a0} \qquad [\because V_b = 3 Z_f I_{a0} \text{ from eq (31)}]$$

$$\therefore V_{a0} = V_{a1} + 3 Z_f I_{a0} \longrightarrow (35)$$

From eqs (33), (35) and (30), we can draw the connection of sequence network as shown in Fig. 6.



$V_{a1} = V_{a2} \rightarrow (33)$

$V_{a0} = V_{a1} + 3Z_f I_{a0} \rightarrow (3$

$I_{a1} + I_{a2} + I_{a0} = 0 \rightarrow (30)$

Also

$V_{a0} = V_{a2} + 3Z_f I_{a0}$

Fig.6: Sequence network connection for L-L-G fault

From Fig.6, we can write

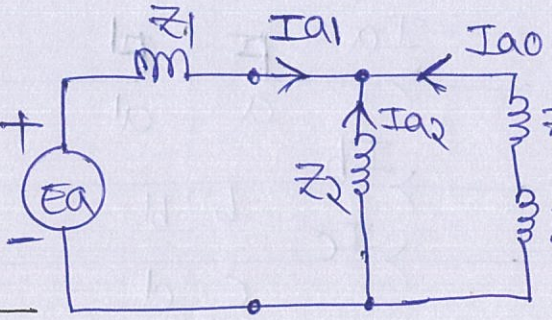


Fig. 6 (a)

$$I_{a1} = \frac{E_a}{\left[Z_1 + \frac{Z_2(Z_0 + 3Z_f)}{(Z_2 + Z_0 + 3Z_f)}\right]} \rightarrow (36)$$

Also,

$$Z_1 I_{a1} - Z_2 I_{a2} - E_a = 0$$

$$\therefore Z_2 I_{a2} = Z_1 I_{a1} - E_a = -(E_a - Z_1 I_{a1})$$

$$\therefore I_{a2} = \frac{-(E_a - Z_1 I_{a1})}{Z_2} \rightarrow (37)$$

Similarly,

$$Z_1 I_{a1} - (Z_0 + 3Z_f) I_{a0} - E_a = 0$$

$$\therefore (Z_0 + 3Z_f) I_{a0} = Z_1 I_{a1} - E_a = -(E_a - Z_1 I_{a1})$$

$$\therefore I_{a0} = \frac{-(E_a - Z_1 I_{a1})}{Z_0 + 3Z_f} \longrightarrow (38)$$

Open Conductor Faults:—

Fig.7 shows transmission line with one conductor open,

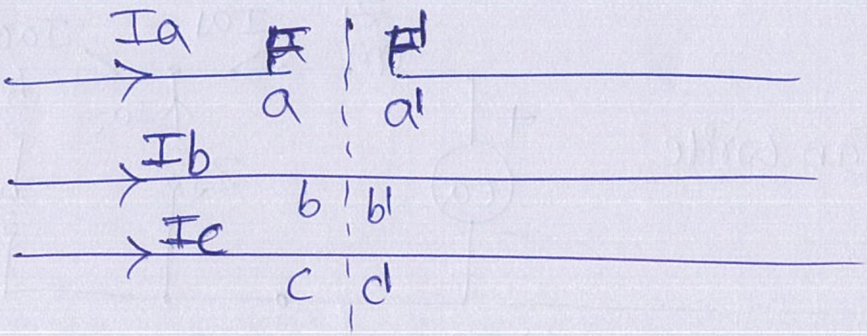


Fig.7: One Conductor Open (Phase – a)

From Fig.7;

$$V_{bb'} = V_{cc'} = 0 \longrightarrow (39)$$

$$I_a = 0 \longrightarrow (40)$$

⇒ In terms of symmetrical components, these conditions can be expressed as:

$$\begin{bmatrix} V_{aa'1} \\ V_{aa'2} \\ V_{aa'0} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & \beta & \beta^2 \\ 1 & \beta^2 & \beta \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} V_{aa'} \\ V_{bb'} \\ V_{cc'} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & \beta & \beta^2 \\ 1 & \beta^2 & \beta \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} V_{aa'} \\ 0 \\ 0 \end{bmatrix}$$

$$\therefore V_{aa'1} = V_{aa'2} = V_{aa'0} = \frac{1}{3} V_{aa'} \longrightarrow (41)$$

and

$$I_{a1} + I_{a2} + I_{a0} = 0 \longrightarrow (42)$$

Eqs (41) and (42) suggest a parallel connection of sequence network as shown in Fig. 8.

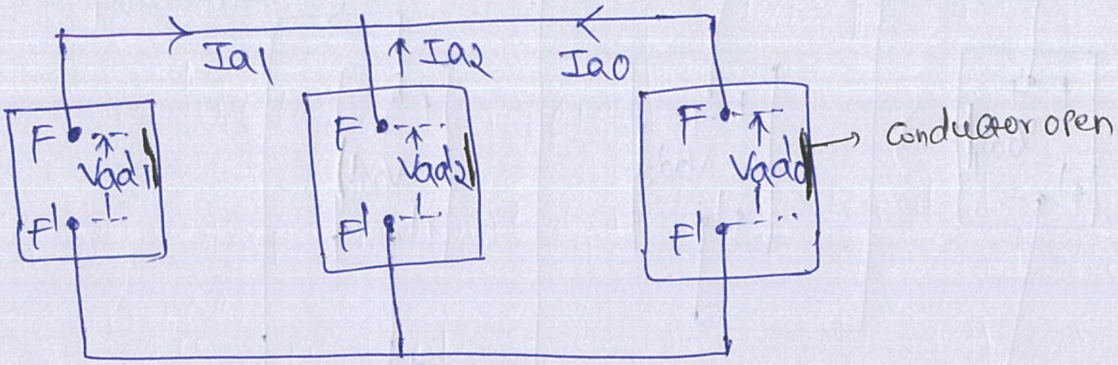


Fig. 8: sequence network for one conductor open.

Two Conductors open:—

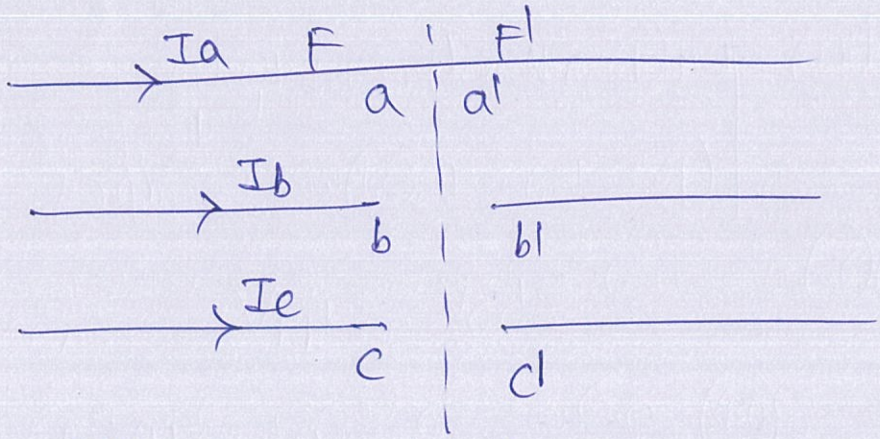


Fig. 9: Two conductors open.

From Fig. 9, we can write

$$V_{aa'} = 0 \longrightarrow (42)$$

$$I_b = I_c = 0 \longrightarrow (43)$$

In terms of symmetrical components, we can write,

$$V_{aa'1} + V_{aa'2} + V_{aa'0} = 0 \longrightarrow (45)$$

and

$$I_{a1} = I_{a2} = I_{a0} = \frac{1}{3} I_a \longrightarrow (46)$$

Eqs (45) and (46) suggest a series connection of sequence network as shown in Fig. 10.

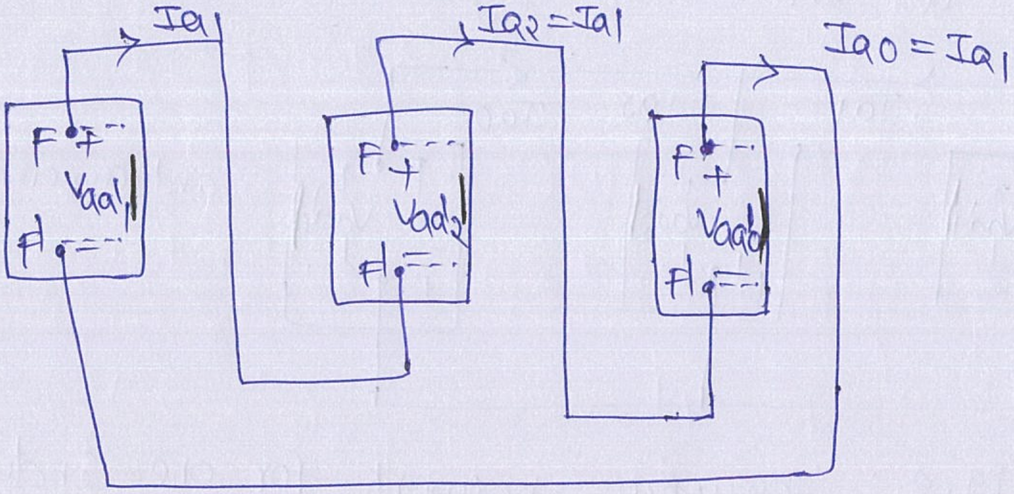


Fig. 10: Sequence network for two conductors open.

Problems

Ex-1) :- Fig.11 shows a sample power system. Before the occurrence of a solid L-G fault at line (g), the motors were loaded. If the prefault current is neglected, calculate the fault current and subtransient currents in all parts of the system.

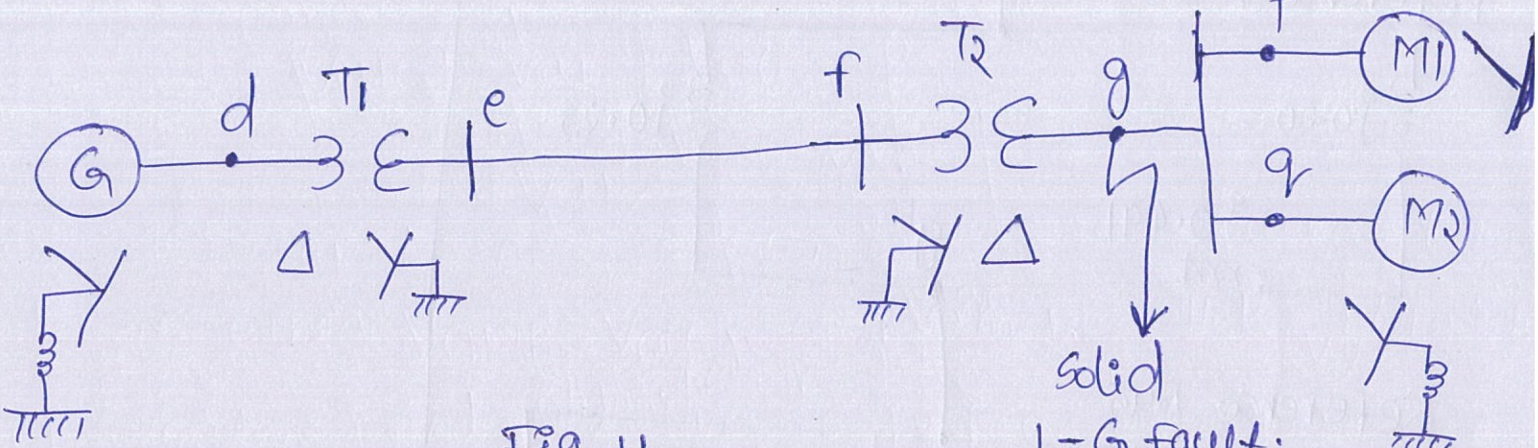


Fig.11

DATA ⇒ same as Ex-4 of the previous topic, symmetrical component.

Sol:- Prefault currents are neglected.

$$E_g'' = E_{m1}'' = E_{m2}'' = V_f^0 = \frac{10}{11} = 0.909 \text{ pu}$$

⇒ Thevenin equivalent of positive sequence network is shown in Fig.13.

$$Z_1 = j\frac{(0.491+0.20)\times 0.23}{(0.491+0.20)+0.23} = j\,0.172 \text{ pu}$$

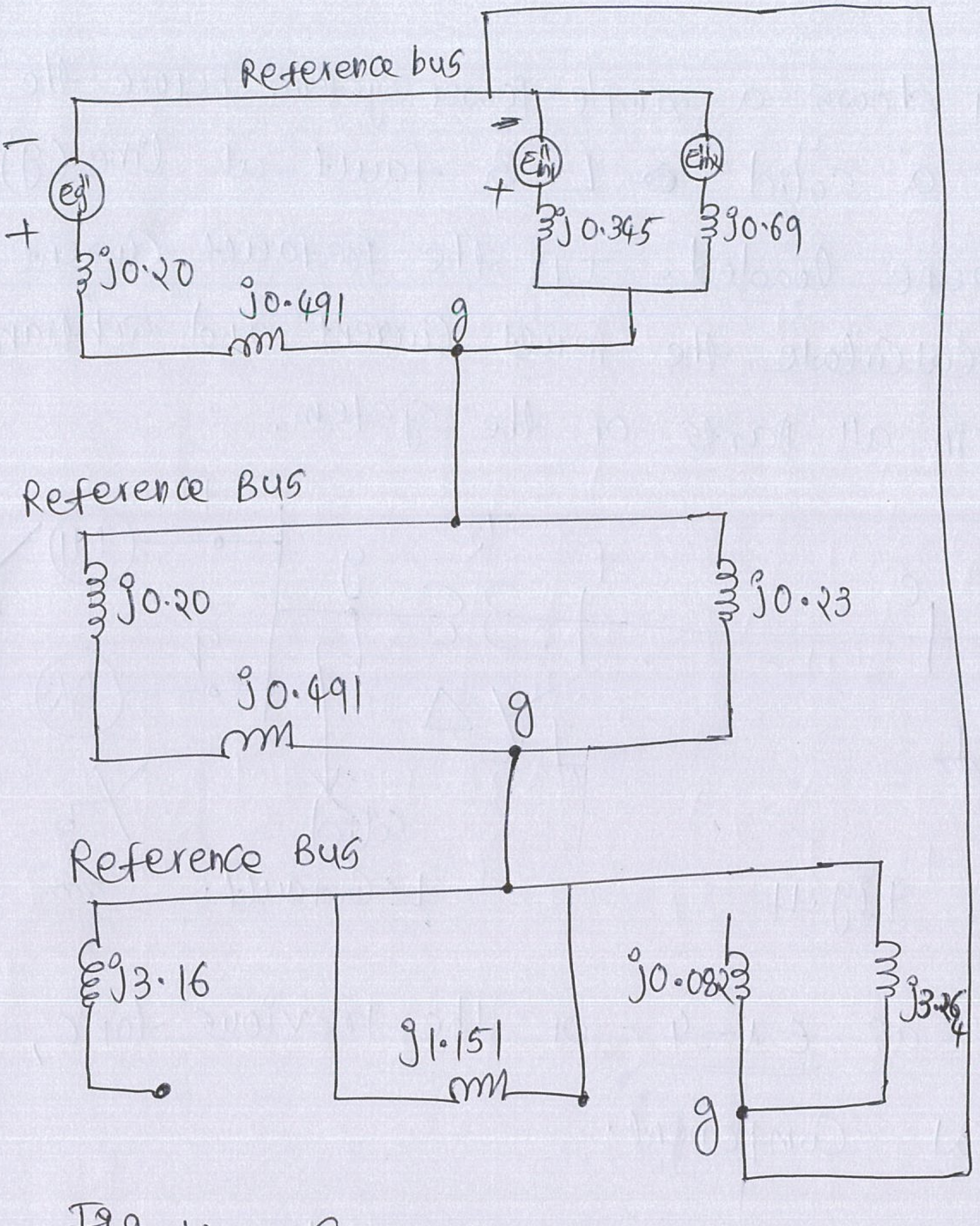


Fig. 12: Connection of the sequence network.

$Z_2 = Z_1 = j0.172$ PU

$Z_0 = j3.264$ PU.

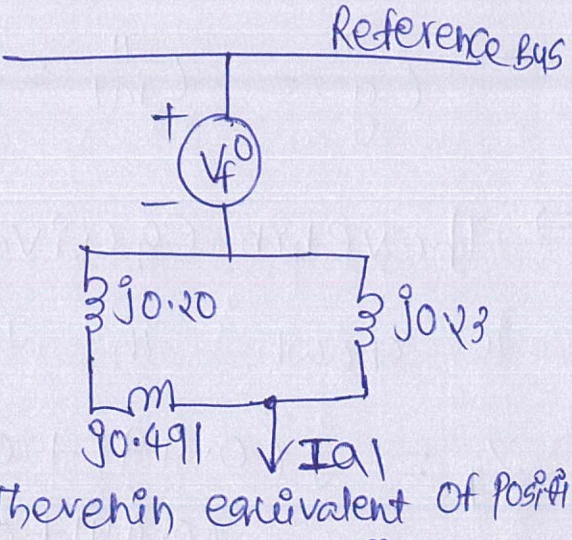
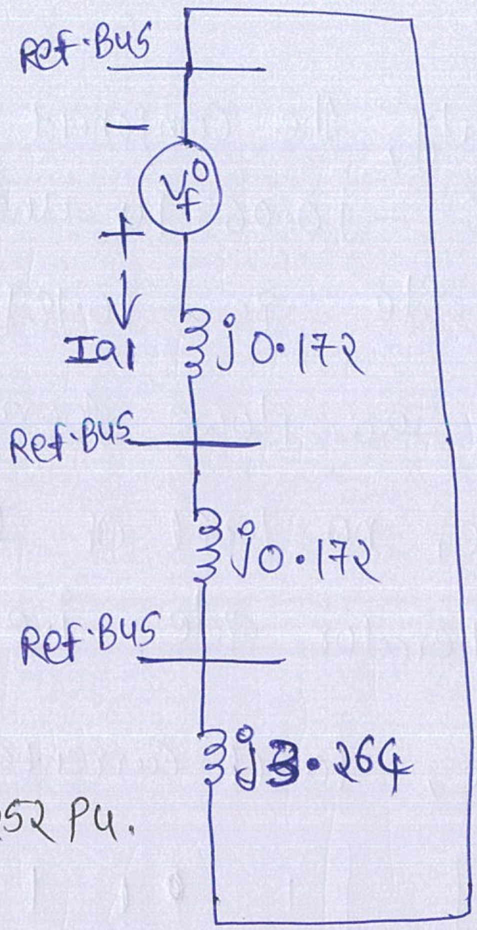


Fig. 13: Thevenin equivalent of positive sequence network of fig. 12.

$$\therefore I_{a1} = \frac{V_f^0}{(Z_1 + Z_2 + Z_0)}$$



$$\therefore I_{a1} = \frac{0.909\angle 0^0}{j(0.172 + 0.172 + 3.264)}$$

$$\therefore I_{a1} = -j0.252 \text{ PU}$$

$$\therefore I_{a1} = I_{a2} = I_{a0} = -j0.252 \text{ PU.}$$

$I_{a1} = I_{a2} = I_{a0}$

Fault Current $= 3 I_{a0}$

$$= 3 \times (-j0.252)$$

$$= -j0.756 \text{ PU.}$$

⇒ The Component of I_{a1} flowing towards 'g' from the generator side.

$$= -j0.252 \times \frac{0.23}{0.921} = -j0.063 \text{ PU}$$

⇒ The Component of I_{a1} flowing towards 'g' from the motor side

$$= -j0.252 \times \frac{0.691}{0.921}$$

$$= -j0.189 \text{ PU.}$$

⇒ Similarly, the component of I_{a2} from generator side is $-j0.063$ pu and its component from the motors side is $-j0.189$ pu.

⇒ All of I_{a0} flows towards "g" from motor-2 side. Therefore, no part of I_{a0} flows towards "g" from the generator side, i.e. 0.0.

Therefore, fault currents from the generator toward "g"

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ \beta^2 & \beta & 1 \\ \beta & \beta^2 & 1 \end{bmatrix} \begin{bmatrix} -j0.063 \\ -j0.063 \\ 0 \end{bmatrix}$$

$\therefore I_a = (-j0.063 - j0.063)$

$I_a = -j0.126$ pu

$\beta^2 + \beta + 1 = 0$

$\therefore \beta^2 + \beta = -1$

$I_b = -j0.063(\beta^2+\beta) = -j(0.063)(-1)$

$\therefore I_b = j0.063$ pu.

$I_c = -j0.063(\beta + \beta^2)$

$\therefore I_c = j0.063$ pu

Fault Current from the motor side.

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ \beta^2 & \beta & 1 \\ \beta & \beta^2 & 1 \end{bmatrix} \begin{bmatrix} -j0.189 \\ -j0.189 \\ -j0.252 \end{bmatrix}$$

$\therefore I_a = (-j0.189 - j0.189 - j0.252)$

$\therefore I_a = -j0.63$ pu.

$I_b = -j0.189(\beta^2 + \beta) - j0.252$

$= -j(0.189)(-1) - j0.252$

$\therefore I_b = -j0.063$ pu

$\therefore I_c = -j0.189(\beta + \beta^2) - j0.252$

$\therefore I_c = -j0.063$ pu.

Ex-(b) :- above problem consider fault at line (c)

Ex-2) :- Two 11 kV, 12 MVA, 3 ϕ, star connected generators operate in parallel (Fig. 13). The positive, negative and zero sequence reactances of each being j0.09, j0.05 and j0.04 pu respectively. A single line to ground fault occurs at the terminals of one of the generators.

Estimate i) the fault Current ii) Current in grounding resistor. iii) voltage across grounding resistor.

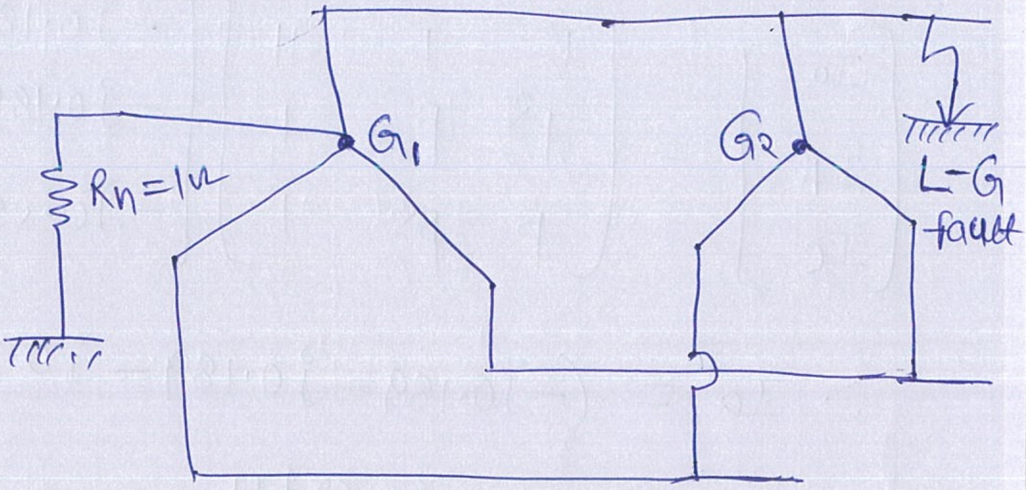


Fig. 13: Circuit Connection of Ex-2

Soln: Two generators operate in parallel.

$$\therefore x_1 = \frac{j0.09}{2} = j0.045 \text{ pu}.$$

$$\therefore x_2 = \frac{j0.05}{2} = j0.025 \text{ pu}.$$

$$Z_0 = j0.04 + 3R_n = j0.04 + \frac{3\times 1}{\left(\frac{(11)^2}{12}\right)}$$

$$Z_0 = (0.297 + j0.04) \text{ pu}$$

(a) Fault Current

$$I_f = I_a = 3I_{a1} = \frac{3E_a}{(x_1 + x_2 + Z_0)} \quad [\because eq(7),\ Z_f = 0]$$

$$\therefore I_f = \frac{3 \times 1\angle 0^\circ}{(j0.045 + j0.025 + 0.297 + j0.04)}$$

$$\therefore I_f = 9.472\angle -20.32^\circ \text{ pu}$$

(b) Current in the grounding resistor,

$$|I_f| = 9.472 \times \frac{12}{\sqrt{3} \times 11} \text{ KA} = 5.96 \text{ KA}$$

(c) Voltage across grounding resistor,

$$= R_n |I_f| = \frac{1}{\left(\frac{(11)^2}{12}\right)} \times 9.472$$

$$= 0.939 \text{ pu}$$

$$= 0.939 \times \frac{11}{\sqrt{3}} = 5.96 \text{ KV}$$

Ex-3):— For example-2, assume that $R_n = 0$, find the fault current in each phase and voltage of the healthy phase for a L-L-G fault on terminals of the generator.

Sol: From eq (36),

$$I_{a1} = \frac{E_a}{Z_1 + \frac{Z_2(Z_0 + 3Z_f)}{(Z_2 + Z_0 + 3Z_f)}}$$

$Z_f = R_n = 0$

$Z_1 = x_1 = j0.045$; $Z_2 = x_2 = j0.025$; $Z_0 = j0.04$ pu

$Z_f = R_n = 0.$

$$\therefore I_{a1} = \frac{1\angle 0^\circ}{j0.045 + \frac{j0.025 \times j0.04}{(j0.025 + j0.04)}}$$

$$\therefore I_{a1} = -j16.56 \text{ pu.}$$

From eq (33),

$$V_{a1} = V_{a2}$$

From eq (35)

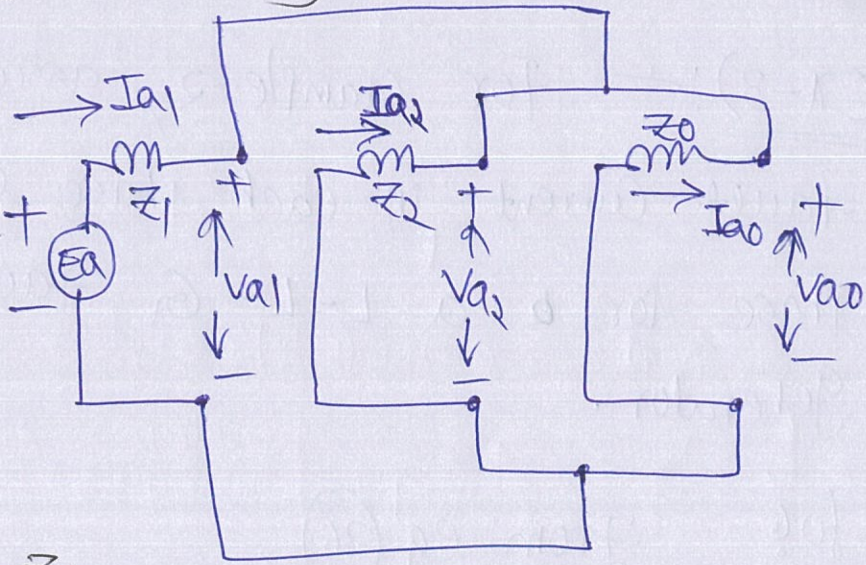
$$V_{a0} = V_{a1} + 3Z_f I_{a0}$$

$$V_{a0} = V_{a1} \quad [\because Z_f = R_n = 0].$$

Therefore,

$$V_{a1} = V_{a2} = V_{a0}$$

~~Va1 = Va2~~ V



$$V_{a1} = V_{a2} = V_{a0} = E_a - I_{a1} Z_1$$

$$\therefore V_{a1} = V_{a2} = V_{a0} = 1\angle 0^\circ - (-j16.56)(j0.045)$$

$$= 0.2548 \text{ pu.}$$

$$I_{a2} = \frac{-V_{a2}}{Z_2} = \frac{-0.2548}{j0.025} = j10.192 \text{ pu.}$$

$$I_{a0} = \frac{-V_{a0}}{Z_0} = \frac{-0.2548}{j0.04} = j6.37 \text{ pu}$$

Now,

$$I_b = \beta^2 I_{a1} + \beta I_{a2} + I_{a0}$$

$$= (-0.5 - j0.866)(-j16.56) + (-0.5 + j0.866)(j10.192) + j6.37$$

$$\therefore I_b = (-23.16 + j9.554) = 25.05 \angle 157.6^\circ \text{ pu}$$

$$I_c = \beta I_{a1} + \beta^2 I_{a2} + I_{a0}$$

$$\therefore I_c = (-0.5 + j0.866)(-j16.56) + (-0.5 - j0.866)(j10.22) + j6.37$$

$$\therefore I_c = (23.16 + j9.554) = 25.05 \angle 22.4^\circ \text{ pu}$$

From eq (31)

$$V_b = V_c = 3Z_f I_{a0}$$

$$\therefore V_b = V_c = 0 \quad [\because Z_f = R_n = 0]$$

From eq (34)

$$V_{a0} = \frac{1}{3}(V_a + 2V_b)$$

$$\therefore V_{a0} = \frac{1}{3} V_a \quad (\because V_b = 0)$$

$$\therefore V_a = 3V_{a0} \quad [\text{voltage of healthy phase}]$$

$$\therefore V_a = 3 \times 0.2548$$

$$\therefore V_a = 0.7644 \text{ pu.}$$

Ex-4) :— A Three Phase synchronous generator with solidly grounded neutral is subjected to a L-L fault on phases b and c accompanied by a L-G fault on phase a, Assume that synchronous generator was running on no load. Develop and draw the sequence networks simulating the above fault condition.

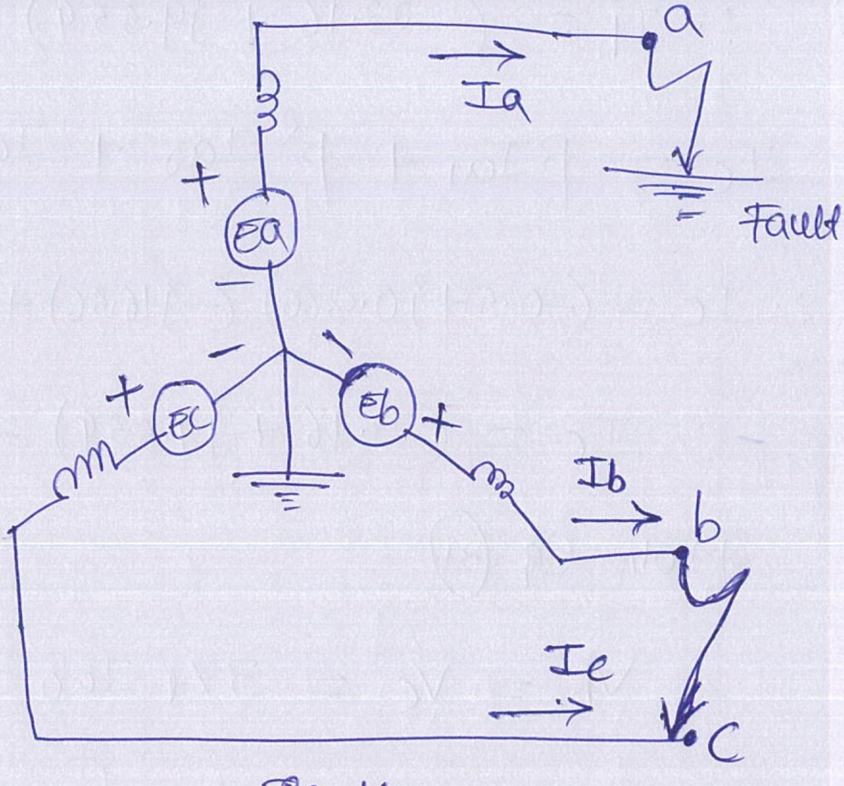


Fig. 14

Sol: There is a L-G fault on Phase "a".

There fore, $V_a = 0$

Further, the phases b and c are short circuited.

Hence

$V_b = V_c \longrightarrow$ (i)

$I_b = -I_c \longrightarrow$ (ii)

$V_a = 0 \longrightarrow$ (iii)

From eq (i)

$$\beta^2 V_{a1} + \beta V_{a2} + V_{a0} = \beta V_{a1} + \beta^2 V_{a2} + V_{a0}$$

$$\therefore (\beta^2 - \beta) V_{a1} = (\beta^2 - \beta) V_{a2}$$

$$\therefore V_{a1} = V_{a2} \longrightarrow (iv)$$

From eq (iii)

$$V_{a1} + V_{a2} + V_{a0} = 0 \longrightarrow (v)$$

From eq (iv) and (v), we get

$$V_{a1} + V_{a1} + V_{a0} = 0$$

$$\therefore V_{a1} = -\frac{V_{a0}}{2}$$

$$\therefore V_{a1} = V_{a2} = -\frac{V_{a0}}{2} \longrightarrow (vi)$$

From eq (ii), we get

$$\beta^2 I_{a1} + \beta I_{a2} + I_{a0} = -(\beta I_{a1} + \beta^2 I_{a2} + I_{a0})$$

$$\therefore (\beta^2 + \beta) I_{a1} + (\beta^2 + \beta) I_{a2} = -2 I_{a0}$$

$$\therefore -I_{a1} - I_{a2} = -2 I_{a0} \qquad [\because \beta^2 + \beta = -1]$$

$$\therefore I_{a1} + I_{a2} = 2 I_{a0} \longrightarrow (vii)$$

⇒ sequence network connection is shown in fig. 15.

⇒ As V_{a1} and V_{a2}, the positive and negative sequence networks are connected in parallel.

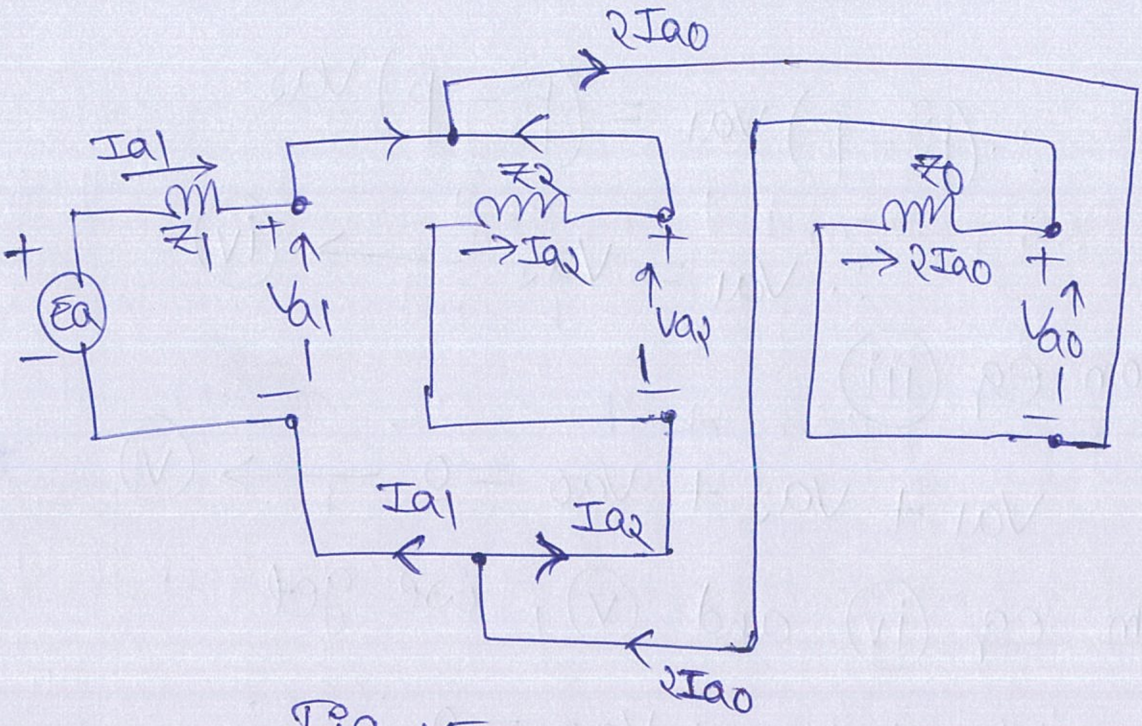


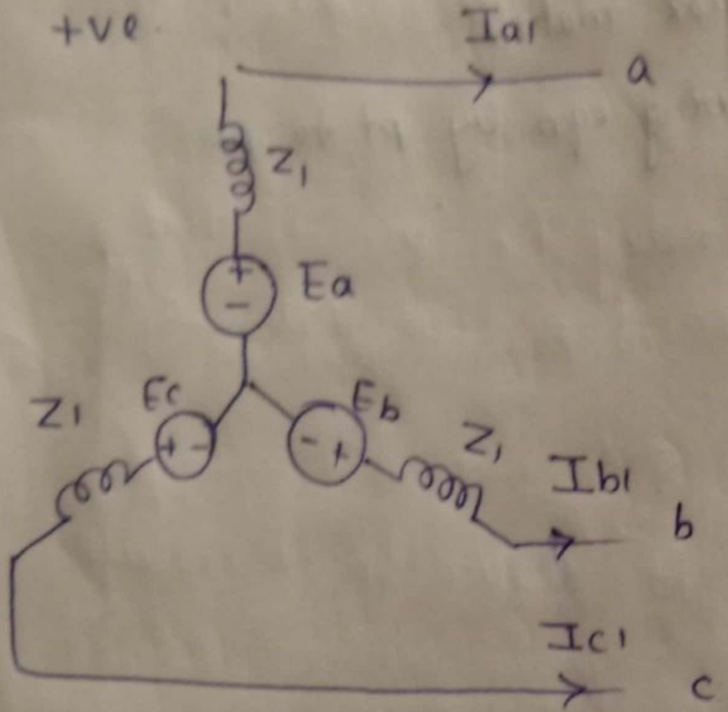
Fig. 15

$\Rightarrow$ As $I_{a1} + I_{a2} = 2I_{a0}$, the zero sequence network is connected in series with the parallel combination of positive and negative sequence networks.

sequence network and sequence imped. are fault analyzing and calculating parametres in power system networks

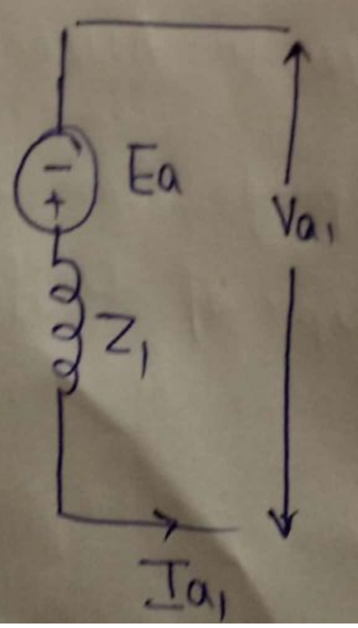
sequence network for synchronous

+ve

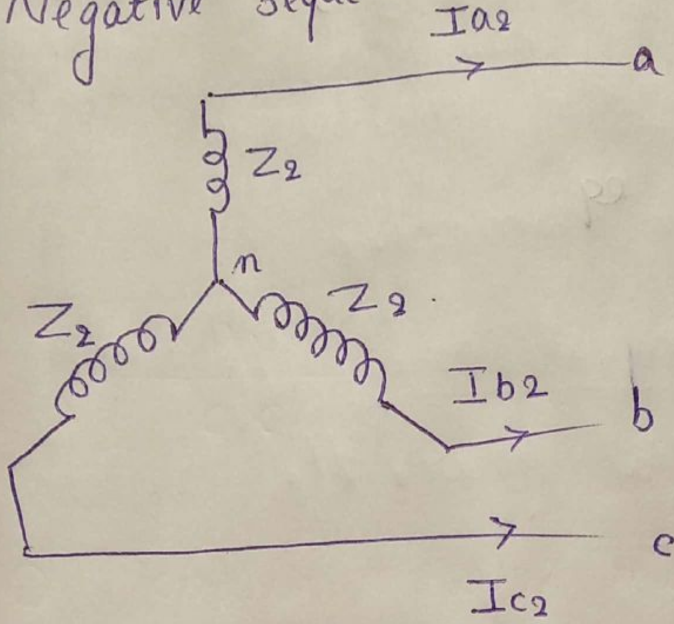


3 - ϕ system.

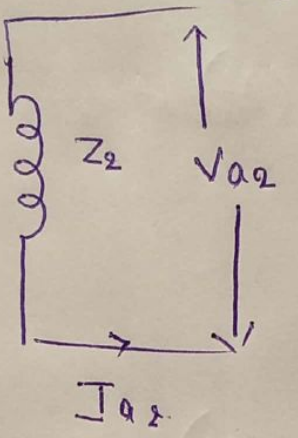
$V_{a1} = E_a - Z_1 I_a$



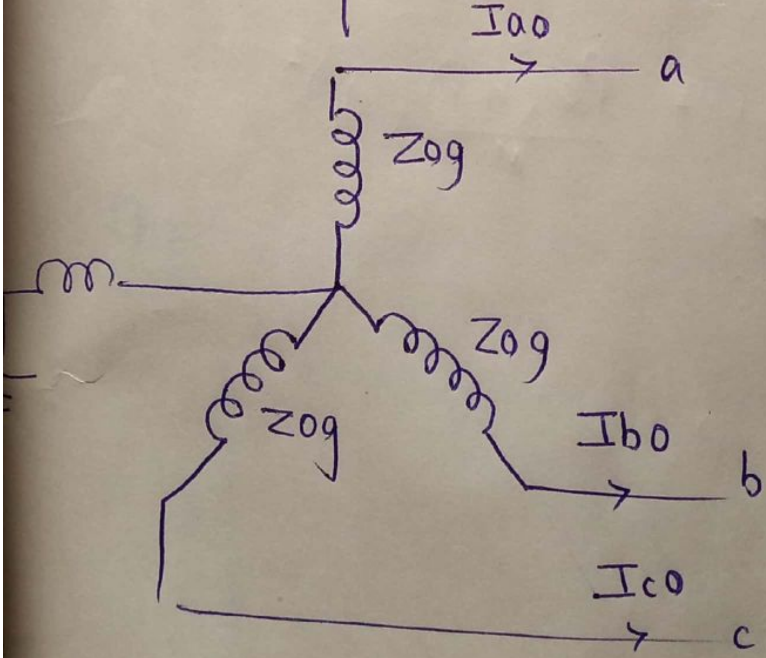
Negative sequence network

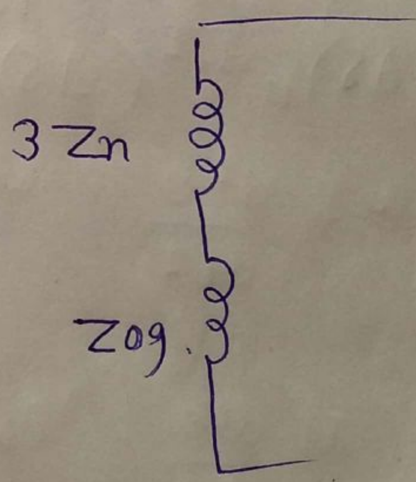


$V_{a2} = -Z_2 I_{a2}$



Zero sequence network





$V_{a0} = -Z_0 I_{a0}$

$Z_0 = 3Z_n + Z_{0g}$

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following assumptions are made in solution of swing eqn by point to point

① accelerating power Pa and angular accelerations α are constant

② angular velocity ω remains constant

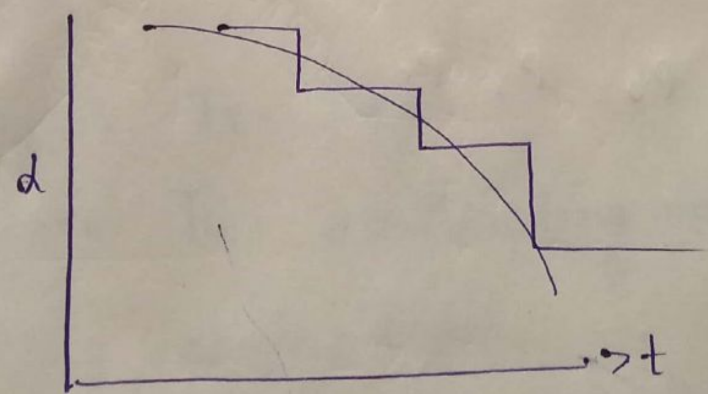
acceleration at $t = (n-1)$ is α_{n-1}

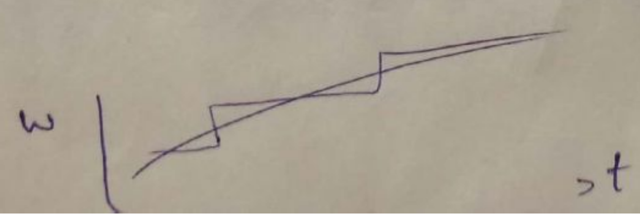
$$\alpha_{n-1} = \frac{\omega_{n-1/2} - \omega_{n-3/2}}{\Delta t}$$

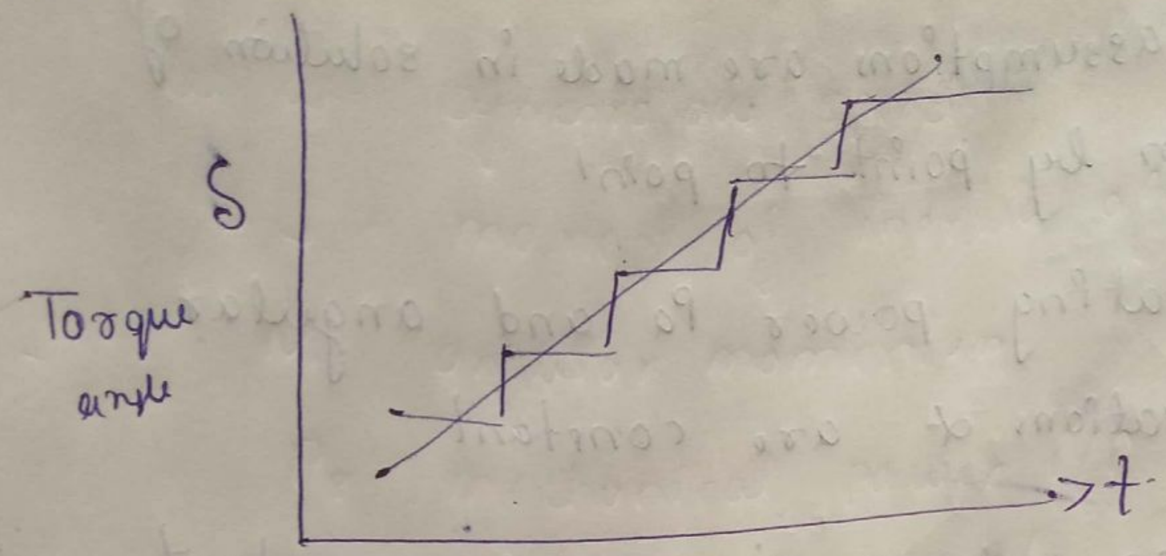
$$\alpha_{n-1} = \frac{Pa(n-1)}{M}$$

$$\therefore \omega_{n-1/2} - \omega_{n-3/2} = \frac{Pa(n-1)}{M} \times \Delta t$$

The following curves are drawn.







$$\omega_{n-1/2} = \frac{\delta_n - \delta_{n-1}}{\Delta t}$$

$$\delta_n - \delta_{n-1} = (\omega_{n-1/2})(\Delta t)$$

$$\omega_{n-3/2} = \frac{\delta_{n-1} - \delta_{n-2}}{\Delta t}$$

$$\delta_{n-1} - \delta_{n-2} = (\omega_{n-3/2})(\Delta t)$$

$$(\Delta\delta)_n = (\Delta\delta)_{n-1} + \frac{P_a(n-1)}{M}(\Delta t)^2$$

Derivation of Swing equation

Let θ = angular position of rotor at any instant t

δ = angular displacement of rotor in electrical degrees

ω_s = synchronous speed.

$$\theta = \omega_s t + \delta$$

Diff w.r.t

$$\frac{d\theta}{dt} = \omega_s + \frac{d\delta}{dt}$$

$$\frac{d^2\theta}{dt^2} = \frac{d^2\delta}{dt^2} = \alpha$$

$$T_a = T_s - T_e$$

where T_a = accelerating torque

T_s = shaft torque

T_e = electrodynamic torque

let ω = synchronous speed.

J = moment of inertia of rotor

M = angular momentum.

P_s = mechanical power i/p.

P_e = electrical power o/p.

$M = J\omega$.

multiplying both sides with ω

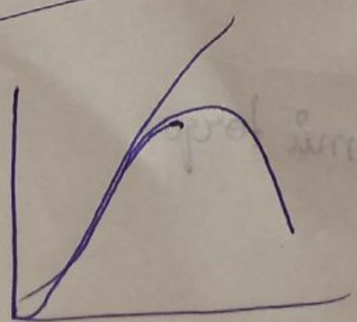
$\omega T_a = \omega T_s - \omega T_e$

$P_a = P_s - P_e$.

$J \dfrac{d^2\theta}{dt^2} = T_a$

$\omega J \dfrac{d^2\theta}{dt^2} = \omega T_a$.

$$M \frac{d^2\theta}{dt^2} = P_a = P_s - P_e$$



Steady state ~~state~~ stability :

It is ability of electrical machine to regain its original state after operation

steady state limit = maximum flow of power through particular point without causing loss of stability

Methods to improve steady state stability

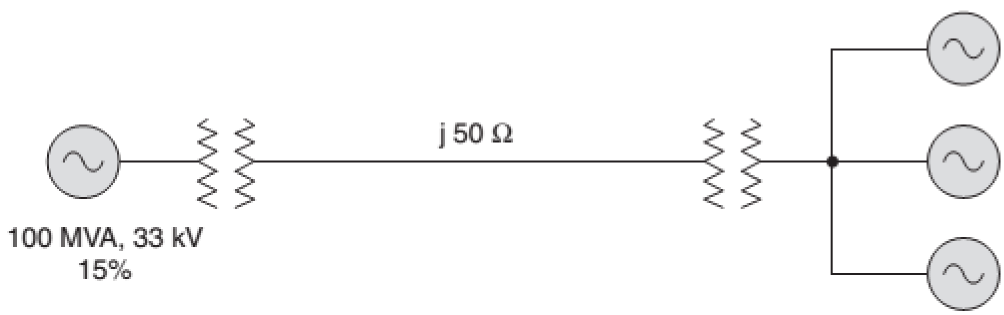
→ By increasing excitation of generator

Academic Year: **2018-19**	**MID Exam – I (Descriptive)**	Date: 05/02/2019
Year: **III**	**COMPUTER METHODS IN POWER SYSTEM**	Duration: **90 min**
Semester: **II**	**Code: GR15A3021**	Max Marks: **15**

Note: Answer any three questions. All questions carry equal marks.

1).a).What are per unit quantities? What are its advantages? **(CO1)** **(2M)**

b). A 100 MVA, 33 kV 3-phase generator has a subtransient reactance of 15%. The generator is connected to the motors through a transmission line and transformers as shown in below Fig. The motors have rated inputs of 30 MVA, 20 MVA and 50 MVA at 30 kV with 20% subtransient reactance. The 3-phase transformers are rated at 110 MVA, 32 kV, Δ/110 kV Y with leakage reactance 8%. The line has a reactance of 50 ohms. Selecting the generator rating as the base quantities in the generator circuit, determine the base quantities in other parts of the system and evaluate the corresponding p.u. values. **(CO1)** **(3M)**



2).LineData:

Bus code	Admittance(p.u.)
1-2	1+j6
1-3	2-j3
2-3	0.8-j2.2
2-4	1.2-j2.3
3-4	2.1-j4.2

Bus Data:

Bus No.	P(p.u)	Q(p.u)	V(p.u)	Remarks
1	---	---	1.03	Slack
2	0.52	0.23	1.0	PQ
3	0.42	0.32	1.0	PQ
4	0.4	0.12	1.0	PQ

Determine the voltages at all the buses at the end of first iteration using GS Method. Take Acceleration Factor (α) = 1.6.**(CO1)** **(5M)**

3).a). What is Slack Bus? Explain its role in the Power Flow Analysis. **(CO1)** **(2M)**

b). Develop load flow equations suitable for solutions by N-R method using rectangular coordinates when only PQ Buses are present. **(CO1)** **(3M)**

4).a). Explain why Fast Decoupled Load Flow(FDLF) method is more widely used in load flow studies compared to other methods. **(CO2)** **(2M)**

b). Explain Fast Decoupled Load Flow(FDLF) methods with neat flow chart. **(CO2)** **(3M)**

Academic Year: **2018-19**
Year: **III**
Semester: **II**

MID Exam – I (Objective)
COMPUTER METHODS IN POWER SYSTEM
Code: GR15A3021

Date:05/02/2019
Duration: **10 min**
Max Marks: **05**

Note : Answer all the questions, all are carry equal marks

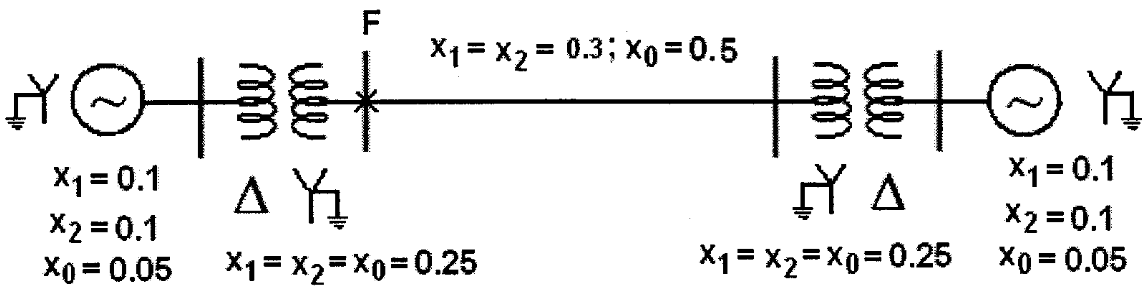
1) What is the simplified diagram called, after omitting all resistances, static loads, capacitance of the transmission lines and magnetizing circuit of the transformer? [ ]
   (a) Single line diagram (b) Resistance diagram
   (c) Reactance diagram (d) None of these
2) In load flow analysis, the load connected at a bus is represented as [ ]
   (a) Constant Current drawn from the bus
   (b) Constant Impedance connected at the bus
   (c) Voltage and Frequency dependent source at the bus
   (d) Constant Real and Reactive Power drawn from the bus
3) The Gauss Seidel Load Flow method has following disadvantages. Tick the incorrect statement [ ]
   (a) Unreliable convergence (b) Slow convergence
   (c) Choice of slack bus affects convergence
   (d) A good initial guess for voltages is essential for convergence
4) In FDLF method the jacobian matrix is [ ]
   (a) To be updated once in a few iterations (b) To be updated at every iteration
   (c) Is constant and need to be computed only once (d) A null matrix
5) The time taken for each iteration in NR method compared to GS method is [ ]
   (a) Equal (b) More
   (c) Less (d) Depend upon the size of PS

6) A synchronous motor having a rating of 50kVA, 6.6kV and having a reactance of 90Ω/ph. Per unit impedance of the synchronous motor is ________________.
7) Expression of complex power in electric circuit is (V is the complex voltage and I is the complex current ____________________.
8) In load flow studies of a power system, the quantities specified at a voltage controlled bus are___________ and _______.
9) Y_{Bus} matrix is a ___________________matrix.
10) A 183-Bus power system has 150 PQ buses and 32 PV buses. In general case, to obtain the load flow solution using NR method in polar co-ordinates, the minimum number of simultaneous equations to be solved is_________.

Academic Year: **2018-19**	**MID Exam – II (Descriptive)**	Date: 05/04/2019
Year:**III**	**COMPUTER METHODS IN POWER SYSTEM**	Duration: **90 min**
Semester: **II**	**Code: GR15A3021**	Max Marks: **15**

Note: Answer any three questions. All questions carry equal marks.

1. For the system shown in figure, an LLG fault occurs at point F. Find fault current.(CO3)[5M]



2. (a) Define the following terms: i) Steady state stability limit. ii) Dynamic state stability limit. iii) Transient state stability limit.(CO4) [2M]
   (b) Derive the expression for steady state stability limit using ABCD parameters.(CO4)[3M]

3. Write short notes on:
   a) Critical Clearing time(CO5) [3M]
   b) Why transient state stability limit is less than steady state stability limit?(CO5) [2M]
4. a) Assume the bus impedance matrix for a partial network is known. Now explain the Z bus building algorithm for addition of a link. (CO3) [3M]
   b) A system of unbalanced three phase voltages are given by 100V, +j200V and (-100-j160)V. Determine the three symmetrical components of the system. (CO3) [2M]

Academic Year: **2018-19**	**MID Exam – II (Objective)**	Date:05/04/2019
Year:**III**	**COMPUTER METHODS IN POWER SYSTEM**	Duration: **10 min**
Semester: **II**	**Code: GR15A3021**	Max Marks: **05**

Note : Answer all the questions, all are carry equal marks

1) Zero sequence currents can flow from a line into a transformer bank if the windings are in [ ]
(*a*) groundedstar/delta
(*b*)delta/star
(*c*) star/grounded star
(*d*) delta/delta.
2) When a line-to-ground fault occurs, the current in a faulted phase is 100 *A*. The zero sequence current in this case will be [ ]
(*a*) zero
(*b*) 33.3 *A*
(*c*) 66.6 *A*
(*d*) 100 *A*.
3) Steady-state stability of a power system is improved by [ ]
(*a*) reducing fault clearing time
(*b*) using double circuit line instead of single circuit line
(*c*) single pole switching
(*d*) decreasing generator inertia.
4) Equal area criterion gives the information regarding [ ]
(*a*) stability region
(*b*) absolute stability
(*c*) relative stability
(*d*) swing curves.
5) The critical clearing time of a fault in power systems is related to [ ]
(*a*) reactive power limit
(*b*) short-circuit current limit
(*c*) steady-state stability limit
(*d*) transient stability limit.
6) A power system is subjected to a fault which makes the zero sequence component of current equal to zero. The nature of fault is [ ]
(*a*) double line to ground fault

(*b*) double line fault
(*c*) line of ground fault
(*d*) three-phase to ground fault.

7) Four alternators, each rated at 5 MVA, 11 kV with 20% reactance are working in parallel. The short-circuit level at bus bars is [ ]
(*a*) 6.25 MVA
(*b*) 20 MVA
(*c*) 25 MVA
(*d*) 100 MVA.

8) If a generator of 250 MVA rating has an inertia constant of 6 MJ/MVA, its inertia constant on 100 MVA base is [ ]
(*a*) 15 MJ/MVA
(*b*) 10.5 MJ/MVA
(*c*) 6 MJ/MVA
(*d*) 2.4 MJ/MVA.

9) Normally ZBUS matrix is a [ ]
(*a*) Null matrix
(*b*) Sparse matrix
(*c*) Full matrix
(*d*) Unity matrix.

10) The inertia constant of two groups of machines, which swing together are $M1$ and $M2$. The inertia constant of the system is: [ ]
(*a*) $M1 + M2$
(*b*) $\frac{M1M2}{M1 + M2}$
(*c*) $\frac{M1 + M2}{M1M2}$
(*d*) $M1 - M2, M1 > M2$

(12 Pages)

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CLASS & BRANCH EEE - A

NAME V. Sowmya SUBJECT CMPS.

SIGNATURE OF THE INVIGILATOR ______ DATE: 08/04/19

SEMESTER	I	~~II~~

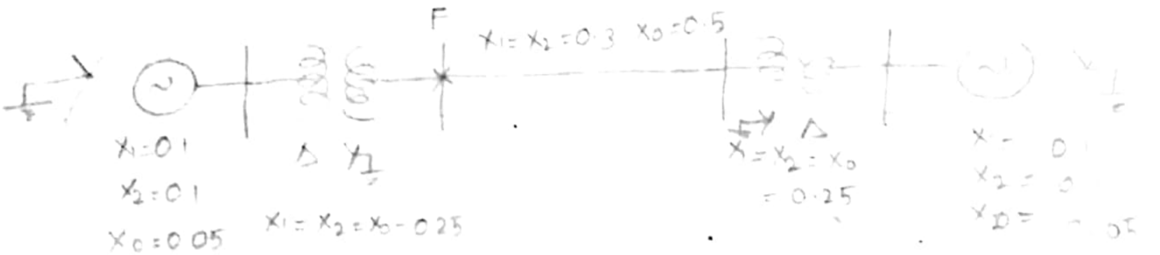
I	~~II~~

MID TERM EXAMINATION

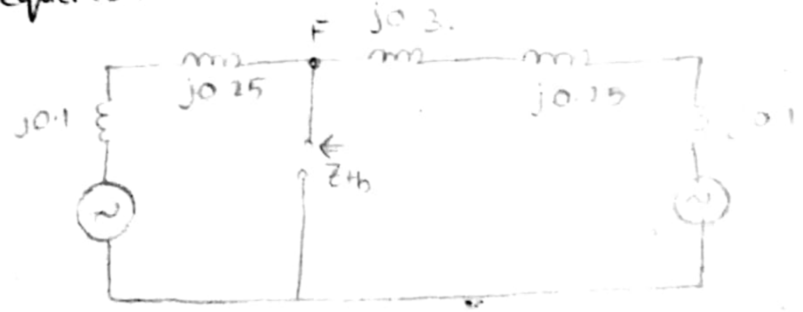
Q.NO.	1		2		3		4		5		TOTAL
	a	b	a	b	a	b	a	b	a	b	
MARKS	5		2	3			3	2			15

V. Sowmya

START WRITING FROM HERE



+ve sequence network



$$Z_1 = (j0.1 + j0.25) \,||\, (j0.3 + j0.25 + j0.1).$$

$$= (0.35j) \,||\, (j0.65) = 0.2275j$$

-ve sequence network is same as +ve sequence network as reactances are equal. Hence $Z_2 = 0.2275j$

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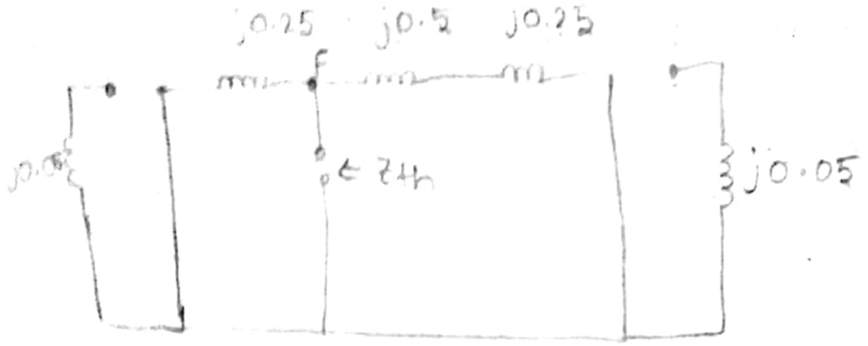
ro sequence network



$$Z_0 = (j0.25) \parallel (j0.5 + j0.25) = (j0.25) \parallel j0.75 = 0.1875j$$

As the fault occured is LLG fault,

$$I_f = 3 I_{a0}.$$

$$I_{a0} = -\frac{(E_a - Z_1 I_{a1})}{Z_0 + 3Z_f}$$

$$I_{a1} = \frac{E_a}{Z_1 + \frac{Z_2(Z_0 + 3Z_f)}{Z_2 + Z_0 + 3Z_f}} \quad (\text{Here } Z_f = 0)$$

$$I_{a1} = \frac{1\angle 0}{j0.2275 + \frac{(j0.2275)(j0.1875)}{j0.2275 + j0.1875}} = -3.027j$$

$$I_{a0} = -\frac{(E_a - Z_1 I_{a1})}{Z_0 + 3Z_f} = -\frac{(1\angle 0 - (j0.2275)(-3.027j))}{j0.1875}$$

$$I_{a0} = 1.66j$$

$$\therefore I_f = 3 I_{a0} = 3 \times 1.66j = 4.98j.$$

4+1=5

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(i) Steady state stability limit:

Steady state stability limit relates to the response of a synchronous machine to gradually increasing load. It is basically concerned with the determination of the upper limit of the machine loading without losing its stability provided the loading is done gradually.

(ii) Dynamic state stability limit:

Dynamic state stability limit relates to the response of small disturbances that occur in a power system produc ing oscillations. A ~~st~~ system is said to be stable dynami -cally if these oscillations donot acquire more than a certa- -in amplitude and die out quickly. A system is said to be dynamically unstable if these oscillations continuosly grow in amplitude.

(iii) Transient state stability limit:

Transient state stability limit relates to the response of large disturbances that occur in power system producing rather large changes in the rotor speed, power angle, power transfer. Transient stability is a fast phenemenon and is usually evident within a few seconds.

The expression for steady state power that can be transmitted or received over a line in terms of sending end voltages, receiving end voltages, line constants can be derived as follows.

The network equations in terms of ABCD parameters are given by

$$E_s = AE_r + BI_r \quad — ①$$

$$I_s = CE_r + DI_r. \quad — ②$$

$$BI_r = E_s - AE_r$$

$$I_r = \frac{E_s}{B} - \frac{AE_r}{B}$$

But, $E_s = |E_s| \angle \delta$, $A = |A| \angle \alpha$,

$B = |B| \angle \beta$, $E_r = |E_r| \angle 0^\circ$.

$$I_r = \frac{|E_s| \angle \delta}{|B| \angle \beta} - \frac{|A| \angle \alpha |E_r| \angle 0^\circ}{|B| \angle \beta}$$

$$I_r = \left|\frac{E_s}{B}\right| \angle \delta - \beta - \left|\frac{AE_r}{B}\right| \angle \alpha - \beta.$$

The conjugate of receiving end current is given by,

$$I_r^* = \left|\frac{E_s}{B}\right| \angle \beta - \delta - \left|\frac{AE_r}{B}\right| \angle \beta - \alpha.$$

The complex power at receiving end is given by.

$$S = P_r + jQ_r = E_r I_r^*$$

$$= E_r \left[\left|\frac{E_s}{B}\right| \angle \beta-\delta - \left|\frac{A E_r}{B}\right| \angle \beta-\alpha \right].$$

$$P_r + jQ_r = \frac{E_r E_s}{B} \angle \beta-\delta - \frac{A E_r^2}{B} \angle \beta-\alpha.$$

Separating the real and imaginary parts, we get

$$P_r = \frac{E_r E_s}{B} \cos(\beta-\delta) - \frac{A E_r^2}{B} \cos(\beta-\alpha)$$

$$Q_r = \frac{E_r E_s}{B} \sin(\beta-\delta) - \frac{A E_r^2}{B} \sin(\beta-\alpha).$$

But, $A = 1\angle 0^\circ$ $\quad B = X\angle 90^\circ$

~~$C=0$~~ $\quad D = 1\angle 0^\circ$

$$P_r = \frac{E_r E_s}{X} \sin\delta - \frac{A E_r^2}{X} \cos 90^\circ$$

$$P_r = \frac{E_r E_s}{X} \sin\delta.$$

The maximum power is transferred when $\delta = 90^\circ$.

$$P_{r,max} = \frac{E_r E_s}{X}.$$

3. a) Critical clearing time:

The critical clearing time is the maximum time during which a disturbance can be applied without the system loosing its synchronism. The aim of this calculation is to determine the characteristics of the protections of the powersystem.

b) Steady state stability limit:

The maximum power that can be transmitted without the system losing its synchronism. If you try to draw more power than this the mechanical input decreases than electrical output and the machine ~~decle~~ decelerates. Hence the speed decreases and its frequency also decreases leading to loss in synchronism.

Transient state stability limit:

When a disturbance occurs such a fault then maximum current flows through the fault, and as the power system network is reactive in nature this current contributes to the reactive power. Hence the maximum active power that can be delivered to the load decreases. This maximum power limit till the transient persists is called transient state stability limit.

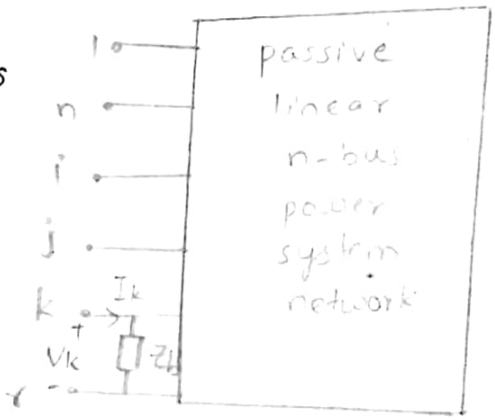
During transient on fault, the real power that can delivered to the load reduces. Hence the transient state stability limit is ...

state stability limit.

4. → Z_{bus} building algorithm is a step by step procedure which procedes branch by branch.

→ The main advantage of Z bus building algorithm is if there is any modification in the network element then there is no need to completely rebuild the Z bus matrix.

Type 1: Impedance Z_b is connected between new bus to reference bus.



→ In this case, the impedance Z_b is connected between new bus to reference bus.

→ The dimension of the Z bus matrix will increase by one.

→ Here, $V_K = I_K Z_b$ and

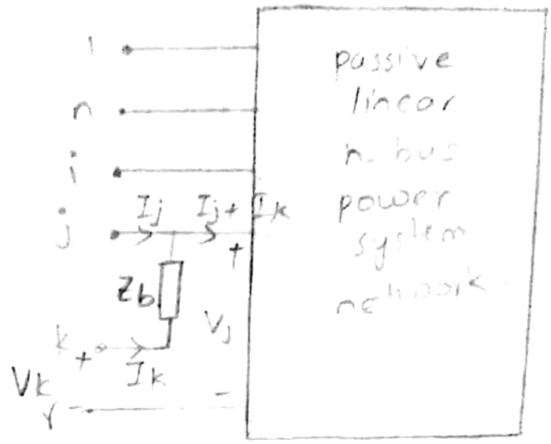
$$Z_{ki} = Z_{ik} = 0 \quad \text{for } i = 1, 2, \ldots n.$$

Hence,

$$Z_{Bus,new} = \begin{bmatrix} & & & & 0 \\ & Z_{Bus,old} & & & 0 \\ & & & & \vdots \\ & & & & 0 \\ 0 & 0 & \cdots & 0 & Z_b \end{bmatrix}$$

Type 2: Impedance Z_L is connected between old bus to new

$V_k = I_k Z_b + V_j$



$V_j = Z_{j1} I_1 + Z_{j2} I_2 + \cdots + Z_{ji} I_i$

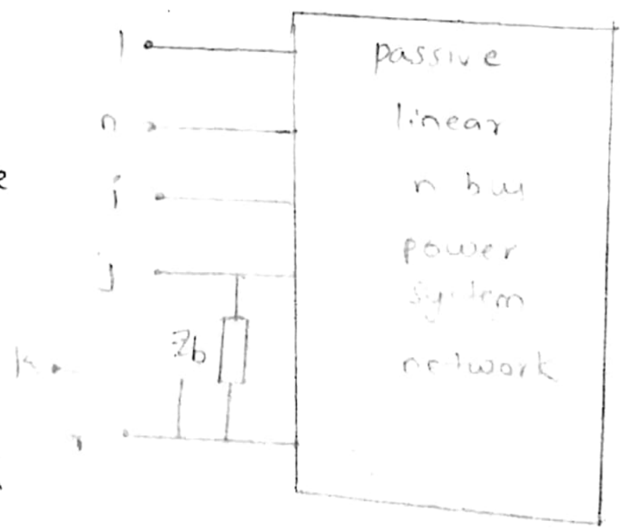
$+ Z_{jj}(I_j + I_k) + Z_{jn} I_n$

$V_k = I_k Z_b + Z_{j1} I_1 + Z_{j2} I_2 + \cdots + Z_{ji} I_i + Z_{jj} I_j + Z_{jj} I_k + Z_{jn} I_n$

$V_k = Z_{j1} I_1 + Z_{j2} I_2 + \cdots + Z_{ji} I_i + Z_{jj} I_j + (Z_{jj} + Z_b) I_k + Z_{jn} I_n$

$$Z_{Bus,new} = \begin{bmatrix} Z_{Bus,old} & \begin{matrix} Z_{1j} \\ Z_{2j} \\ \vdots \\ Z_{nj} \end{matrix} \\ Z_{j1} \; Z_{j2} \cdots Z_{jn} & (Z_{jj} + Z_b) \end{bmatrix}$$

Type 3: Impedance Z_b connected between old bus to reference bus.



Here, $V_k = 0$,

Hence, expression for V_k can be written as

$0 = Z_{j1} I_1 + Z_{j2} I_2 + \cdots$

$\cdots + Z_{jn} I_n + (Z_{jj} + Z_b) I_k$

$$I_k = \frac{-1}{Z_{jj} + Z_b} (Z_{j1} I_1 + Z_{j2} I_2 + \cdots + Z_{jn} I_n)$$

The expression for V_i can be written as

$$V_i = Z_{i1} I_1 + Z_{i2} I_2 + \cdots + Z_{in} I_n + Z_{ij} I_k$$

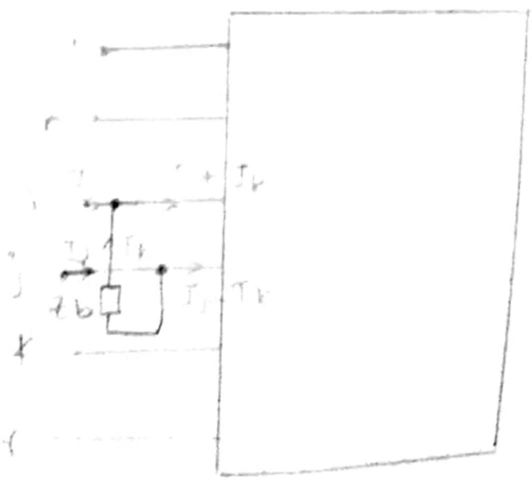
$$= Z_{i1} I_1 + Z_{i2} I_2 + \cdots + Z_{in} I_n + Z_{ij} \left[-\frac{1}{Z_{jj} + Z_b} \left(Z_{j1} I_1 + Z_{j2} I_2 + \cdots + Z_{jn} I_n \right) \right]$$

$$V_i = \left[Z_{i1} - \frac{Z_{ij} Z_{j1}}{Z_{jj} + Z_b} \right] I_1 + \left[Z_{i2} - \frac{Z_{ij} Z_{j2}}{Z_{jj} + Z_b} \right] I_2 + \cdots$$

$$\cdots + \left[Z_{in} - \frac{Z_{jn} Z_{ij}}{Z_{jj} + Z_b} \right] I_n =$$

$$\therefore Z_{BUS,new} = Z_{BUS,old} - \frac{1}{Z_{jj} + Z_b} \begin{bmatrix} Z_{1j} \\ Z_{2j} \\ \vdots \\ Z_{nj} \end{bmatrix} \begin{bmatrix} Z_{j1} & Z_{j2} & \cdots & Z_{jn} \end{bmatrix}$$

Type 4: Impedance Z_b is connected between old bus to old bus



We can write

$$V_j = I_k Z_b + V_i$$

$$V_i = Z_{i1} I_1 + Z_{i2} I_2 + \cdots + Z_{ii}(I_i + I_k)$$
$$+ Z_{ij}(I_j - I_k) + Z_{in} I_n$$

$$V_j = Z_{j1} I_1 + Z_{j2} I_2 + \cdots + Z_{ji}(I_i + I_k) + Z_{jj}(I_j - I_k) + Z_{jn} I_n$$

$$Z_{j1}I_1 + Z_{j2}I_2 + \cdots + Z_{jn}I_n + Z_{ji}(I_i + I_k) + Z_{jj}(I_j - I_k)$$

$$= I_k Z_b + Z_{i1}I_1 + Z_{i2}I_2 + \cdots + (Z_{ii}(I_i + I_k)$$

$$+ (Z_{ij}(I_j - I_k)$$

$$0 = (Z_{i1} - Z_{j1})I_1 + (Z_{i2} - Z_{j2})I_2 + \cdots + (Z_b + Z_{ii} + Z_{jj} - 2Z_{ij})I_k$$

$$+ (Z_{in} - Z_{jn}) I_n.$$

$$Z_{BUS,new} = Z_{BUS,old} - \frac{1}{(Z_b + Z_{ii} + Z_{jj} - 2Z_{ij})} \begin{bmatrix} Z_{1i} - Z_{1j} \\ Z_{2i} - Z_{2j} \\ \vdots \\ Z_{ni} - Z_{nj} \end{bmatrix} \begin{bmatrix} Z_{i1} - Z_{j1} & Z_{i2} - Z_{j2} & \cdots & Z_{in} - Z_{jn} \end{bmatrix}$$

$V_a = 100V$, $V_b = j200\ V$ $V_c = -100 - j160\ V$

$$\begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \beta & \beta^2 \\ 1 & \beta^2 & \beta \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

$$V_{a0} = \frac{1}{3}[V_a + V_b + V_c]$$

$$V_{a1} = \frac{1}{3}[V_a + \beta V_b + \beta^2 V_c]$$

$$V_{a2} = \frac{1}{3}[V_a + \beta^2 V_b + \beta V_c]$$

$V_{a0} = 13.33j = 13.33\angle 90$

$V_{a1} = -53.923 + j22.2 = 58.314\angle 157.62$

$V_{a2} = 153.92 - j35.53 = 157.96\angle -12.99.$

$V_{a0} = V_{b0} = V_{c0} = 13.33\angle 90°$

$V_{b1} = \beta^2 V_{a1}$

$= 46.187 + j35.59$

$V_{b1} = 58.31\angle 37.61$

$V_{c1} = \beta V_{a1}$

$= 7.732 - j57.79$

$V_{c1} = 58.3\angle -82.37.$

$V_{b2} = \beta V_{a2}$

$= -46.209 + j151.04$

$= 157.95\angle 107$

$V_{c2} = \beta^2 V_{a2}$

$= -107.708 - j115.54$

$= 157.95\angle -132.99.$

$\therefore V_{a0} = 13.33\angle 90°, \quad V_{a1} = 58.314\angle 157.62, \quad V_{a2} = 157.96\angle -12.9$

$V_{b0} = 13.33\angle 90°, \quad V_{b1} = 58.31\angle 37.61 \quad V_{b2} = 157.95\angle 107$

$V_{c0} = 13.33\angle 90° \quad V_{c1} = 58.3\angle -82.37 \quad V_{c2} = 157.95\angle -132.9$

(12 Pages)

Gokaraju Rangaraju Institute of Engineering & Technology

(Autonomous)

Bachupally, Kukatpally, Hyderabad - 500090

No. 290782

ROLL NO.:	1	6	2	4	1	A	0	2	6	1

CLASS & BRANCH III B.Tech EEE II Semester

NAME A.Prashanth SUBJECT CMPS

SIGNATURE OF THE INVIGILATOR ______ DATE: 8/4/19

SEMESTER	I	II ✓

I	II ✓	MID TERM EXAMINATION

Q.NO.	1		2		3		4		5		TOTAL
	a	b	a	b	a	b	a	b	a	b	
MARKS			2		2	1	3	1			09

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Steady state stability :- It is defined as the response of the system under gradually increasing load. It includes finding the upper limit of synchronism provided it is loaded gradually.

Dynamic state stability :- It is defined as the response for small faults due to which oscillations are developed in the system. If the oscillations die quickly then the system is said to be dynamically stable. If the oscillat[ions] pertain in the system then the system is said to be dynamically unstable.

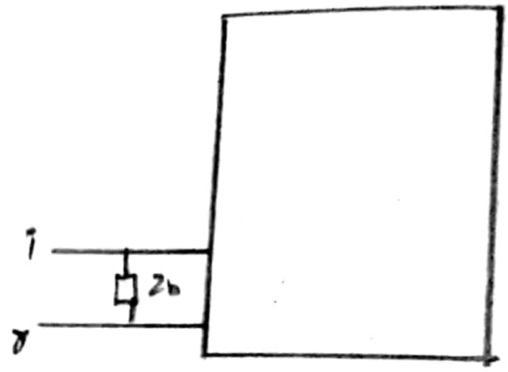
Transient stability :- It is defined as the response of the system for large faults which try to bring the system out of synchronism.

1) Type-1 modification

If a link is added between reference bus & new bus with an impedance Z_b

then

$$Z_{bus_{new}} = \begin{bmatrix} Z_{bus_{old}} & \begin{matrix} 0 \\ 0 \\ \vdots \\ 0 \end{matrix} \\ 0 \; 0 \cdots 0 & Z_b \end{bmatrix}$$

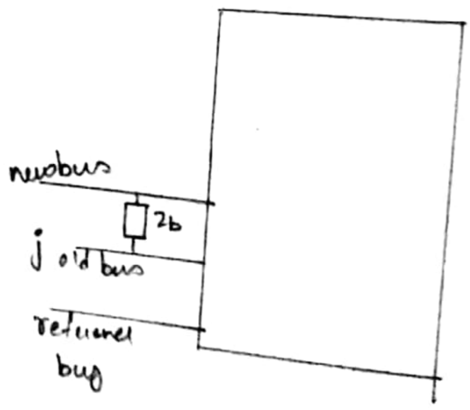


Type-2 modification

If a link is added between old bus and a new bus with an impedance Z_b

the

$$Z_{bus_{new}} = \begin{bmatrix} Z_{bus_{old}} & \begin{matrix} Z_{1j} \\ Z_{2j} \\ \vdots \\ Z_{nj} \end{matrix} \\ Z_{j1} \; Z_{j2} \cdots Z_{jn} & Z_{jj}+Z_b \end{bmatrix}$$



Here j = no. of the old bus

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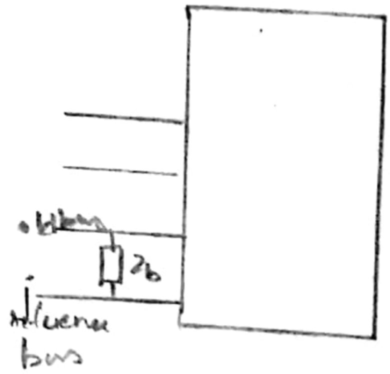
Type-3 modification

If a link is added between an old bus and the reference bus with impedance Z_b

$$Z_{bus_{new}} = Z_{bus_{old}} - \frac{1}{Z_{jj}+Z_b}\begin{bmatrix} Z_{1j} \\ Z_{2j} \\ \vdots \\ Z_{nj} \end{bmatrix}\begin{bmatrix} Z_{j1} & Z_{j2} & \cdots & Z_{jn} \end{bmatrix}$$



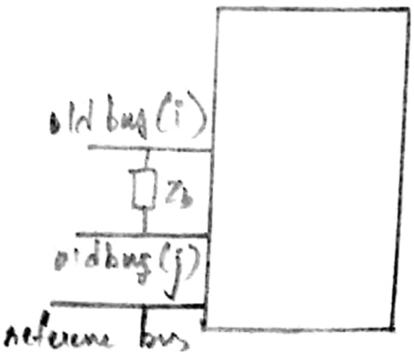
Here j = no. of the old bus
n = total no. of buses

Type-4 modification

If a link is added between two old buses with an impedance Z_b then

$$Z_{bus_{new}} = Z_{bus_{old}} - \frac{1}{Z_{ii}+Z_{jj}+Z_b-2Z_{ij}}\begin{bmatrix} Z_{i1} - Z_{j1} \\ \vdots \\ Z_{in} - Z_{jn} \end{bmatrix}\begin{bmatrix} (Z_{i1}-Z_{1j}) & \cdots & (Z_{in}-Z_{nj}) \end{bmatrix}$$

Here i = number of the 1st old bus
j = number of the 2nd old bus
n = total number of buses.



Given $V_a = 100V$

$V_b = +j200V$

$V_c = (-100-j160)V$

we know

$$V_a = V_{a1} + V_{a2} + V_{a0}$$

$$V_b = V_{b1} + V_{b2} + V_{b0}$$

$$V_c = V_{c1} + V_{c2} + V_{c0}$$

The voltages with prefixes 1 are all positive sequence voltages. Similarly with 2 they are negative sequence components & with 3 they are zero sequency components.

we know

$$V_p = A \cdot V_s$$

where $A = \begin{bmatrix} 1 & 1 & 1 \\ \beta^2 & \beta & 1 \\ \beta & \beta^2 & 1 \end{bmatrix}$

$V_p = \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$; $V_s = \begin{bmatrix} V_{a1} \\ V_{b1} \\ V_{c1} \end{bmatrix}$

Here $\beta = e^{j120}$

$\beta^2 = e^{j240} = e^{-j120} = \beta^*$

$\beta^3 = 1$

$1 + \beta + \beta^2 = 0$

$= -0.5 + j0.86$

$^2 = -0.5 - j0.86$

~~$V_{a1} =$~~ ~~$V_{a1} = V_a$~~

~~$= 100V.$~~

~~$V_{b1} = \beta^2 \cdot V_a + \beta \cdot V_b + V_c$~~

~~$= (-50 - 86.6j) + (-172 - 100i) + (-100 - j160)$~~

$=$ ~~-222~~ -322

$$A^T = \begin{bmatrix} 1 & \beta^2 & \beta \\ 1 & \beta^1 & \beta^2 \\ 1 & 1 & 1 \end{bmatrix}$$

$V_{a1} = V_a + \beta^2 \cdot V_b + \beta \cdot V_c$

$= 100 + (172 - 100j) + (187.6 - 6j)$

$459.6 - 106j$

$V_{b1} = V_a + \beta \cdot V_b + \beta^2 \cdot V_c$

$100 + (1200 + j37520) + (-33200 - 17520j)$

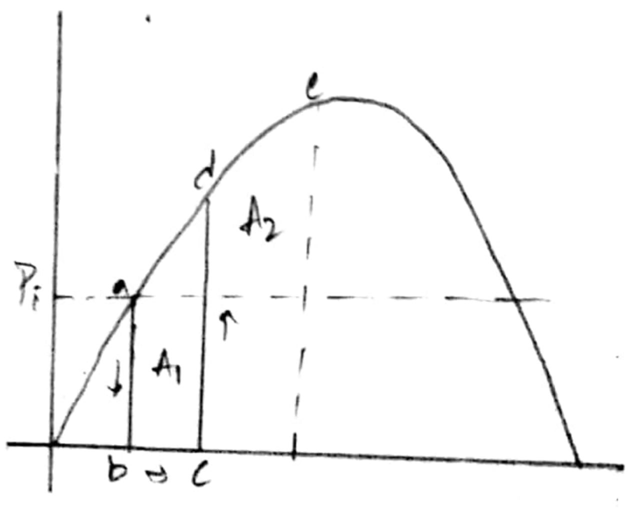
$= -31900 + 20000j$

$V_{c1} = V_c$

$= -100 - j160$

Critical Clearing time :- When a fault either symmetrical or unsymmetrical is into the system δ goes on increasing as a result the system comes out of synchronism. The time taken to clear the fault is called critical clearing time and δ at the instant of clearing time is called clearing angle.

Initially the system is in synchronism with power P_i when a fault occurs its power output becomes zero and drops from a to b as shown in the graph. Now the accelerating area increases from b to c. At c where time is t_c and angle is δ_c the fault is cleared and the system gains synchronism. Now the new point of synchronism is d



From equal Angle criterion

$$\text{Area } A_1 = \text{Area } A_2.$$

we know.

$$\frac{d\delta^2}{dt^2} = \frac{\pi f}{H}$$

On integrating twice

$$\delta_1 = \frac{H}{\pi f} t^2 + \delta_0$$

Now

$$t = \frac{(\delta_1 - \delta_0)\pi f}{H}$$

Transient stability limit is less than steady state stability limit because in transient conditions the fault is severe and in few seconds that must be cleared else it brings out system out of synchronism and shorts it. whereas in steady state the load is gradually added on to the system under healthy conditions so steady state limit is high.

(12 Pages)

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CLASS & BRANCH EEE-B, B.tech (3rd year)

NAME J. Devi prasad SUBJECT CMPS

SIGNATURE OF THE INVIGILATOR [signature] DATE: 8/4/19

SEMESTER I II ✓ | I II ✓ MID TERM EXAMINATION

Q.NO.	1		2		3		4		5		TOTAL
	a	b	a	b	a	b	a	b	a	b	
MARKS			2	1	1	1					05

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a) (i) Steady State Stability limit :-

→ Steady state Stability relates to the response of Synchronous machine to a gradually increasing load.

→ It is basically concered to the determination of upper limit of machine loadings before losing the synchronism provided the loads increase gradually.

(ii) Dynamic State stability limit :-

→ Dynamic Stability (or) small signal stability involves in the response of small disturbances which occur in the system, producing oscillations.

→ The system is said to be dynamically stable if these oscillations do not acquire more than certain amplitude and die out quickly.

→ The system is said to be dynamically unstable if these oscillations continuously grow up in amplitude.

(iii) Transient state stability :-

→ Transient state stability involves in the response of large disturbances, which may rather cause large change in rotor speed, power angles and power transfers.

→ Transient stability is a fast phenomenon, usally evident (or) clearly visible within few seconds.

a) Critical clearing time :-

→ In critical clearing time the response of time laps is considered. As the time is critically at peak value of the graph then the clearing of critical time comes into picture.

→ The main purpose of critical clearing time occurs in the dynamic stability of the system occur's in the small disturbances as well as large disturbances.

→ The critical angle keeps on change widing increa-sing with respect to time as the clearing time acquires more initial angle to acquire addactive time managment.

→ critical clearing time clear's the critical angle and makes into a critical stabiliy limit to acquire limited quantities.

b) Transient state stability limit is less than steady state stability limit, as in transient stability it is a fast process phenomenon whereas in steady state stability it a response of synchronous machine with gradually increasing load. So, ~~the~~ transient stability limit has evident ~~time to~~ sustain the limit compared to steady state ~~limit~~ stability. Steady state stability is basically determined to the upper limit of the machine loadings and the transient state stability determine for large disturbances for usally lower limits. There is more changes in transient state stability and have less changes in steady state stability. Therefore Transient state stability is less than that of steady state stability.

b) Steady state stability limit :-

$$M \frac{d^2\delta}{dt^2} = P_r - P_e = P_a$$

$$\frac{d^2\delta}{dt^2} = \frac{P_a}{M}$$

multiplying both sides by $\left(2\frac{d\delta}{dt}\right)$

$$2\frac{d\delta}{dt}\left(\frac{d^2\delta}{dt^2}\right) = 2\frac{P_a}{M}\frac{d\delta}{dt}$$

$$\frac{d}{dt}\left(\frac{d\delta}{dt}\right)^2 = 2\frac{P_a}{M}\frac{d\delta}{dt}$$

By integrating we get,

$$\left(\frac{d\delta}{dt}\right)^2 = \frac{2}{M}\int_{\delta_0}^{\delta_0} P_a \cdot d\delta$$

therefore the stability state steady limit i

$$\boxed{\int_{\delta}^{\delta_0} P_a \cdot d\delta}$$

Ch. pranavi
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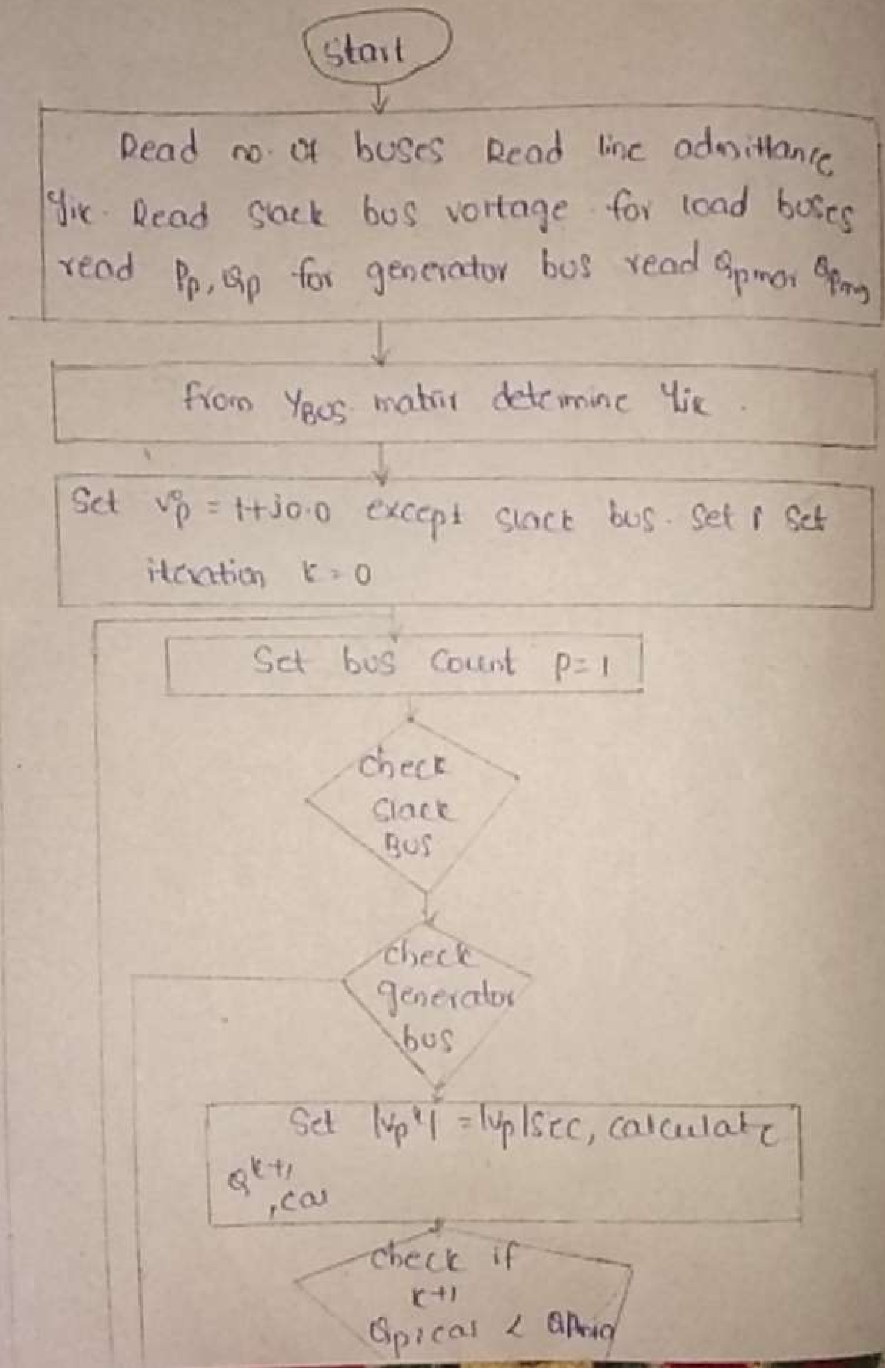
Assignment-1

1) Explain with flowchart computation procedure for load flow seidal method when system contains all buses?



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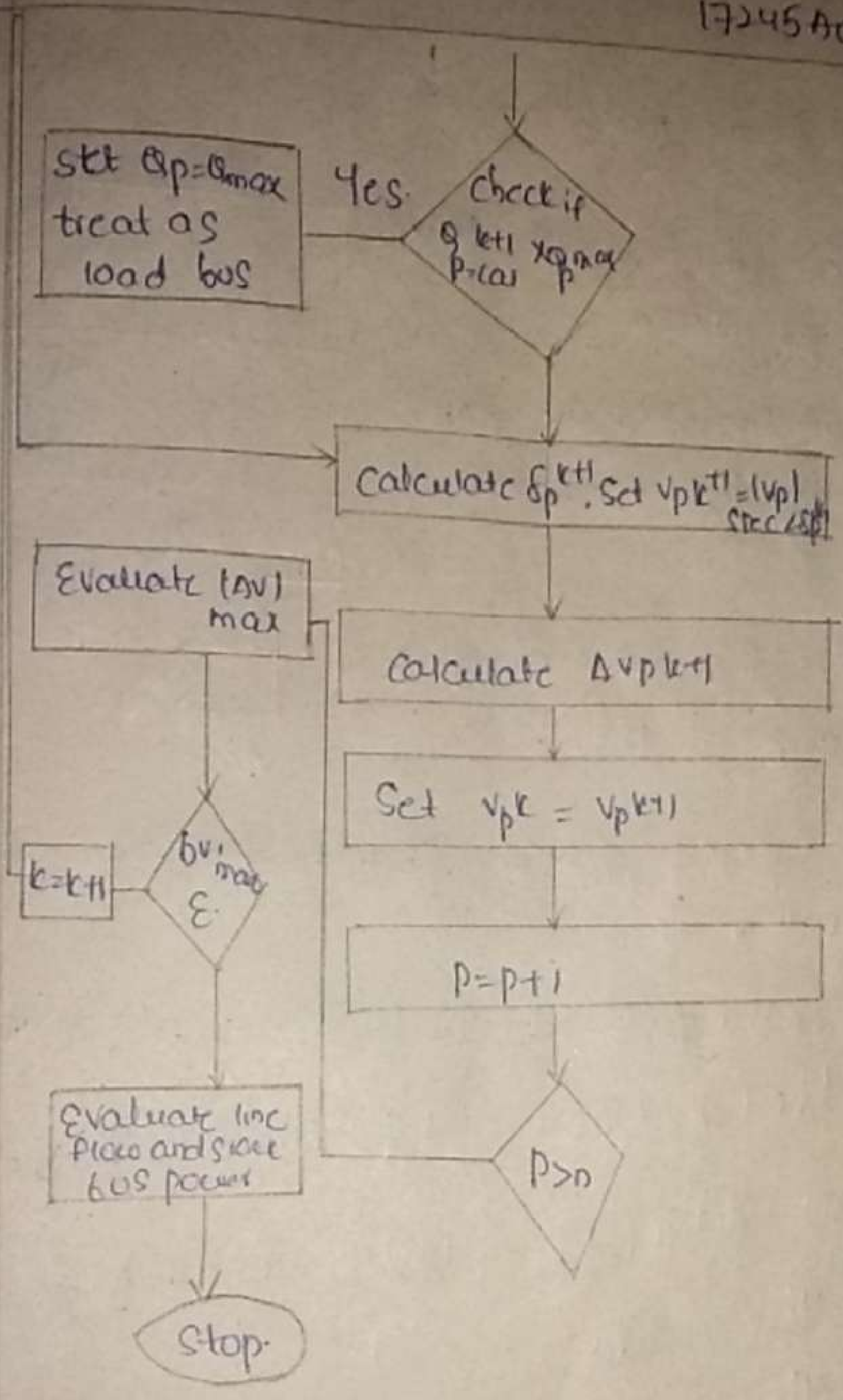

2) Develop load flow equations for solution by i) G.S method ii) NR method using nodal admittance approach.

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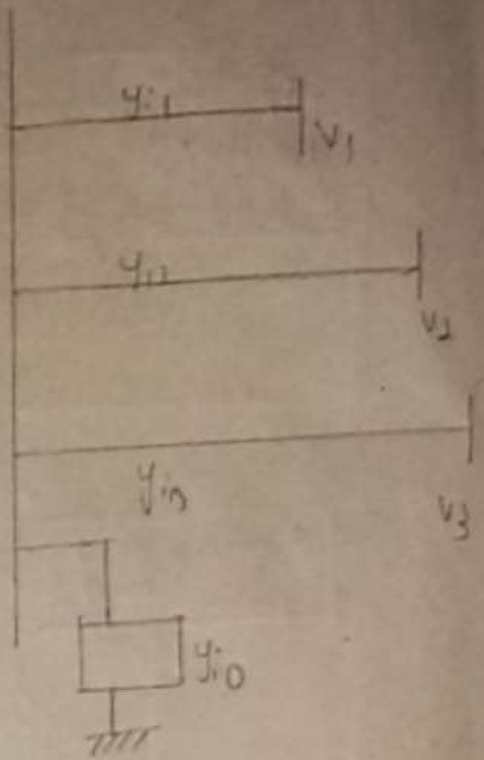
i) Gauss - Seidel method



Consider ith bus of power System as shown

→ Transmission lines are represented by their equivalent π method

→ y_{i0} is the total charging admittance at bus.

→ Net injected current I_i in to the bus i can be written as

$$I_i = y_{i0} V_i + y_{i1}(V_i - V_1) + y_{i2}(V_i - V_2) + \dots + y_{in}(V_i - V_n)$$

$$I_1 = (y_{i0} + y_{i1} + y_{i2} + \dots + y_{in}) V_i - y_{i1} V_1 - y_{i2} V_2 - y_{in} V_n$$

let us define $Y_{ii} = (y_{i0} + y_{i1} + y_{i2} + y_{in})$

$$Y_{i1} = -y_{i1}$$

$$Y_{i2} = -y_{i2}$$

$$Y_{in} = -y_{in}$$

$$\therefore \quad I_i = Y_{ii} V_i + Y_{i1} V_1 + Y_{i2} V_2 + \dots + Y_{in} V_n \quad — ①$$

(or)

$$I_i = Y_{ii} V_i + \sum_{\substack{k=1 \\ k \neq i}}^{n} Y_{ik} V_k \quad — ②$$

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The real and reactive power at bus i is

$$P_i - jQ_i = V_i^* I_i$$

$$\therefore I_i = \frac{P_i - jQ_i}{V_i^*} \quad -④$$

from ② & ③

$$\frac{P_i - jQ_i}{V_i^*} = Y_{ii} V_i + \sum_{\substack{k=1 \\ k \neq i}}^{n} Y_{ik} V_k \quad -⑤$$

$$\therefore Y_{ii} V_i = \frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{k=1 \\ k \neq i}}^{n} Y_{ik} V_k$$

$$V_i = \frac{1}{Y_{ii}} \left(\frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{k=1 \\ k \neq i}}^{n} Y_{ik} V_k \right)$$

$$P_i - jQ_i = V_i^* \left(Y_{ii} V_i + \sum_{\substack{k=1 \\ k \neq i}}^{n} Y_{ik} V_k \right)$$

Let, $Y_{ii} = |Y_{ii}| \angle \theta_{ii}$; $Y_{ik} = -|Y_{ik}| \angle \theta_{ik}$,

$V_i = |V_i| \angle \delta_i$, $V_i^* = |V_i| \angle -\delta_i$, $V_k = |V| \angle \delta_k$

$$P_i - jQ_i = |V_i| \angle -\delta_i, \ |Y_{ii}| \angle \theta_{ii}, \ |V_i| |\angle \delta_i| + \sum_{\substack{k=1 \\ k \neq i}}^{n} |V_i|$$

$\angle -\delta_i$

$|Y_{ik}| \angle \theta_{ik} \ |V_k| \angle \delta_k$

$$= |V_i|^2 |Y_{ii}| \angle \theta_{ii} + \sum_{\substack{k=1 \\ k \neq i}}^{n} |Y_{ik}| |V_i| |V_k| \angle \theta_{ik} + \delta_k - \delta_i$$

$= |V_i|^2 |Y_{ii}| \cos\theta_{ii} + j |V_i|^2 Y_{ii} \sin\theta_{ii} + \sum_{k=1, k\neq i} |Y_{ik}|$

$|V_i||V_k| \cos(\theta_{ik} + \delta_k - \delta_i) + j \sum_{k=1, k\neq i}^{n} |Y_{ik}| |V_i||V_k| \sin(\theta_{ik} + \delta_k - \delta_i)$

Separating real & imaginary

$P_i = |V_i|^2 |Y_{ii}| \cos\theta_{ii} + \sum_{k=1, k\neq i}^{i} |Y_{ik}||V_i||V_k| \cos(\theta_{ik} + \delta_k - \delta_i)$

$P_i = \sum_{k=1}^{n} |V_i||V_k||Y_{ik}| \cos(\theta_{ik} - \delta_i + \delta_k)$

$Q_i = -\sum_{k=1}^{n} |V_i||V_k||Y_{ik}| \sin(\theta_{ik} - \delta_i + \delta_k)$

N-R method:- The set of non-linear eqn

$y_1 = f_1(x_1, x_2, \ldots x_n)$

$y_2 = f_2(x_1, x_2, \ldots x_n)$

$y_n = f_n(x_1, x_2, \ldots x_n)$

initial estimates are $x_1^{(0)}, x_2^{(0)}, x_n^{(0)}$

Assuming $\Delta x_1, \Delta x_2, \ldots \Delta x_n$ are corrections required

So, $y_1 = f_1(x_1^{(0)} + \Delta x_1, \ldots x_2^{(0)} + \Delta x_2 \ldots x_n^{(0)} + \Delta x_n)$

$y_2 = f_2(x_1^{(0)} + \Delta x_1, x_2^{(0)} + \Delta x_2, x_n^{(0)} + \Delta x_n)$

$y_n = f_n(x_1^{(0)} + \Delta x_1, x_2^{(0)} + \Delta x_2, \ldots x_n^{(0)} + \Delta x_n)$

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$y_1 = f_1(x_1^{(0)}, x_2^{(0)}, \ldots x_n^{(0)} + \Delta x_1 \frac{\partial f_1}{\partial x_1}\Big| + \Delta x_2 \frac{\partial f_1}{\partial x_2}\Big|$

$+ \Delta x_n \frac{\partial f_1}{\partial x_n}) + D_1$

Neglecting D_1 we can write

$$\begin{bmatrix} y_1 - f(x_1^{(0)}, x_2^{(0)}, x_3^{(0)}) \\ y_2 - f_2(x)^{(0)}, x_2^{(0)}, x_3^{(0)} \\ \vdots \\ y_n - f_n(x_1^{(0)}, x_2^{(0)}, x_n^{(0)}) \end{bmatrix} \begin{bmatrix} \frac{\partial f_1}{\partial x_1} & \frac{\partial f_1}{\partial x_2} & \cdots & \frac{\partial f_1}{\partial x_n} \\ \frac{\partial f_2}{\partial x_1} & \frac{\partial f_2}{\partial x_2} & \cdots & \frac{\partial f_2}{\partial x_n} \\ \frac{\partial f_n}{\partial x_1} & \frac{\partial f_n}{\partial x_2} & \cdots & \frac{\partial f_n}{\partial x_n} \end{bmatrix} \begin{bmatrix} \Delta x_1 \\ \Delta x_2 \\ \Delta x_3 \end{bmatrix}$$

$D = JR$

$D^{(P)} = J^{(P)} \cdot R^{(P)}$

$\Rightarrow R^{(P)} = \left(J^{(P)}\right)^{-1} D^P$

The new values for x_i is $x_p^{(p+1)} = x_i^{(p)} + \Delta x_i^{(0)}$

The load flow problem is formulated in polar form as

$$P_i = \sum_{k=1}^{n} |V_i||V_k||Y_{ik}| \cos(\theta_{ik} - \delta_i + \delta_k)$$

$$Q_i = -\sum_{k=1}^{n} |V_i||V_k||Y_{ik}| \sin(\theta_{ik} - \delta_i + \delta_k)$$

we can write

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$$\begin{bmatrix} \Delta P_2^{(p)} \\ \Delta P_3^{(p)} \\ \Delta P_n^{(p)} \\ \vdots \\ \Delta Q_2^{(p)} \\ \Delta Q_3^{(p)} \\ \vdots \\ \Delta Q_n^{(p)} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_2}{\partial \delta_2} & \frac{\partial P_2}{\partial \delta_3} & \cdots & \frac{\partial P_2}{\partial \delta_n} & \frac{\partial P_2}{\partial V_2} & \frac{\partial P_2}{\partial V_3} & \cdots & \frac{\partial P_2}{\partial V_n} \\ \frac{\partial P_3}{\partial \delta_2} & \frac{\partial P_3}{\partial \delta_3} & \cdots & \frac{\partial P_3}{\partial \delta_n} & \frac{\partial P_3}{\partial V_2} & \frac{\partial P_3}{\partial V_3} & \cdots & \frac{\partial P_3}{\partial V_n} \\ \frac{\partial P_n}{\partial \delta_2} & \frac{\partial P_n}{\partial \delta_3} & \cdots & \frac{\partial P_n}{\partial \delta_n} & \frac{\partial P_n}{\partial V_2} & \frac{\partial P_n}{\partial V_3} & \cdots & \frac{\partial P_n}{\partial V_n} \\ \frac{\partial Q_2}{\partial \delta_2} & \frac{\partial Q_2}{\partial \delta_3} & \cdots & \frac{\partial Q_2}{\partial \delta_n} & \frac{\partial Q_2}{\partial V_2} & \frac{\partial Q_2}{\partial V_3} & \cdots & \frac{\partial Q_n}{\partial \delta_n} \\ \frac{\partial Q_3}{\partial \delta_2} & \frac{\partial Q_3}{\partial \delta_3} & \cdots & \frac{\partial Q_3}{\partial \delta_n} & \frac{\partial Q_3}{\partial V_2} & \frac{\partial Q_3}{\partial V_3} & \cdots & \frac{\partial Q_n}{\partial \delta_n} \\ \frac{\partial Q_n}{\partial \delta_2} & \frac{\partial Q_n}{\partial \delta_3} & \cdots & \frac{\partial Q_n}{\partial \delta_n} & \frac{\partial Q_n}{\partial V_2} & \frac{\partial Q_n}{\partial V_3} & \cdots & \frac{\partial Q_n}{\partial V_n} \end{bmatrix} \begin{bmatrix} \Delta\delta_2 \\ \Delta\delta_3 \\ \Delta\delta_n \\ \Delta V_2 \\ \Delta V_3 \\ \Delta V_n \end{bmatrix}$$

Hence we can write

$$\begin{pmatrix} \Delta P \\ \Delta Q \end{pmatrix} = \begin{pmatrix} J_1 & J_2 \\ J_3 & J_4 \end{pmatrix} \begin{pmatrix} \Delta \delta \\ \Delta |V| \end{pmatrix}$$

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3) comparison b/w GS method and NR method.

G.S method	N.R method.
1) Variable are expressed in Rectangular co-ordinates	1) Variable are Expressed in polar co-ordinates
2) Computation time per iteration is less	2) Computation time per iteration is more
3) It has linear convergence characteristics	3) It has quadratic convergence characteristics
4) The no. of iterations required convergence increase with size of the system	4) The no. of iteration are independent of the size of the system
5) The choice of slack bus critical.	5) The choice of slack bus is arbitary.

SET - 2

GR 11

07/05/2015, FN

CODE: GR11A3026

III B. Tech II Semester Regular Examinations, May, 2015
Computer Methods in Power Systems
(Electrical and Electronics Engineering)

Time: 3 hours

Max Marks: 75

Answer any FIVE questions
All questions carry equal marks
*****

1). a The four – bus system is having the line impedances as given in the table. The shunt admittance at all buses is assumed negligible. Draw one-line diagram & find Y_{Bus} assuming that the line between buses 1 & 2 is not connected. [8]

Line	R, p.u.	X, p.u.
1-2	0.05	0.15
1-3	0.10	0.30
2-3	0.15	0.45
2-4	0.10	0.30
3-4	0.05	0.15

b Explain the concept for the modification of Z bus matrix for the addition of element from a old bus to an reference bus. [7]

2). a Draw and explain the flowchart for Newton Raphson Load Flow Analysis. [10]

b What is Slack Bus? Explain its role in the Power Flow Analysis. [5]

3). a Derive an expression for the fault current of a Single line to ground fault as an unloaded alternator. [8]

b A single phase transformer is rated at 110/440 V, 3 KVA. Its leakage reactance measured on 110 V side is 0.05 ohm. Determine the leakage impedance referred to 440 V side. [7]

4). a Discuss the various methods of improving Steady State Stability. [7]

b A generator rated 75 MVA is delivering 0.8 p.u. power to a motor through a transmission line of reactance j0.2 p.u. The terminal voltage of the generator is 1.0 p.u. and that of the motor is also 1.0 p.u. Determine the generator e.m.f behind transient reactance. Find also the maximum power that can be transferred. [8]

5). a State and derive the necessary expressions for the Swing Equation. [8]

b What is Equal Area Criterion? Explain its applications. [7]

6). a Explain various types of Series Reactors and their applications. [8]

b Derive the necessary expressions for the steady state stability and condition for the maximum power transfer between two nodes. [7]

7) a What are Symmetrical Components? Explain. [10]

b What is short circuit MVA? Explain. [5]

*****

CODE: GR11A3026

GR 11

SET - 4

III B. Tech II Semester Regular Examinations, May/June 2016
Computer Methods in Power Systems
(Electrical & Electronics Engineering)

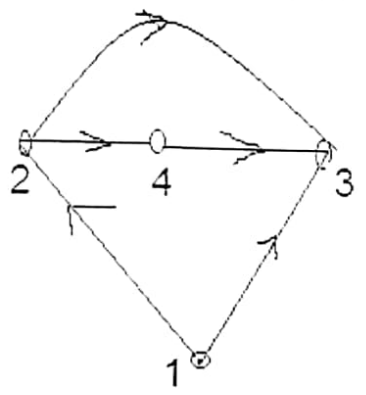
Time: 3 hours

Max Marks: 75

Answer any FIVE questions
All questions carry equal marks
*****

1). a Prove that there is no mutual coupling between the diagonal and off diagonal elements of Y_{BUS} and can be computed from $Y_{ii} = \sum y_{ij}$ and $Y_{ij} = -y_{ij}$ [8]

b Define the terms graph, tree, co-tree, tree branches and links. Write relation between branches, links and number of nodes [7]



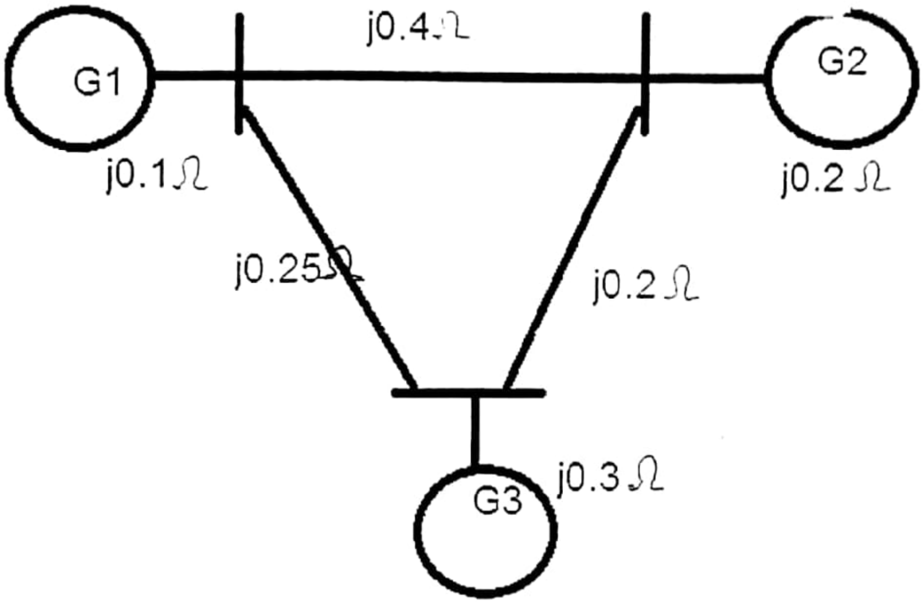
2). a Develop load flow equations suitable for solutions by N-R method using rectangular coordinates when only PQ Busses are present. [11]

b Explain why fast decoupled load flow method is more widely used in load flow studies compared to other methods. [4]

3). a Draw the connection of sequence networks for the following types of faults i) single line to ground fault ii) double line to ground fault and iii) line to line fault [8]

b What are the advantages of Y-Bus matrix over Z-Bus Matrix? [7]

4). a [8]



Compute the bus admittance matrix for the power system by direct inspection method and singular transformation method.

b What are the advantages of Per Unit System? [7]

5).a What is the significance of Symmetrical Components? [5]

b Derive the expression for fault currents and voltages during LG fault at p^{th} bus in an n-bus system. [10]

6). a A 50 Hz, 4-pole generator rated 100MVA,11kV has an inertia constant of 8MJ/MVA i) find the stored energy in the rotor at synchronous speed [10]
ii) if the mechanical input is suddenly raised to 80MW for electrical load of 50MW find rotor acceleration
iii) if the acceleration calculated in ii) is maintained for 10 cycles, find the change in torque angle and rotor speed in rpm at the end of this speed
iv) another generator 200MVA, 3000rpm having H= 6MJ/MVA is put in parallel with above generator. Find the inertia constant for equivalent generator on a base of 100MVA.

b Write short notes i) Transfer Reactance ii) Synchronizing Power Coefficient [5]

7) a How do you explain equal area criteria for determining stability of system for sudden change in mechanical input? [8]

b Derive from fundamentals, swing equation of synchronous machine. Also give the various assumptions made in transient stability analysis. [7]

*****

CODE: GR14A3021 | GR 14 | SET - 3

III B. Tech II Semester Regular Examinations, May 2017
Computer Methods in Power Systems
(Electrical and Electronics Engineering)

Time: 3 hours **Max Marks: 70**

PART – A

Answer ALL questions. All questions carry equal marks.

*****

10 * 2 Marks = 20 Marks

1). a Define per-unit system of representation. [2]

b What is the necessity of power flow studies? [2]

c Write the Power System Characteristics used in Decoupled Method. [2]

d Write the merits and demerits of using polar and rectangular coordinates in load flow studies. [2]

e Classify the unsymmetrical faults. [2]

f What are the applications of series reactors? [2]

g Define stability limit of the system. [2]

h What is the use of synchronizing power coefficient? [2]

i List the assumptions made in the transient stability solution techniques. [2]

j Write the state variable formulation of swing equations. [2]

PART – B

Answer any FIVE questions. All questions carry equal marks.

*****

5 * 10 Marks = 50 Marks

2. Describe load flow solution with P.V buses using G-S method. [10]

3. Describe the Newton-Raphson Method for the solution of power flow equations in power systems deriving necessary equations. [10]

4. Derive the expressions for bus voltages, line currents when a Line to Ground Fault through a fault impedance occurs at a particular bus using bus impedance matrix. [10]

5. Derive the expression for steady state stability limit using ABCD parameters. [10]

6. What is equal area criterion? Explain how it can be used to study stability with a suitable example. [10]

7. The data for 2-bus system is given below. [10]
S_{G1} =Unknown; SD_1=Unknown $V1=1.0\angle 0^0$ p.u., S1=To be determined
$S_{G2}=0.25+jQ_{G2}$ p.u., $SD_2=1+j\,0.5$ p.u. The two buses are connected by a transmission line of p.u. reactance of 0.5 p.u. Find Q_2 and $\angle V2$. Neglect shunt susceptance of the tie line. Assume $|V_2|=1.0$. Perform iterations using G.S. method.

8. What are the steps followed for determining multi machine stability? [10]

*****

Vijaya Ram Raj

CODE: GR14A3021 | GR 14 | SET - 1

III Year II Semester Supplementary Examinations, Nov/Dec 2018

Computer Methods in Power Systems

(Electrical and Electronics Engineering)

Time: 3 hours **Max Marks: 70**

PART – A

Answer ALL questions. All questions carry equal marks.

*****

10 * 2 Marks = 20 Marks

1). a Write about Classification of buses. [2]

b What happens if we select wrong value of acceleration factor? [2]

c List out some advantages of FDLF method with DLF method. [2]

d What are the assumptions made in the FDLF method? [2]

e What are the advantages of Ybus matrix over ZBus Matrix? [2]

f Discuss the main objective of finding fault level of a bus. [2]

g Why transient stability limit is lower than steady state stability limit? [2]

h Define Transfer reactance. [2]

i List out applications of auto reclosing and fast operating circuit breakers. [2]

j Define critical clearing angle. [2]

PART – B

Answer any FIVE questions. All questions carry equal marks.

*****

5 * 10 Marks = 50 Marks

2. **a)** Explain Gauss-Seidal iterative method for power flow analysis of any given power system with a flow chart. [10]

b) A 2000 bus system has 250 generators, all of which are modeled in a power flow program with constant (known) terminal voltage.

i. How many type PV buses are there in the power flow model?

ii. How many type PQ buses are there in the power flow model?

iii. What is the minimum number of equations required to solve this problem?

iv. How many bus voltage magnitudes are unknown in this problem?

v. How many bus voltage angles are unknown in this problem?.

3. Explain fast decoupled load flow methods with neat flow chart. [10]

4. Assume the bus impedance matrix for a partial network is known. Now explain the Z bus building algorithm for the following modifications. (i) Addition of a branch and (ii) Addition of a link. [10]

5. a) Write short notes on elementary concepts of steady state stability dynamic stability and Transient stability. [10]

b) Derive the maximum steady state power.

6. Derive an expression for the critical clearing angle for a power system consisting of a single machine supplying to an infinite bus. for a sudden mechanical load increment. [10]

7. a) Discuss about load flow solution without PV bus by using FDLF method. [10]

b) Distinguish between D.C load flow and A.C load flow

8. a) What are per unit quantities? What are its advantages? [10]

b) Derive an expression for the fault current for a line-to-line fault at an unloaded generator.

*****

CODE: GR15A3021 | GR 15 | SET - 2

III B. Tech II Semester Regular Examinations, Apr/May 2018

Computer Methods in Power Systems

(Electrical and Electronics Engineering)

Time: 3 hours **Max Marks: 70**

PART – A

Answer ALL questions. All questions carry equal marks.

*****

10 * 2 Marks = 20 Marks

1). a Classify various Buses. [2]

b What is the normal value of acceleration factor used in GS Method? [2]

c Which is the best method for accurate load flow calculations on a large power system? [2]

d Compare Newton Raphson method with DLF Method. [2]

e Define Z_{Bus}. [2]

f Explain voltage and current in positive, negative and zero sequence networks. [2]

g Define Inertia Constant. [2]

h What is Power Angle Curve? [2]

i What are the advantages of fast operating circuit breakers? [2]

j What are the applications of Equal Area Criterion? [2]

PART – B

Answer any FIVE questions. All questions carry equal marks.

*****

5 * 10 Marks = 50 Marks

2. Line Data: [10]

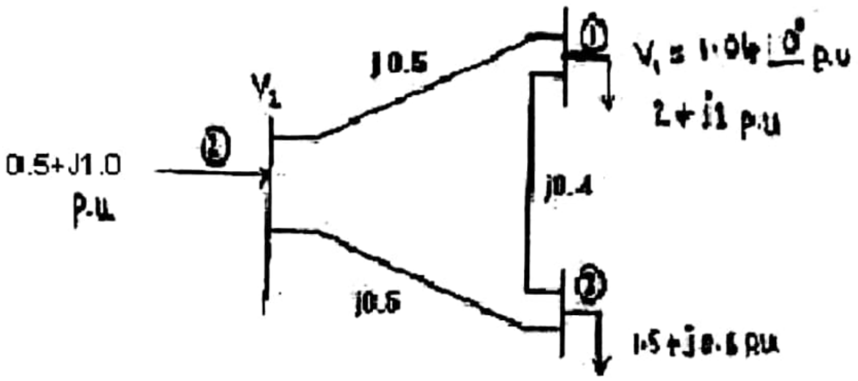
Bus code	Admittance(p.u.)
1-2	1+j6
1-3	2-j3
2-3	0.8-j2.2
2-4	1.2-j2.3
3-4	2.1-j4.2

Bus Data:

Bus No.	P(p.u)	Q(p.u)	V(p.u)	Remarks
1	---	---	1.03	Slack
2	0.52	0.23	1.0	PQ
3	0.42	0.32	1.0	PQ
4	0.4	0.12	1.0	PQ

Determine the voltages at all the buses at the end of first iteration using GS Method?

3. A sample power system is shown in figure. Determine V_2 and V_3 by N.R. method after one iteration? The p.u. values of line impedances are shown in figure. [10]



4. a) What are the advantages of Z_{BUS} building algorithm? [10]
b) Z_{bus} matrix elements are given by Z_{11}= 0.2, Z_{22}= 0.6, Z_{12}=0 find the modified Z_{BUS} if a branch having an impedance 0.4 p.u. is added from the reference bus (Bus -1) to new bus? Also find the modified Z_{BUS} if a branch having an impedance 0.4 p.u. is added from existing bus (other than reference bus) to new bus?

5. a) Explain the power angle curve and determination of steady state stability. [10]
b) Differentiate between steady state stability and transient state stability of power systems. Discuss the factors that affect the above stability.

6. A 20 MVA, 50Hz generator delivers 18 MW over a double circuit line to an infinite bus. The generator has kinetic energy of 2.52 MJ/MVA at rated speed. The generator transient reactance is X'_d=0.35pu. Each transmission circuit has R=0 and a reactance of 0.2pu on a 20MVA base. $|E'|$=1.1pu and infinite bus voltage V= $1.0\angle 0^\circ$ A three phase short circuit occurs at the midpoint of one the transmission lines. Plot swing curves with fault cleared by simultaneous opening of breakers at both ends of the line at 2.5 cycles after the occurrence of fault. [10]

7. a) Discuss about load flow solution with PV bus by using FDLF Method. [10]
b) What are the advantages and disadvantages of GS and NR methods with reference to load flow problem.

8. a) Explain what is "swing equation"? Explain its practical significance in stability analysis. [10]
b) Give the mathematical model for the transient analysis of multi machine power system

*****

EVALUATION STRATEGY

Academic **Y**ear : 2018-2019

Semester : II

Name of the Program: B.Tech ……..…**Electrical**……..… Year: ……**III**……….. Section: A&B

Course/Subject: … **Computer Methods in power System** …Course Code: .. GR15A3021.

Name of the Faculty: …… **V.Vijaya Rama Raju/M.Prashanth** ………………..Dept.: …**EEE**………

Designation: ASSOC.PROFESSOR/ASST.PROFESSOR

1. TARGET:

A) Percentage for pass: 40%

b) Percentage of class: 85%

2. COURSE PLAN& CONTENT DELIVERY:

- OHP presentation of the Lectures
- Solving exercise problems
- Model questions

3. METHOD OF EVALUATION

3.1 Continuous Assessment Examinations (CAE-I, CAE-II)

3.2 Assignments

3.3 Seminars

3.4 Quiz

3.5 Semester/End Examination

Signature of HOD

Date:

Signature of faculty

Date:

Gokaraju Rangaraju Institute of Engineering & Technology
(Autonomous)

Summation of Teacher Appraisal by Student
Academic Year 2018-19

Name of the Instructor	V.Vijaya Rama Raju
Faculty ID	361
Branch	EEE
Class and Semester/Section	III / II / A
Academic Year	2018-19
Subject Title	Computer Methods in Power systems
Total No. of Responses/class strength	11/71

Average rating on a scale of 4 for the responses considered:

S. No	Questions of Feedback	Average
1	How do the teacher explain the subject?	3.2
2	The teacher pays attention to	3.3
3	The Language and communication skills of the teacher is	3.2
4	Is the session Interactive?	3.2
5	Rate your teacher's explanation in clearing the doubts	3.3
6	Rate your teacher's commitment in completing the syllabus	3.1
7	Rate your teacher's punctuality	3.5
8	Rate your teachers use of teaching aids	3.2
9	Rate your teacher's guidance in other activities like NPTEL, Moodle, Swayam, Projects.	3.1
10	What is your overall opinion about the teacher?	3.1

Net Feedback on a scale of 1 to 4: 3.22

Remarks by HOD:

____

Remarks by Principal:

____

Remarks by Director:

____

Gokaraju Rangaraju Institute of Engineering & Technology
(Autonomous)

Summation of Teacher Appraisal by Student
Academic Year 2018-19

Name of the Instructor	M Prashanth
Faculty ID	1279
Branch	EEE
Class and Semester/Section	III / II / A
Academic Year	2018-19
Subject Title	Computer Methods in Power systems
Total No. of Responses/class strength	11/71

Average rating on a scale of 4 for the responses considered:

S. No	Questions of Feedback	Average
1	How do the teacher explain the subject?	3.5
2	The teacher pays attention to	3.6
3	The Language and communication skills of the teacher is	3.4
4	Is the session Interactive?	3.5
5	Rate your teacher's explanation in clearing the doubts	3.6
6	Rate your teacher's commitment in completing the syllabus	3.7
7	Rate your teacher's punctuality	3.6
8	Rate your teachers use of teaching aids	3.5
9	Rate your teacher's guidance in other activities like NPTEL, Moodle, Swayam, Projects.	3.7
10	What is your overall opinion about the teacher?	3.6

Net Feedback on a scale of 1 to 4: 3.57

Remarks by HOD:

____

Remarks by Principal:

____

Remarks by Director:

____

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

CO Attainment for all Mid Exams

I mid COS

Computer Methods in Power System(2018-19) SEM-II, MID-I
III YEAR SEC-A

Question number	1(a)	1(b)	2	3(a)	3(b)	4(a)	4(b)
CO	**CO1**	**CO1**	**CO1**	**CO1**	**CO1**	**CO2**	**CO2**
Maxmimum Marks	**2**	**3**	**5**	**2**	**3**	**2**	**3**
15241A0243	2					1	
16241A0201	2		1				1
16241A0202	2	2	4	2	3		
16241A0203	2	2	4	2	2		
16241A0205	2			1	2	2	2
16241A0206	2	2				1	2
16241A0207	2		4				
16241A0208	2	1		1		1	
16241A0209	2			1	3		
16241A0210			3				
16241A0211		1					
16241A0212			1				
16241A0213	2			2		2	2
16241A0214	1			2			
16241A0216							
16241A0217	2	2	5	2	1		
16241A0218	2	3	4				
16241A0219							
16241A0220	1						
16241A0221	2						
16241A0222	1		2	1			
16241A0223	2	3	5	2	3		
16241A0224			3	2			
16241A0225			3	2	1	1	2
16241A0226			4	2	1		
16241A0227	2		1	1	1		
16241A0228							
16241A0229	1			2	1		
16241A0230	2	2	4				
16241A0231	2			2			
16241A0232							

16241A0233	1					1	3
16241A0234	2	2		2			
16241A0235	2			1	2		
16241A0236	2	2	3	2			
16241A0237	2					1	
16241A0238	1		3				
16241A0239	2		1				
16241A0240	2		2	2			
16241A0241	1	1	2	2	1		
16241A0242			2	2	2	2	2
16241A0243	1			1	2		2
16241A0244	1						2
16241A0245				1	2		
16241A0246	2		3	2			
16241A0247	2			2		2	2
16241A0248			2	2	2	2	2
16241A0249	1			2		1	2
16241A0250	2	2	3	1			
16241A0251	2						
16241A0252	2	3	5			2	2
16241A0253	2		1				
16241A0254	2			2		2	1
16241A0255	1			1		1	
16241A0256	1			1	2	2	2
16241A0257	2	3	3	2	1		
16241A0258	2			2			
16241A0259			5	2	3	2	3
16241A0260	2			2			
17245A0201	2	3	5	1	3		
17245A0202	1						
17245A0203	1						
17245A0204	2		3	1			
17245A0205	2	3	4	2	2		
17245A0206	2	1	1				
17245A0207		1					
17245A0208							
17245A0209	1	1	5				
17245A0210	1		3	2	1		
17245A0211							

17245A0212	2	3		2	1	1	1
Total	92	43	104	69	42	27	33
No of students attempted	54	21	34	41	23	18	17
attempted%	76.05634	29.57746	47.88732	57.74648	32.39437	25.35211	23.94366
average(attainment)	1.703704	2.047619	3.058824	1.682927	1.826087	1.5	1.941176
%attainment	85.18519	68.25397	61.17647	84.14634	60.86957	75	64.70588

CO1	**71.92**
CO2	**69.85**

Computer Methods in Power System(2018-19) SEM-II, MID-I

III YEAR SEC-B

Question number	**1(a)**	**1(b)**	**2**	**3(a)**	**3(b)**	**4(a)**	**4(b)**
CO	**CO1**	**CO1**	**CO1**	**CO1**	**CO1**	**CO2**	**CO2**
Maxmimum Marks	**2**	**3**	**5**	**2**	**3**	**2**	**3**
16241A0261	1	3	5	1			
16241A0262	1	2	3	1	2		
16241A0263	2		2	2			
16241A0264	2			1			
16241A0265	2			2		2	
16241A0266	2			2	3		
16241A0267	2	1	5	2	1		
16241A0268	2	1		2	3	1	
16241A0269			5	2	3	2	2
16241A0270	2			2			
16241A0271	2			2			
16241A0272	2	3	5				3
16241A0273	1					1	2
16241A0274	2	3	5			2	3
16241A0275	2	2	5	1			
16241A0276				2	3	2	3
16241A0277	2			2	1	1	
16241A0278	2		5	2			
16241A0279				2	1	2	3
16241A0280	2	1	3	2	3		
16241A0281	2	2	5	2	2		
16241A0282	2			2		2	3
16241A0283	2			1	3		
16241A0284	2	1		2			2

16241A0285				2	1	2	3
16241A0286	2	1		2	3		
16241A0287						2	3
16241A0288	2						3
16241A0289	2	3	2	2			
16241A0290	2		5	2	2		
16241A0291	2	2	5	2			
16241A0292	2	1		2	3		
16241A0293	2	1		2	3		
16241A0294	2			1			
16241A0295	2		2	2			
16241A0296	2	1		2			
16241A0297	2		2	2	2		
16241A0298				2			
16241A0299	2			2			
16241A02A0	2						
16241A02A2	2		5			2	3
16241A02A3			2	2	3		
16241A02A4	2	2	2	1			
16241A02A5	2			2	3	2	
16241A02A6	2			2		1	
16241A02A7	5			2	3	2	
16241A02A8	2	3	5			2	3
16241A02A9			2	2		2	
16241A02B0				2			
16241A02B1	2	1	4	2			
16241A02B2	1	1	2	1			
16241A02B3	2	1		2			
16241A02B4	2			2		1	
16241A02B5	2		3	2	3		
16241A02B6	2	1	3	2	2		
16241A02B7	2	3	5	2	3		
16241A02B8	2	3	5	2			
16241A02B9	1			1		1	
17245A0213	1		1	2			
17245A0214	2	3	5	2	3		
17245A0215	2	3					
17245A0216	2		3				
17245A0217	2					1	

17245A0218			5	2	2	2	3
17245A0219	1			2		1	2
17245A0220	2	3		2	3	1	2
17245A0221	2	3	5			2	3
17245A0222	2	1	4	2			
17245A0223			2	1		1	3
17245A0224	2		2	1			
18248A0201	2		2	2			
Total	116	56	131	107	64	40	49
No of students attempted	60	29	36	59	26	25	18
attempted%	84.50704	40.84507	50.70423	83.09859	36.61972	35.21127	25.35211
average(attainment)	1.933333	1.931034	3.638889	1.813559	2.461538	1.6	2.722222
%attainment	96.66667	64.36782	72.77778	90.67797	82.05128	80	90.74074

CO1	**81.3**
CO2	**85.37**

II MID

Computer Methods in Power System(2018-19) SEM-II, MID-II
III YEAR SEC-A

Question number	**1**	**2(a)**	**2(b)**	**3(a)**	**3(b)**	**4(a)**	**4(b)**
CO	**CO3**	**CO4**	**CO4**	**CO5**	**CO5**	**CO3**	**CO3**
Maxmimum Marks	**5**	**2**	**3**	**3**	**2**	**3**	**2**
15241A0243	3						
16241A0201						3	
16241A0202		2	3	3	1	3	2
16241A0203	5	2	3	2	2		
16241A0205		2	2	1	1		
16241A0206		2	3	1		3	2
16241A0207		2				3	
16241A0208		2				2	
16241A0209		1		3	2		2
16241A0210	2	1	3				
16241A0211		2		1		1	
16241A0212		2	1	1	1		
16241A0213	1	2	1	1			

16241A0214		2				2	
16241A0216		2	2				
16241A0217	4	2				2	3
16241A0218		2			1		
16241A0219		2		1	1	1	
16241A0220	1		3				
16241A0221		2	3				
16241A0222		2	1	1	1	1	
16241A0223	5	2	3			3	2
16241A0224	1					1	1
16241A0225	3			2	1	3	2
16241A0226		2	3	1		2	2
16241A0227		2	2	1	1		2
16241A0228		2	1	2			
16241A0229		2	1		1		
16241A0230		2		1			
16241A0231		2		1			
16241A0232							
16241A0233			3				
16241A0234	2	2	1	1			
16241A0235		2	1	1		1	
16241A0236		2			1		1
16241A0237		2		1			
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16241A0239		2	1				1
16241A0240		2		1			2
16241A0241		2		2	1		
16241A0242		2	3	3	2	3	1
16241A0243		2		1	1	3	
16241A0244		2				2	
16241A0245		2		1	1		
16241A0246		2	3	1	2		
16241A0247		2	3	1	1	1	
16241A0248		2	3	1	1	3	
16241A0249		2	2	1			
16241A0250	1	2		2	1		
16241A0251		2		1			
16241A0252	2	2		1	1		
16241A0253		2	1				

16241A0254		2		1	1		
16241A0255		2		1	1		
16241A0256		2	3	1	1	3	2
16241A0257	3	2	3	1	2		
16241A0258		2		1	1		
16241A0259	5	2	3			3	2
16241A0260		2		1			
17245A0201	5	2	3			3	2
17245A0202	1						2
17245A0203							
17245A0204		2	3	1	1	2	2
17245A0205	5	2	3			3	2
17245A0206		2		1	1		1
17245A0207						1	
17245A0208		2			2		
17245A0209		2	3	1	2	3	2
17245A0210	5	2	3			3	2
17245A0211		2		1	2		
17245A0212	3	2	3		2		
Total	57	120	83	52	41	64	40
No of students attempted	19	61	35	41	32	28	22
attempted%	26.76056	85.91549	49.29577	57.74648	45.07042	39.43662	30.98592
average(attainment)	3	1.967213	2.371429	1.268293	1.28125	2.285714	1.818182
%attainment	60	98.36066	79.04762	42.27642	64.0625	76.19048	90.90909

CO3	**75.69**
CO4	**87.41**
CO5	**51.98**

Computer Methods in Power System(2018-19) SEM-II, MID-II

III YEAR SEC-B

Question number	**1(a)**	**2(a)**	**2(b)**	**3(a)**	**3(b)**	**4(a)**	**4(b)**
CO	**CO3**	**CO4**	**CO4**	**CO5**	**CO5**	**CO3**	**CO3**
Maxmimum Marks	**5**	**2**	**3**	**3**	**2**	**3**	**2**
16241A0261		2		2	1	3	1
16241A0262	5	2	3	1	2		
16241A0263		2		1			
16241A0264							
16241A0265		1		1			

16241A0266	1						2
16241A0267		2		1	1	3	1
16241A0268		2		1	2		
16241A0269	5	2		3	2		
16241A0270		2		1	1		
16241A0271		2		1	1		
16241A0272		2		1	1	3	
16241A0273		2		1	1		
16241A0274	2	2	1			3	1
16241A0275		2		1	1		1
16241A0276		2	1	1	1		
16241A0277		2		1	2		
16241A0278	1	2				1	2
16241A0279		2		1	1		
16241A0280	3	2	1	2	1		
16241A0281		2	2	2	1	3	2
16241A0282		2		2	1	1	
16241A0283		1		1	1		
16241A0284		2		1		3	
16241A0285		2		1	1		
16241A0286	2	2				3	
16241A0287		2		1			
16241A0288							
16241A0289		2	1	1	1		
16241A0290	4	2	3	2	2		
16241A0291		2		1	2		
16241A0292	2	2				3	1
16241A0293		2		1	1		
16241A0294				2	1		
16241A0295		2		1	1		1
16241A0296				2	1		
16241A0297		2	3	1	1	1	
16241A0298		2		1	1		
16241A0299		2		1	1		
16241A02A0		2		1			
16241A02A2		2	1	1	1		
16241A02A3		2		1	1		
16241A02A4		2			1	2	1
16241A02A5		2	3		1	3	

16241A02A6	2						
16241A02A7	4	2	3	1	2		
16241A02A8	5	2	2			3	1
16241A02A9	1						
16241A02B0		1					
16241A02B1		2					
16241A02B2		2		1			
16241A02B3		2		1			
16241A02B4	1						
16241A02B5		2	1	1			
16241A02B6	1	2				3	
16241A02B7	4	2	1			3	2
16241A02B8		2		1	1	3	
16241A02B9							
17245A0213	1						
17245A0214	5	2	3	2	2		
17245A0215	1						
17245A0216	1						
17245A0217		1				2	
17245A0218		2		1	2	1	2
17245A0219	1			1	1		
17245A0220	4	2	3			3	2
17245A0221	5	2	3	3	2		
17245A0222	1	2		1	1		
17245A0223	1	1					
17245A0224			1			2	
18248A0201							
Total	63	107	36	57	49	52	20
No of students attempted	25	56	18	45	39	21	14
attempted%	35.21127	78.87324	25.35211	63.38028	54.92958	29.57746	19.71831
average(attainment)	2.52	1.910714	2	1.266667	1.25641	2.47619	1.428571
%attainment	50.4	95.53571	66.66667	42.22222	62.82051	82.53968	71.42857

CO3	**68.11**
CO4	**81.09**
CO5	**52.52**