SYLLABUS

Regulations - 2019

191EEC611L POWER SYSTEM SIMULATION LABORATORY **L T P R C**
0 0 3 1 2

OBJECTIVES:

- To provide better understanding of power system analysis through digital simulation.

LIST OF EXPERIMENTS

1. Computation of Parameters and Modeling of Transmission Lines
2. Formation of Bus Admittance and Impedance Matrices and Solution of Networks.
3. Load Flow Analysis - I : Solution of load flow and related problems using Gauss-Seidel Method
4. Load Flow Analysis - II: Solution of load flow and related problems using Newton Raphson.
5. Fault Analysis
6. Transient and Small Signal Stability Analysis: Single-Machine Infinite Bus System
7. Transient Stability Analysis of Multi machine Power Systems
8. Electromagnetic Transients in Power Systems
9. Load – Frequency Dynamics of Single- Area and Two-Area Power Systems
10. Economic Dispatch in Power Systems.

TOTAL : 60 PERIODS

OUTCOMES:

Upon completion of this course, student will be able to:

- Develop simple MATLAB programs to compute the transmission line parameters.
- Build the network matrices and analyze the power flow using computer based iterative techniques.
- Compute the fault currents under Symmetric and Unsymmetrical fault conditions using programming platform.
- Estimate the transient stability of a single and multi machine system and analyze the electromagnetic transient phenomena in power system using MATLAB and Electromagnetic Transients Program.
- Simulate the Load-Frequency Dynamics in single area and multi area power systems.
- Solve the Economic Load Dispatch problem using MATLAB.

EASWARI ENGINEERING COLLEGE
(Autonomous)

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

LESSON PLAN FOR LABORATORY - EVEN SEM (2022-23)

Regulations 2019

Subject Code: 191EEC611L
Subject Name: Power System Simulation Laboratory
Year /Semester: III /VI
Faculty Incharge: Dr.K.Prabaakaran & Mrs.D.Chandrakala

Degree/ Branch : B.E/EEE
Total No of Hrs : 60
Lecture: : 0
Tutorial : 0
Practical : 45
Research : 15
Grand Total : 60

Course Objective:

- To provide better understanding of power system analysis through digital simulation.

S. No.	Experiment Name	Hours
1	Computation of Parameters and Modeling of Transmission Lines.	4
2.	Formation of Bus Admittance and Impedance Matrices and Solution of Networks	8
3.	Load Flow Analysis - I : Solution of load flow and related problems using Gauss-Seidel Method	4
4.	Load Flow Analysis - II: Solution of load flow and related problems using Newton Raphson.	4
5.	Fault Analysis	5
6.	Transient and Small Signal Stability Analysis: Single-Machine Infinite Bus System	4
7.	Transient Stability Analysis of Multi machine Power Systems	4
8.	Electromagnetic Transients in Power Systems	4
9.	Load – Frequency Dynamics of Single- Area and Two-Area Power Systems	4
10.	Economic Dispatch in Power Systems	4
11	Mini Project	15
	Total Hours	**60**

Content beyond Syllabus

S. No.	Experiment Name
1.	Study Of Variable Speed Wind Energy Conversion System Using –PMSG
2.	Automatic voltage regulator

COURSE OUTCOMES

Upon completion of the course, the students will be able to

191EEC611L.1	Develop simple MATLAB programs to compute the transmission line parameters.
191EEC611L.2	Build the network matrices and analyze the power flow using computer based iterative techniques.
191EEC611L.3	Compute the fault currents under Symmetric and Unsymmetrical fault conditions using programming platform
191EEC611L.4	Estimate the transient stability of a single and multi machine system and analyze the electromagnetic transient phenomena in power system using MATLAB and Electromagnetic Transients Program.
191EEC611L.5	Simulate the Load-Frequency Dynamics in single area and multi area power systems.
191EEC611L.6	Solve the Economic Load Dispatch problem using MATLAB.

PROGRAM OUTCOMES (POs)

Engineering Graduates will be able to:

PO1: Engineering knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.

PO2: Problem analysis: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

PO3: Design/development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

PO4: Conduct investigations of complex problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

PO5: Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

PO6: The engineer and society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

PO7: Environment and sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

PO8: Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

PO9: Individual and team work: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.

PO10: Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

PO11: Project management and finance: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

PO12: Life-long learning: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

PROGRAM SPECIFIC OUTCOMES:

PSO1: Use logical & technical skills to model, simulate and analyze electrical components and systems.

PSO2: Integrate the knowledge of fundamental electronics, power electronics and embedded systems for the controllability, reliability and sustainability of electrical systems.

PSO3: Contribute for the development of smart power grid and integrating green energy on it to meet the increasing demand of the society.

Mapping of Course Outcome with Program Outcome

CO/PO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
191EEC611L.1	3	3	3	3	3	1	1	-	1	1	2	2
191EEC611L.2	3	3	3	3	3	1	1	-	1	1	2	2
191EEC611L.3	3	3	3	3	3	1	1	-	1	1	2	2
191EEC611L.4	3	3	3	3	3	1	1	-	1	1	2	2
191EEC611L.5	3	3	3	3	3	1	1	-	1	1	2	2
191EEC611L.6	3	3	3	3	3	1	1	-	1	1	2	2
191EEC611L	3	3	3	3	3	1	1	-	1	1	2	2

Justification of the Mapping

191EEC611L.1	By computing the parameters for the given transmission line, it attributes strongly to Engineering knowledge (PO1) as the student will apply the engineering fundamentals. This will help in problem analysis (PO2), Design development of solutions (PO3) and in Investigation of complex problems (PO4) strongly. By developing the coding to compute the parameters using MATLAB, this highly attributes to the modern tool usage (PO5). The analysis carried out weakly maps with the engineer and society (PO6) and Environment and sustainability (PO7). The student will be able to apply the fundamentals to his own work maps the Individual and team work (PO9),Communications (PO10) and keep progressing in his research field lifelong which moderately maps the Project Management and Finance (PO11) and lifelong learning

	(PO12).
191EEC611L.2	By building the network matrices and analyzing the power flow using Gauss seidel and Newton Raphson method for the given network it strongly maps with Engineering knowledge (PO1), Problem analysis (PO2), Design /development of solutions (PO3) and Investigation of complex problems (PO4). By developing the coding to find the load flow analysis using MATLAB this highly attributes to modern tool usage (PO5). Power system planning and operational studies weakly maps the Engineer and society (PO6) and Environment and sustainability (PO7), the Individual and team work (PO9) and Communications (PO10). By analyzing the power flow problems using iterative techniques it moderately maps with Project Management and Finance (PO11) and lifelong learning (PO12).
191EEC611L.3	By Computing the fault currents during Symmetric and Unsymmetrical fault, it strongly maps with Engineering knowledge (PO1) and Problem analysis (PO2), Design/ development of solutions (PO3) and Investigation of complex problems (PO4). By developing the coding to calculate the Symmetric and Unsymmetrical fault component using MATLAB this highly attributes to modern tool usage (PO5). The Symmetric and Unsymmetrical fault analysis promotes the engineer and society (PO6), Environment and sustainability (PO7), Individual and team work (PO9) and Communications (PO10) weakly. By analyzing the various faults he/she can able to identify the fault current in a network and it moderately maps with Project Management and Finance (PO11) and lifelong learning (PO12).
191EEC611L.4	By estimating the transient stability of a single and multi machine system and analyzing the electromagnetic transient phenomena in power system, it strongly contributes to Engineering knowledge (PO1) and Problem analysis (PO2). By developing the coding to find the state of the system and the transient analysis using MATLAB it strongly maps with Design/development of solutions (PO3) and Investigation of complex problems (PO4) and modern tool usage (PO5). The analysis of transient stability of a machine carried out weakly maps with the engineer and society (PO6), Environment and sustainability (PO7), the Individual and team work (PO9) and Communications (PO10). By analyzing the electromagnetic transient phenomena in power system it moderately maps with Project Management and Finance (PO11) and lifelong learning (PO12).
191EEC611L.5	By developing the load frequency dynamics for single area and multi area power systems strongly maps with Engineering knowledge (PO1) and Problem analysis (PO2). By designing the load frequency dynamics for single area and multi area power systems using MATLAB SIMULINK MODEL strongly attributes with Design/development of solutions (PO3), Investigation of complex problems (PO4) and modern tool usage (PO5). Modeling the frequency and tie-line flow dynamics of a power system without and with load frequency controllers (LFC) weakly maps with the engineer and society (PO6), Environment and sustainability (PO7), Individual and team work (PO9) and Communications (PO10). By analyzing the frequency and tie-line flow

	dynamics of a power system it moderately maps with Project Management and Finance (PO11) and lifelong learning (PO12).
191EEC611L.6	By solving the economic load dispatch problem it attributes strongly to Engineering knowledge (PO1), problem analysis (PO2), Design/ development of solutions (PO3) and Investigation of complex problems (PO4). Developing the coding to find the optimal load dispatch schedule using MATLAB attributes strongly to modern tool usage (PO5). By determining the low possible cost it maps weakly with the engineer and society (PO6), Environment and sustainability (PO7), individual and team work (PO9) and Communications (PO10) and he/she can able to do research in this field moderately with Project Management and Finance (PO11) and lifelong learning (PO12).

Mapping of Course Outcomes with the Program Specific Outcomes:

CO/PSO	PSO1	PSO2	PSO3
191EEC611L.1	3	1	3
191EEC611L.2	3	1	3
191EEC611L.3	3	1	3
191EEC611L.4	3	1	3
191EEC611L.5	3	1	3
191EEC611L.6	3	1	3
191EEC611L	3	1	3

Justification of the Mapping

191EEC611L.1	By computing the parameters for the given transmission line it strongly maps with logical and technical skills (PSO1), weakly maps with the sustainability of electrical systems (PSO2) and strongly maps with the development of smart grid (PSO3).
191EEC611L.2	By building the network matrices and analyzing the power flow using Gauss seidel and Newton Raphson method for the given network it strongly maps with logical and technical skills (PSO1) weakly maps with the sustainability of electrical systems (PSO2) and strongly maps with the development of smart grid (PSO3).
191EEC611L.3	By Computing the fault currents during Symmetric and Unsymmetrical fault it strongly maps with logical and technical skills (PSO1) weakly maps with the sustainability of electrical systems (PSO2) and strongly maps with the development of smart grid (PSO3).
191EEC611L.4	By estimating the transient stability of a single and multi machine system and analyzing the electromagnetic transient phenomena in power system, it strongly maps with logical and technical skills (PSO1) and weakly maps with the sustainability of electrical systems (PSO2) and strongly maps with the development of smart grid (PSO3).

191EEC611L.5	By developing the load frequency dynamics for single area and multi area power systems it strongly maps with logical and technical skills (PSO1) weakly maps with the sustainability of electrical systems (PSO2) and strongly maps with the development of smart grid (PSO3).
191EEC611L.6	By solving the economic load dispatch problem it strongly maps with logical and technical skills (PSO1) weakly maps with the sustainability of electrical systems (PSO2) and strongly maps with the development of smart grid (PSO3).

Ex. No.:	COMPUTATION OF PARAMETERS AND MODELING OF TRANSMISSION LINES
Date:	

1.1 AIM

To determine the positive sequence line parameters L and C per phase per kilometer of a three phase transmission lines for different conductor arrangements.

1.2 OBJECTIVES

i. To become familiar with different arrangements of conductors of a three phase single and double circuit transmission lines and to compute the GMD and GMR for different arrangements.
ii. To compute the series inductance and shunt capacitance per phase, per km of a three phase single and double circuit overhead transmission lines with solid and bundled conductors.

1.3 SOFTWARE REQUIRED

The software required is **MATLAB.**

1.4. THEORETICAL BACK GROUND

1.4.1 Inductance

The inductance is computed from flux linkage per ampere. In the case of the three phase lines, the inductance of each phase is not the same if conductors are not spaced equilaterally. A different inductance in each phase results in unbalanced circuit. Conductors are transposed in order to balance the inductance of the phases and the average inductance per phase is given by simple formulas, which depends on conductor configuration and conductor radius.

General Formula

The general formula for computing inductance per phase in mH per km of a transmission is given by

$$\mathbf{L = 0.2 \ln D_m/D_s} \quad (1)$$

where

D_m = Geometric Mean Distance (GMD)

D_s = Geometric Mean Radius (GMR)

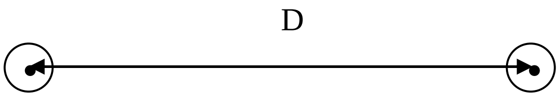
The expression for GMR and GMD for different arrangement of conductors of the transmission lines are given in the following section.

EXERCISES

1. A single circuit three phase transposed transmission line is composed of four ACSR 1,272,000 cmil conductor per phase with flat horizontal spacing of 14 m between phases a and b and between phases b and c. The bundle spacing is 45 cm. The conductor diameter is 3.416 cm.

a) Determine the inductance and capacitance per phase per kilometer of the line.
b) Verify the results using available program.

I. Single Phase - 2 Wire System

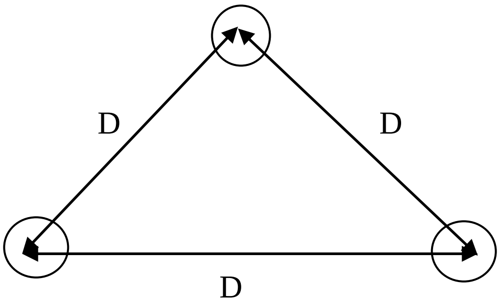


GMD = D (2)

GMR = $re^{-1/4} = r'$ (3)

r = radius of conductor

II. Three Phase - Symmetrical Spacing:

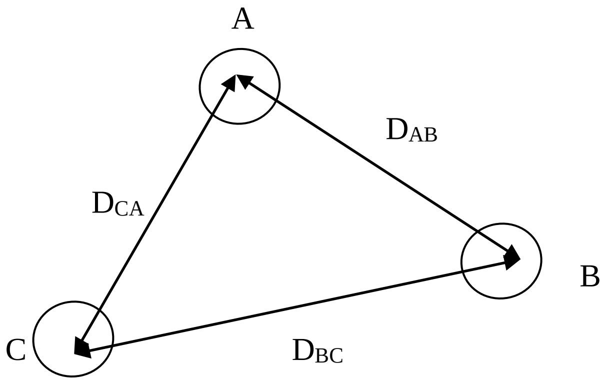


GMD = D (4)

GMR = $re^{-1/4} = r'$ (5)

r = radius of conductor

III. Three Phase - Asymmetrical Transposed:



GMD = Geometric mean of the three distances of the asymmetrically placed conductors

$= \sqrt[3]{D_{AB}D_{BC}D_{CA}}$ (6)

GMR = $re^{-1/4} = r'$ (7)

r = radius of conductors

2. A three-phase transposed line composed of one ACSR, 1,43,000 cmil, 47/7 Bobolink conductor per phase with flat horizontal spacing of 11m between phases a and b and between phases b and c. The conductors have a diameter of 3.625 cm and a GMR of 1.439 cm. The line is to be replaced by a three conductor bundle of ACSR 477,000-cmil, 26/7 Hawk conductors having the same c ross sectional area of aluminum as the single-conductor line. The conductors have a diameter of 2.1793 cm and a GMR of 0.8839 cm. The new line will also have a flat horizontal configurations, but it is to be operated at a higher voltage and therefore the phase spacing is increased to 14m as measured from the centre of the bundles. The spacing between the conductors in the bundle is 45 cm.

a) Determine the inductance and capacitance per phase per kilometer of the above two lines.
b) Verify the results using the available program.
c) Determine the percentage change in the inductance and capacitance in the bundle conductor system. Which system is better and why?

Composite Conductor Lines

Composite conductor is composed of two or more elements or strands electrically in parallel. The expression derived for the inductance of composite conductors can be used for the stranded and bundled conductors and also for finding GMD and GMR of parallel transmission lines. Fig shows a single phase line with two composite conductors.

Conductor X-with n strands **Conductor Y with m strands**

The inductance of composite conductor X is given by

$$L_x = 0.2 \ln GMD/GMRx \qquad (8)$$

where

$$GMD = \sqrt[mn]{(D_{aa'}\,D_{ab'}\,\ldots\,D_{am'})\ \ldots\ldots\ (D_{na'}\,D_{nb'}\ldots..\,D_{nm'})} \qquad (9)$$

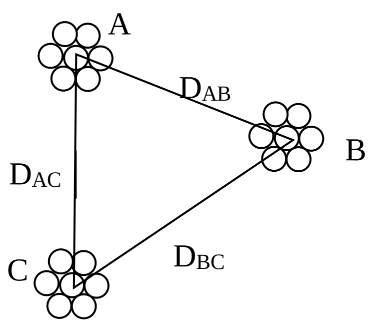
$$GMRx = \sqrt[n^2]{(D_{aa'}\,D_{ab'}\,\ldots\,D_{am'})\ \ldots\ldots\ (D_{na'}\,D_{nb'}\ldots..\,D_{nn'})} \qquad (10)$$

$r'_a = r_a e^{-1/4}$

The distance between elements are represented by D with respective subscripts and r'_a, r'_b and r'_n have been replaced by D_{aa}, D_{bb} …… and D_{nn} respectively for symmetry.

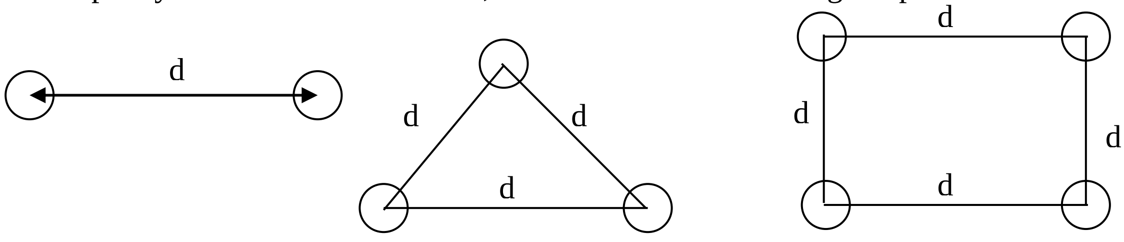
Stranded Conductors:

The GMR for the stranded conductors are generally calculated using equation (10). For the purpose of GMD calculation, the stranded conductors can be treated as solid conductor and the distance between any two conductors can be taken as equal to as center-to-center distance between the stranded conductors as shown in Figure, since the distance between the conductors is high compared to the distance between the elements in a stranded conductor. This method is sufficiently accurate.



Bundle Conductors

EHV lines are constructed with bundle conductors. Bundle conductors improves power transfer capacity and reduces corona loss, radio interference and surge impedance.



Examples of bundles

The GMR of a bundle conductor is normally calculated using (10).

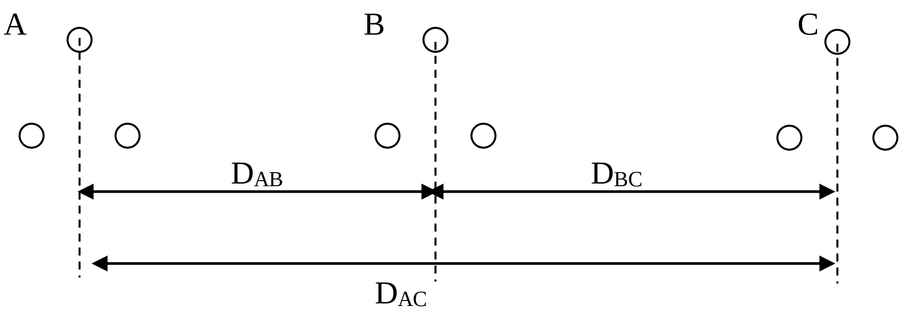
GMR for two subconductor $D_s^b = \sqrt{D_s \text{ x } d}$

GMR for three subconductor $D_s^b = (D_s x d^2)^{1/3}$

GMR for four subconductor $D_s^b = 1.09x\ (D_s x d^3)^{1/4}$

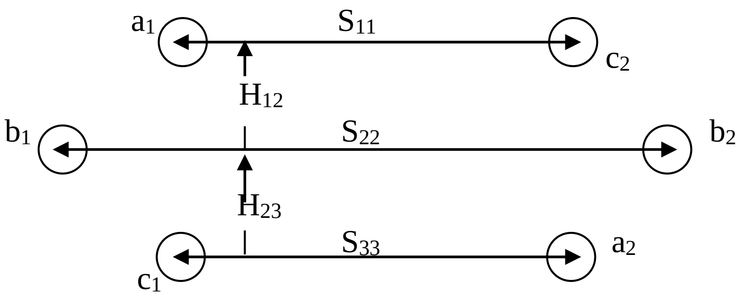
Where D_s is the GMR of each sub conductor and d is the bundle spacing

For the purpose of GMD calculation, the bundled conductor can be treated as a solid conductor and the distance between any two conductors can be taken as equal to center-to-center distance between the bundled conductors as shown in Fig, since the distance between the conductors is high compared to bundle spacing.



Three phase - Double circuit transposed

A three-phase double circuit line consists of two identical three-phase circuits. The phases a, b and c are operated with a_1-a_2, b_1-b_2 and c_1-c_2 in parallel respectively. The GMD and GMR are computed considering that identical phase forms a composite conductor. For example, phase a conductors a_1 and a_2 form a composite conductor and similarly for other phases.



Relative phase position $a_1b_1c_1 - c_2b_2a_2$.

It can also be $a_1b_1c_1 - a_2b_2c_2$.

The inductance per phase in milli henries per km is

$L = 0.2 \ln (GMD/GMR_L)$ mH/km. (11)

where

GMR_L is equivalent geometric mean radius and is given by

$GMR_L = (D_{SA}\, D_{SB}\, D_{SC})^{1/3}$ (12)

where

D_{SA} D_{SB} and D_{SC} are GMR of each phase group and given (refer 1.10) by

$D_{SA} = \sqrt[4]{(D_s^b\, D_{a1a2})^2} = [D_s^b\, D_{a1a2}]^{1/2}$

$D_{SB} = \sqrt[4]{(D_s^b\, D_{b1b2})^2} = [D_s^b\, D_{b1b2}]^{1/2}$ (13)

$D_{SC} = \sqrt[4]{(D_s^b\, D_{c1c2})^2} = [D_s^b\, D_{c1c2}]^{1/2}$

where

D_s^b = GMR of bundled conductor if conductor a_1, a_2 …. are bundle conductor.

$D_s^b = r_{a1}' = r_{b1}' = r_{c1}' = r_{a2}' = r_{b2}' = r_{c2}'$ if a_1, a_2 ….. are not bundled conductor.

GMD is the "equivalent GMD per phase" & is given by

$GMD = [D_{AB}\, D_{BC}\, D_{CA}]^{1/3}$ (14)

where

$D_{AB},$ $D_{BC},$ & D_{CA} are GMD between each phase group A-B, B-C, C-A which are given by

$D_{AB} = [D_{a1b1}\, D_{a1b2}\, D_{a2b1}\, D_{a2b2}]^{1/4}$ (15)

$D_{BC} = [D_{b1c1}\, D_{b1c2}\, D_{b2c1}\, D_{b2c2}]^{1/4}$ (16)

$D_{CA} = [D_{c1a1}\, D_{c2a1}\, D_{c2a1}\, D_{c2a2}]^{1/4}$ (17)

1.4.2 Capacitance

A general formula for evaluating capacitance per phase in micro farad per km of a transmission line is given by

$C = 0.0556/\ln (GMD/GMR)$ μF/km (18)

where

GMD is the "Geometric Mean Distance" which is the same as that defined for inductance under various cases.

GMR is the Geometric Mean Radius and is defined case by case below:

(i) Single phase two wires system (for diagram see inductance):

GMD = D

GMR = r (as against r' in the case of L)

(ii) Three phase - symmetrical spacing (for diagram see inductance):

GMD = D

GMR = r in the case of solid conductor

$= D_s$ in the case of stranded conductor to be obtained from manufacturer's data.

(iii) Three-phase – Asymmetrical - transposed (for diagram see Inductance):

$$GMD = [D_{AB}\, D_{BC}\, D_{CA}]^{1/3} \tag{19}$$

GMR = r ; for solid conductor

GMR = D_s for stranded conductor

= r^b for bundled conductor

where

$r^b = [r*d]^{1/2}$ for 2 conductor bundle

$r^b = [r*d^2]^{1/3}$ for 3 conductor bundle (20)

$r^b = 1.09\,[r*d^3]^{1/4}$ for 4 conductor bundle

where

r = radius of each subconductor

d = bundle spacing

(iv) Three phase - Double circuit - transposed (for diagrams see inductance):

C = 0.0556 / ln (GMD/GMRc) μF/km

GMD is the same as for inductance as equation (14).

GMRc is the equivalent GMR, which is given by

$$GMRc = [r_A\, r_B\, r_C\,]^{1/3} \tag{21}$$

3. Determine the receiving end voltage and current of a 3 phase,100 km long,50 Hz line having sending end quantities such as 75 MW, 66 kV , 0.99 leading power factor. Also find %regulation and efficiency.

Given that r=0.1 Ω/km, Inductive reactance= 0.2 Ω/km ;

Shunt susceptance = 4 x 10^{-4} siemens.

where

r_A, r_B and r_C are GMR of each phase group obtained as

$r_A = [r^b \, D_{a1a2}]^{1/2}$

$r_B = [r^b \, D_{b1b2}]^{1/2}$

$r_C = [r^b \, D_{c1c2}]^{1/2}$ (22)

where r^b GMR of bundle conductor

1.4.3 Line Modelling and Performance Analysis

The following nomenclature adopted in modelling:

- z = series impedance per unit length per phase
- y = shunt admittance per unit length per phase to neutral.
- L = inductance per unit length per phase
- C = capacitance per unit length per phase
- r = resistance per unit length per phase
- l = length of the line
- Z = zl = total series impedance
- Y = yl = total shunt admittance per phase to neutral.

Short line Model and Equations (Lines Less than 80km)

The equivalent circuit of a short transmission line is shown in Fig.1

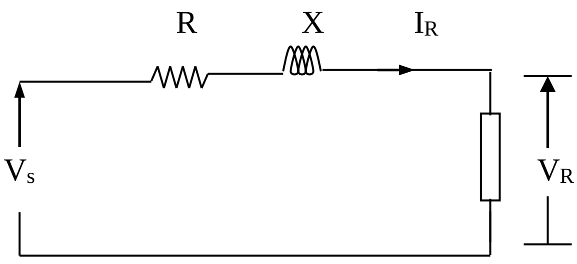


Figure 1. Short Line Model

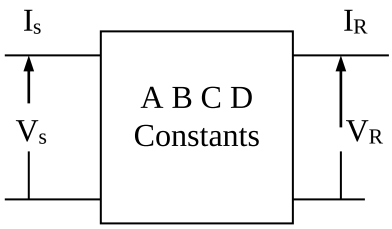


Figure 2. Two port representation of a Line

In this representation, the lumped resistance and inductance are used for modelling and the shunt admittance is neglected. A transmission line may be represented by a two port network as shown and current and voltage equations can be written in terms of generalised constants known as A B C D constants.

For the circuit shown above the voltage and currents relationships are given by

$$V_s = V_R + Z\,I_R \qquad (23)$$

$$I_s = I_R \qquad (24)$$

In terms of A B C D constants

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \quad (25)$$

where

A = 1, B = Z, C = 0 D= 0.

$$\text{Percentage regulation} = \frac{|V_{R\,(NL)}| - |V_{R\,(FL)}|}{|V_{R(\,FL)}|} \times 100 \quad (26)$$

$$|V_{R\,(NL)}| = |V_S| / A$$

$$\text{Transmission efficiency of the line} = \frac{\text{Receiving end power in MW}}{\text{Sending end power in MW}} = \frac{P_R\,(3\Phi)}{P_s\,(3\Phi)} \quad (27)$$

Medium Line Model and equations (Lines above 80km):

The shunt admittance is included in this model. The total shunt admittance is divided into two equal parts and placed at the sending and receiving end as in Fig.3

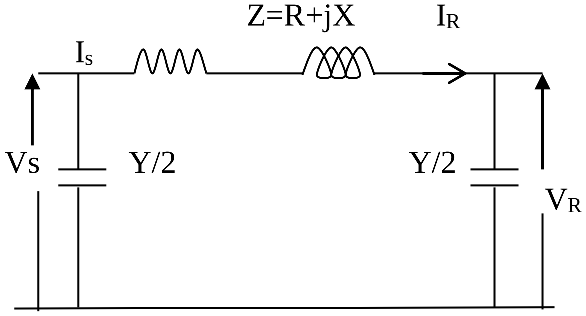


Fig.3 Nominal π Model

The voltage current relations are given by

$$V_s = \left(1+\frac{ZY}{2}\right) V_R + ZI_R \quad (28)$$

$$I_s = Y\left(1+\frac{ZY}{4}\right) V_R + \left(1+\frac{ZY}{2}\right) I_R \quad (29)$$

In terms of ABCD constants

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{pmatrix} A & B \\ C & D \end{pmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \quad (30)$$

where

$A = \left(1+\frac{ZY}{2}\right)$, B=Z ;

$C = Y\left(1+ \frac{ZY}{4}\right)$, $D=\left(1+\frac{ZY}{2}\right)$

The receiving end quantities can be expressed in terms of sending end quantities as

$$\begin{pmatrix} V_R \\ I_R \end{pmatrix} = \begin{pmatrix} D & -B \\ -C & A \end{pmatrix} \begin{pmatrix} V_s \\ I_s \end{pmatrix} \qquad (31)$$

Long line Model and Equations (lines above 250 km):

In the short and Medium lines, lumped line parameters are used in the model. For accurate modelling, the effect of the distributed line parameter must be considered. The voltage and current at any specific point along the line in terms of the distance x from the receiving end is given by

$$V(x) = \left(\frac{V_R + Z_c I_R}{2}\right) e^{\gamma x} + \left(\frac{V_R - Z_c I_R}{2}\right) e^{-\gamma x} \qquad (32)$$

$$I(x) = \left(\frac{(V_R / Z_c) + I_R}{2}\right) e^{\gamma x} - \left(\frac{(V_R/Z_C) - I_R}{2}\right) e^{-\gamma x} \qquad (.33)$$

In term of Hyperbolic functions

$$V(x) = V_R \cosh \gamma x + Z_c I_R \sinh \gamma x \qquad (34)$$

$$I(x) = (1/Z_c)\, V_R \sinh \gamma x + I_R \cosh \gamma x \qquad (35)$$

where

$Z_c = \sqrt{z/y}$ is called characteristic impedance

$\gamma = \sqrt{zy}$ is called propagation constant

$= \alpha + j\beta = \sqrt{zy} = \sqrt{(\gamma + j\omega L)(g + j\omega c)}$

α – is called attenuation constant

β – is called phase constant

The relation between sending and receiving end quantities is given by

$V_s = V_R \cosh \gamma l + Z_c I_R \sinh \gamma l$

$I_S = (V_R/Z_c) \sinh \gamma l + I_R \cosh \gamma l \qquad (36)$

The equivalent π model of the long line is given in Fig. 1.12.

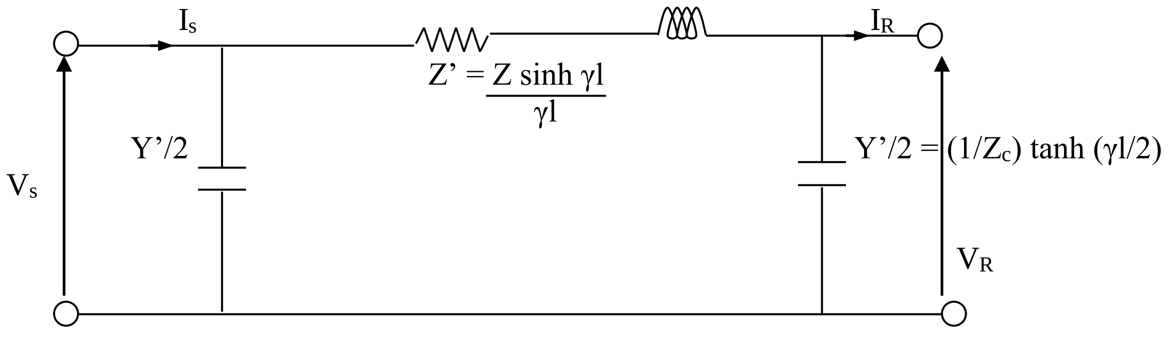


Figure 4 Equivalent π model

1.5 PROGRAMS

1.6 VIVA QUESTIONS

1. What is GMD?
2. What is GMR?
3. What is known as skin effect?
4. What are the advantages of standard conductor over a solid conductor?
5. What is meant by ACSR?

Preparation (2)	Model calculation/Execution(5)	Viva (3)

1.7 RESULT

The line parameters L and C per phase per kilometer of a three phase transmission lines for different conductor arrangements were determined and verified using MATLAB.

Ex. No.:	FORMATION OF BUS ADMITTANCE AND IMPEDANCE MATRICES AND SOLUTION OF NETWORKS
Date:	

2.1 AIM

To understand the formation of network matrices, the bus admittance matrix **Y** and the bus impedance matrix **Z** of a power network.

2.2 OBJECTIVES

i. To write a MATLAB program to form bus admittance matrix **Y**, given the impedances of the elements of a power network and their connectivity (mutual coupling between elements neglected)

ii. To obtain the bus impedance matrix **Z** using bus building algorithm.

2.3 SOFTWARE REQUIRED

The software required is **MATLAB.**

2.4 THEORETICAL BACKGROUND

2.4.1 Formation of Y_{bus}

The Y_{bus} matrix constitutes the models of the passive portions of the power network. Y_{bus} matrix is often used in solving load flow problems. It has gained widespread applications owing to its simplicity of data preparation and the ease with which the bus admittance matrix can be formed and modified for network changes. Of course, sparsity is one of its greatest advantages as it heavily reduces computer memory and time requirement.

The performance equation for a n-bus system in terms of admittance matrix can be written as,

$$\begin{bmatrix} I_1 \\ I_2 \\ . \\ . \\ I_n \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} \dots Y_{1n} \\ Y_{21} & Y_{22} \dots Y_{2n} \\ . & . \\ . & . \\ Y_{n1} & Y_{n2} \dots Y_{nn} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ . \\ . \\ V_n \end{bmatrix} \quad \text{(or)}$$

$$I = Y_{bus}.V \qquad (1)$$

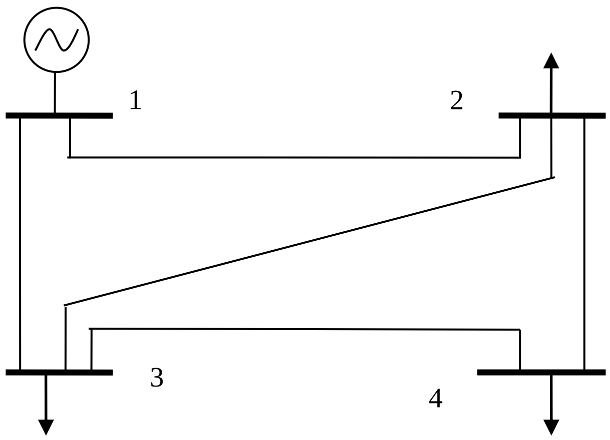
The admittances Y_{11}, $Y_{12,}$ Y_{1n} are called the self-admittances at the nodes and all other admittances are called the mutual admittances of the nodes.

EXERCISES

1. Form the Y_{bus} matrix for the four-bus system shown in Figure .The line parameters are given in the following table:

Line Data:

Bus code	Impedance	Line charging admittance
1 – 2	0.02 + j0.08	j0.04
1 – 3	0.06 + j0.24	j0.03
2 – 3	0.04 + j0.16	j0.025
2 – 4	0.04 + j0.16	j0.025
3 – 4	0.01 + j0.04	j0.015



Formulae Used

Main diagonal element in Y-bus matrix = $\sum_{j=1}^{n} Y_{ij} + B_{IJ}$ (2)

Where Bij is the half line shunt admittance in mho.

Y_{ij} is the series admittance in mho.

Off-diagonal element in Y-bus matrix, $Y_{ij} = -Y_{ij}$

Where Y_{ij} is the series admittance in mho.

Algorithm

Step 1: Read the values of number of buses and the number of lines of the given system.

Step 2: Read the self-admittance of each bus and the mutual admittance between the buses.

Step 3: Calculate the diagonal element term called the bus driving point admittance, Y_{ij} which is the sum of the admittance connected to bus i.

Step 4: The off-diagonal term called the transfer admittance, Y_{ij} which is the negative of the admittance connected from bus i to bus j.

Step 5: Check for the end of bus count and print the computed Y-bus matrix.

Step 6: Compute the Z-bus matrix by inverting the Y-bus matrix.

Step 7: Stop the program and print the results.

2.4.2 Formation of Z_{bus}

The Z_{bus} matrix constitutes the models of the passive portions of the power network. The impedance matrix is a full matrix and is most useful for short circuit studies. An algorithm for formulating $[Z_{bus}]$ is described in terms of modifying an existing bus impedance matrix designated as $[Z_{bus}]_{old}$. The modified matrix is designated as $[Z_{bus}]_{new}$. The network consists of a reference bus and a number of other buses. When a new element having self impedance Z_b is added, a new bus may be created (if the new element is a tree branch) or a new bus may not be created (if the new element is a link). Each of these two cases can be subdivided into two cases so that Z_b may be added in the following ways:

Adding Z_b from a new bus to reference bus.

Adding Z_b from a new bus to an existing bus.

Adding Z_b from an existing bus to reference bus.

Adding Z_b between two existing buses.

Type 1 modification:

In type 1 modification, an impedance Z_b is added between a new bus *p* and the reference bus as shown in Figure 1

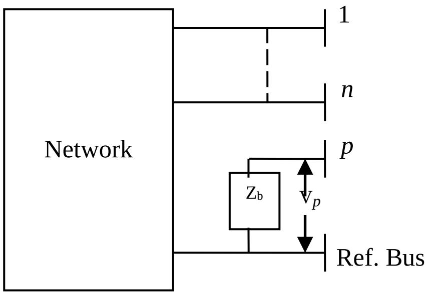


Figure 1. Type 1 modification of Z_{bus}

Let the current through bus *p* be I_p, then the voltage across the bus *p* is given by,

$$V_p = I_p Z_b \qquad (3)$$

The potential at other buses remains unaltered and the system equations can be written as,

$$\begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ \vdots \\ V_n \\ \cdots \\ V_p \end{bmatrix} = \begin{bmatrix} & & & & & \vdots & 0 \\ & & & & & \vdots & 0 \\ & & [Z_{bus}]_{old} & & & \vdots & 0 \\ & & & & & \vdots & 0 \\ & & & & & \vdots & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \vdots & \cdots \\ 0 & 0 & 0 & 0 & 0 & \vdots & Z_b \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ \vdots \\ I_n \\ \cdots \\ I_p \end{bmatrix}$$

Type 2 modification:

In type 2 modification, an impedance Z_b is added between a new bus *p* and an existing bus *k* as shown in Figure 2. The voltages across the bus *k* and *p* can be expressed as,

$$V_{k(new)} = V_k + I_p Z_{kk}$$

$$V_p = V_{k(new)} + I_p Z_p = V_k + I_p(Z_b + Z_{kk}) \qquad (4)$$

where, V_k is the voltage across bus *k* before the addition of impedance Z_b

Z_{kk} is the sum of all impedance connected to bus *k*.

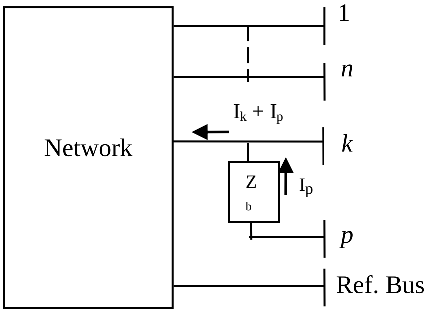
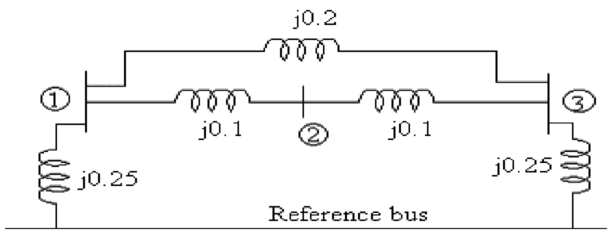


Figure 2.Type 2 Modification of Z_{bus}

2. Form the Bus Impedance Matrix of the network shown in Figure 1 using bus building algorithm



The system of equations can be expressed as,

$$
\begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ \vdots \\ V_n \\ \cdots \\ V_p \end{bmatrix}
=
\left[\begin{array}{ccccc|c}
 & & & & & Z_{1k} \\
 & & & & & Z_{2k} \\
 & & [Z_{bus}]_{old} & & & \vdots \\
 & & & & & \vdots \\
 & & & & & \vdots \\
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots\ \cdots \cdots \\
Z_{k1} & Z_{k2} & \cdots & \cdots & \cdots & Z_{kk} + Z_b
\end{array}\right]
\begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ \vdots \\ I_n \\ \cdots \\ I_p \end{bmatrix}
$$

Type 3 Modification:

In this modification, an impedance Z_b is added between a existing bus *k* and a reference bus. Then the following steps are to be followed:
Add Z_b between a new bus *p* and the existing bus *k* and the modifications are done as in type 2.
Connect bus *p* to the reference bus by letting $V_p = 0$.
To retain the symmetry of the Bus Impedance Matrix, network reduction technique can be used to remove the excess row or column.

Type 4 Modification:

In this type of modification, an impedance Z_b is added between two existing buses j and k as shown in Figure 3. From Figure 3, the relation between the voltages of bus *k* and *j* can be written as,

$$V_k – V_j = I_b Z_b \tag{5}$$

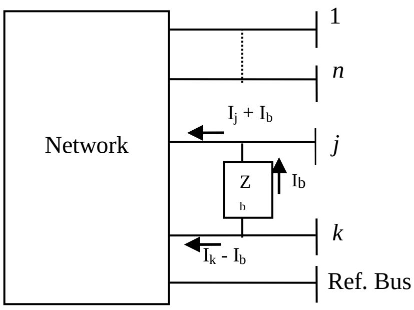


Figure 3.Type 4 Modification of Z_{bus}

The voltages across all the buses connected to the network changes due to the addition of impedance Z_b and they can be expressed as,

$$V_1 = Z_{11}I_1 + Z_{12}I_2 + \text{- - - - - - - -} + Z_{1j}(I_j + I_b) + Z_{1k}(I_k - I_b) + \text{- - -}$$

$$V_2 = Z_{21}I_1 + Z_{22}I_2 + \text{- - - - - - - -} + Z_{2j}(I_j + I_b) + Z_{2k}(I_k - I_b) + \text{- - -}$$

$$\vdots \qquad\qquad \vdots \qquad\qquad \vdots \qquad\qquad \vdots$$

$$V_j = Z_{j1}I_1 + Z_{j2}I_2 + \text{- - - - - - - -} + Z_{jj}(I_j + I_b) + Z_{jk}(I_k - I_b) + \text{- - -}$$

$$V_k = Z_{k1}I_1 + Z_{k2}I_2 + \text{- - - - - - - -} + Z_{kj}(I_j + I_b) + Z_{kk}(I_k - I_b) + \text{- - -}$$

$$\vdots \qquad\qquad \vdots \qquad\qquad \vdots \qquad\qquad \vdots$$

$$V_n = Z_{n1}I_1 + Z_{n2}I_2 + \text{- - - - - - - -} + Z_{nj}(I_j + I_b) + Z_{nk}(I_k - I_b) + \text{- - -}$$

On solving the Equations (3) and (4), the system of equations can be rewritten as,

$$\begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ \vdots \\ V_n \\ \cdots \\ V_p \end{bmatrix} = \left[\begin{array}{ccccc:c} & & & & & (Z_{1j} - Z_{1k}) \\ & & & & & \vdots \\ & [Z_{bus}]_{old} & & & & \vdots \\ & & & & & \vdots \\ & & & & & (Z_{kj} - Z_{kk}) \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ (Z_{j1} - Z_{k1}) & \cdots & \cdots & \cdots & (Z_{jk} - Z_{kk}) & Z_{bb} \end{array}\right] \begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ \vdots \\ I_n \\ \cdots \\ I_p \end{bmatrix}$$

where,

$$Z_{bb} = Z_{jj} + Z_{kk} - 2\,Z_{jk} + Z_b \qquad (6)$$

Algorithm

Step1: Number the nodes of the given network, starting with those nodes at the ends of branches connected to the reference node.

Step2: Start with a network composed of all those branches connected to the reference node.

Step3: Add a new node to the i^{th} node of the existing network.

Step4: Add a branch between i^{th} and j^{th} nodes. Continue until all the remaining branches are connected.

2.5 PROGRAMS

2.6 VIVA QUESTIONS

1. What is primitive impedance matrix?
2. What is a sparse matrix?
3. What is driving point and transfer admittance?
4. What are the methods to obtain Zbus?
5. Why is computation hard with Zbus when compared to Ybus?

Preparation (2)	Model calculation/Execution(5)	Viva (3)

2.7 RESULT

The bus admittance matrix by direct inspection method and the bus impedance matrix by bus building algorithm were formed for the given system and the results were verified using MATLAB program.

Ex. No.:	LOAD FLOW ANALYSIS - I : SOLUTION OF LOAD FLOW AND RELATED PROBLEMS USING GAUSS-SEIDEL METHOD
Date:	

3.1 AIM

(i) To understand, the basic aspects of steady state analysis of power systems that are required for effective planning and operation of power systems.

(ii) To understand, in particular, the mathematical formulation of load flow model in complex form and a simple method of solving load flow problems of small sized system using Gauss-Seidel iterative algorithm

3.2 OBJECTIVES

To write a Mat lab program to solve the set of non-linear load flow equations using Gauss-Seidel Load Flow (GSLF) algorithm and present the results in the format required for system studies.

3.3 SOFTWARE REQUIRED

The software required is **MATLAB.**

3.4 THEORETICAL BACKGROUND

3.4.1 Need for Load Flow Analysis

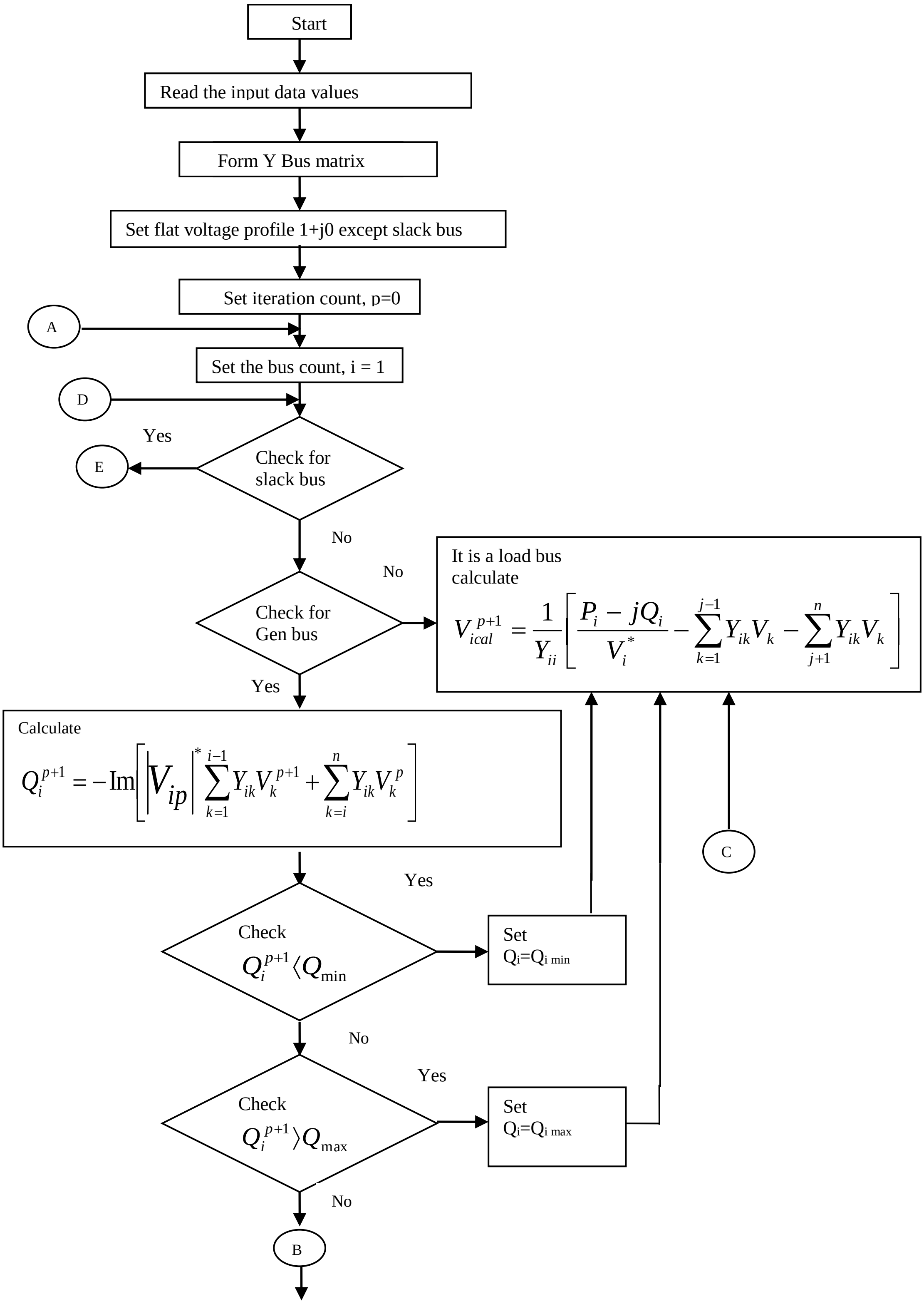
Load Flow analysis, is the most frequently performed system study by electric utilities. This analysis is performed on a symmetrical steady-state operating condition of a power system under “normal” mode of operation and aims at obtaining bus voltages and line / transformer flows for a given load condition. This information is essential both for long term planning and next day operational planning.

The Gauss seidal method is an iterative algorithm for solving a set of non- linear algebraic equations. The relationship between network bus voltages and currents may be represented by either loop equations or node equations. Node equations are normally preferred because the number of independent node equation is smaller than the number of independent loop equations.

The network equations in terms of the bus admittance matrix can be written as,

$$\bar{I}_{bus} = [Y_{bus}]\overline{V}_{bus} \qquad (1)$$

Flowchart


Start
Read the input data values
Form Y Bus matrix
Set flat voltage profile 1+j0 except slack bus
Set iteration count, p=0
A
Set the bus count, i = 1
D
Yes
E
Check for slack bus
No
No
Check for Gen bus
It is a load bus calculate
$V_{ical}^{p+1} = \frac{1}{Y_{ii}}\left[\frac{P_i - jQ_i}{V_i^*} - \sum_{k=1}^{j-1} Y_{ik}V_k - \sum_{j+1}^{n} Y_{ik}V_k\right]$
Yes
Calculate
$Q_i^{p+1} = -\mathrm{Im}\left[\left|V_{ip}\right|^* \sum_{k=1}^{i-1} Y_{ik}V_k^{p+1} + \sum_{k=i}^{n} Y_{ik}V_k^{p}\right]$
C
Yes
Check
$Q_i^{p+1} \langle Q_{\min}$
Set
$Q_i=Q_{i\ min}$
No
Yes
Check
$Q_i^{p+1} \rangle Q_{\max}$
Set
$Q_i=Q_{i\ max}$
No
B

For a n bus system, the above performance equation can be expanded as,

$$\begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ \vdots \\ I_p \\ \vdots \\ I_n \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & \dots & Y_{1p} & \cdots & Y_{1n} \\ Y_{12} & Y_{22} & \cdots & Y_{2p} & \cdots & Y_{2n} \\ \vdots & \vdots & & \vdots & & \vdots \\ \vdots & \vdots & & \vdots & & \vdots \\ Y_{p1} & Y_{p2} & \dots & Y_{pp} & & Y_{pn} \\ \vdots & \vdots & & \vdots & & \vdots \\ Y_{n1} & Y_{n2} & \dots & Y_{np} & & Y_{nn} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ \vdots \\ V_p \\ \vdots \\ V_n \end{bmatrix} \tag{2}$$

where n is the total number of nodes.

V_p is the phasor voltage to ground at node p.

I_p is the phasor current flowing into the network at node p.

At the p^{th} bus, current injection:

$$I_p = Y_{p1}V_1 + Y_{p2}V_2 + \dots\dots\dots.. + Y_{pp}V_p + \dots\dots\dots...Y_{pn}V_n$$

$$= \sum_{q=1}^{n} Y_{pq}V_q \quad = \quad Y_{pp}V_p + \sum_{\substack{q=1 \\ q \neq p}}^{n} Y_{pq}V_q \tag{3}$$

$$V_p = \frac{1}{Y_{pp}} \left[I_p - \sum_{\substack{q=1 \\ q \neq p}}^{n} Y_{pq}V_q \right]; \quad p = 2,\dots.n \tag{4}$$

At bus p, we can write $P_p - jQ_p = V_p^* I_p$

Hence, the current at any node p is related to P, Q and V as follows:

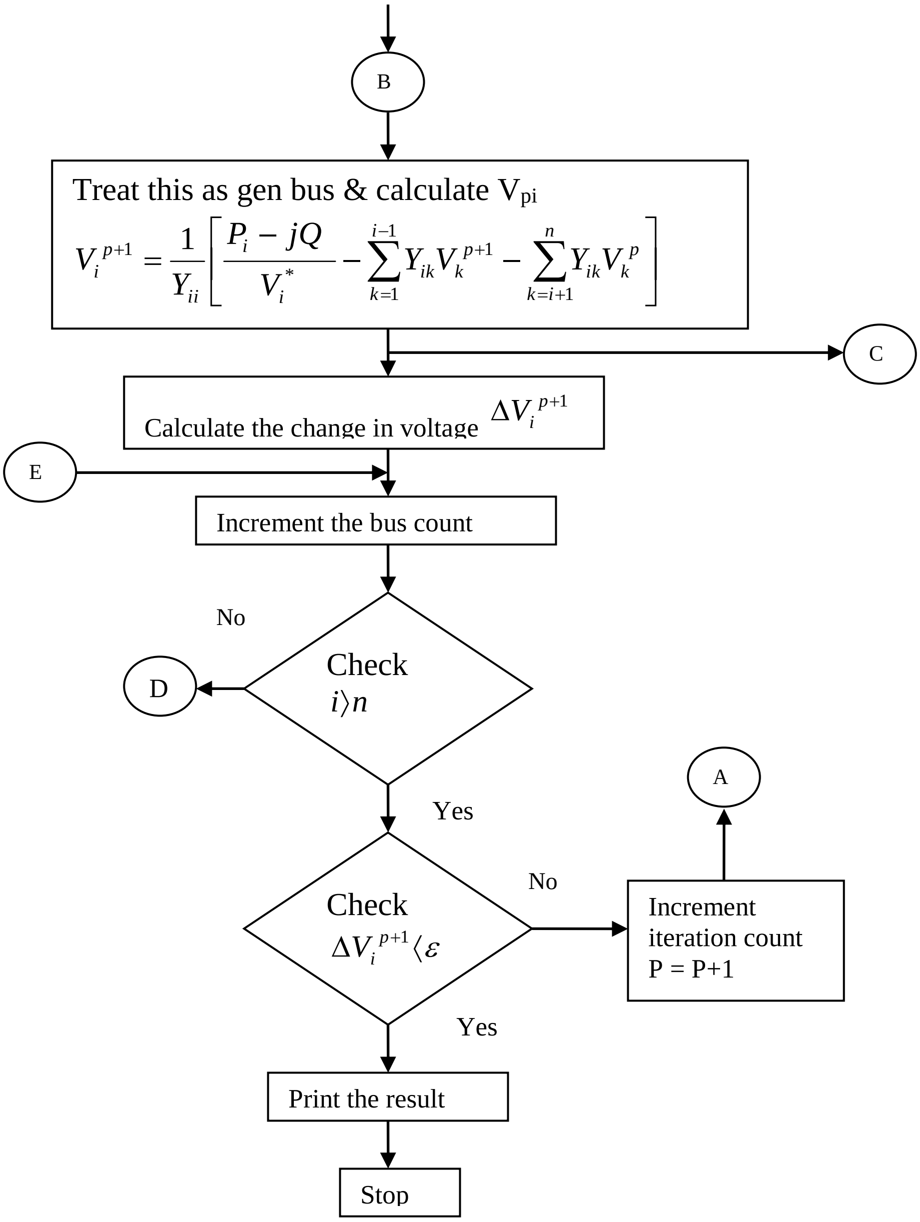
.

$$\therefore I_p = \frac{(P_p - jQ_p)}{V_p^*} \quad \text{(for any bus } p \text{ except slack bus } s\text{)} \tag{5}$$

Substituting for I_p in Equation (4),

$$V_p = \frac{1}{Y_{pp}} \left[\frac{P_p - jQ_p}{V_p^*} - \sum_{\substack{q=1 \\ q \neq p}}^{n} Y_{pq}V_q \right]; \; p = 2,\dots..n \tag{6}$$

I_p has been substituted by the real and reactive powers because normally in a power system these quantities are specified.


B
Treat this as gen bus & calculate V_{pi}
$V_i^{p+1} = \frac{1}{Y_{ii}}\left[\frac{P_i - jQ}{V_i^*} - \sum_{k=1}^{i-1} Y_{ik} V_k^{p+1} - \sum_{k=i+1}^{n} Y_{ik} V_k^{p}\right]$
C
Calculate the change in voltage ΔV_i^{p+1}
E
Increment the bus count
No
Check $i \rangle n$
D
A
Yes
No
Check $\Delta V_i^{p+1} \langle \varepsilon$
Increment iteration count P = P+1
Yes
Print the result
Stop

In case of PV bus,

$$V_i^{k+1} = |V_i|^{(specified)} . \angle \delta_i^{k+1}$$

$$V_i^{k+1} = |V_i|^{(specified)} .(\cos\delta_i^{k+1} + \sin\delta_i^{k+1})$$

Acceleration factor:

To speed up the convergence, the node voltage (Vi(k+1)) of the succeeding iteration can be modified(accelerated) by multiplication factor called as Acceleration factor(α) .

$$\Delta V_i = V_i^{k+1} - V_i^k$$

$$V_i^{k+1} = V_i^k + \infty . \Delta V_i$$

Algorithm:

Step 1: Read the input data.

Step 2: Find out the admittance matrix.

Step 3: Choose the flat voltage profile 1+j0 to all buses except slack bus.

Step 4: Set the iteration count p = 0 and bus count i = 1.

Step 5: Check the slack bus, if it is the generator bus then go to the next step otherwise go to next step 7.

Step 6: Before the check for the slack bus if it is slack bus then go to step 11 otherwise go to next step.

Step 7: Check the reactive power of the generator bus within the given limit.

Step 8: If the reactive power violates a limit then treat the bus as load bus.

Step 9: Calculate the phase of the bus voltage on load bus

Step 10: Calculate the change in bus voltage of the repeat step mentioned above until all the bus voltages are calculated.

Step 11: Stop the program and print the results

EXERCISE

1. The line admittances of a 4 bus system are as under:

Bus code	Admittance
1-2	2-j8
1-3	1-j4
2-3	0.666-j2.664
2-4	1-j4
3-4	2-j8

The schedule of active and reactive powers is as follows:

Bus Code	P	Q	V	Bus
1	---	---	$1.06\angle 0$	Slack
2	0.5	0.2	1	PQ
3	0.4	0.3	1	PQ
4	0.3	0.1	1	PQ

Form Y_{bus}, compute the voltages at buses 2,3 and 4 at the end of first iteration using Gauss-Seidal method take α =1.6

3.5 PROGRAM

3.6 VIVA QUESTIONS

1. What is the need for load flow study?
2. Name various bus classifications in load flow study.
3. What is acceleration factor? What is the general value recommended for the acceleration factor in the Gauss- Seidel method?
4. What are the disadvantages of Gauss seidal method?
5. What will be the reactive power and bus voltage when the generator bus is treated as load bus?

Preparation (2)	Model calculation/Execution(5)	Viva (3)

3.7 RESULT

The given set of load flow equations for a given power system were solved using Gauss-Seidal method and verified using MATLAB .

Ex. No.:	LOAD FLOW ANALYSIS - II: SOLUTION OF LOAD FLOW AND RELATED PROBLEMS USING NEWTON RAPHSON
Date:	

4.1 AIM

i. To understand the following for medium and large scale power systems:
   a) Mathematical formulation of the load flow problem in real variable form
   b) Newton-Raphson method of load flow (NRLF) solution

ii. To become proficient in the usage of software for practical problem solving in the areas of power system planning and operation

4.2 OBJECTIVES

To investigate the convergence characteristics of load flow solutions using NRLF algorithm for different sized systems.

4.3 SOFTWARE REQUIRED:

The software required is **MATLAB.**

4.4 THEORETICAL BACKGROUND

Necessity of Load Flow Analysis:

The steady state load flow analysis is more useful in finding bus voltages and line flows for a given load condition. Hence it is necessary for Power Station design, operational planning, long term planning, and alternative planning and for further extension.

Newton-Raphson Load Flow Model:

Load flow study in power system parlance is the steady state solution of the power system network. The main information obtained from this study comprises the magnitudes and phase angles of load bus voltages, reactive powers at generator buses, real and reactive power flow on transmission lines, other variables being specified. This information is essential for the continuous monitoring of current state of the system and for analyzing the effectiveness of alternative plans for future system expansion to meet increased load demand.

Newton-Raphson method is an iterative method that approximates the set of nonlinear simultaneous equations to a set of linear simultaneous equations using Taylor's series expansion and the terms are limited to first approximation.

The non-linear equations governing the power system network are,

$$I_p = \sum_{p \in q} Y_{pq} V_p \quad for\, all\; p$$

where I_p is the current injected into bus *p*.

EXERCISE

1. Perform the power flow study for the given system using NR method.

The line Admittance:

Bus code	Impedance
1 – 2	0.02+j0.04
1 – 3	0.01+j0.03
2 – 3	0.0125+j0.025

The schedule of active and reactive powers:

Bus Code	**P**	**Q**	**V**	**Bus**
1	--	--	1.05	Slack
2	400	250	-	PQ
3	200	-	1.04	PV

The complex power in p^{th} bus is given by,

$$S_p = V_p I_p^*$$

$$= V_p \left[\sum_{q=1}^{n} Y_{pq} V_q \right]^* \qquad = V_p \left[\sum_{q=1}^{n} Y_{pq}^* V_q^* \right]; \;\; p = 2, \ldots\ldots\ldots n. \tag{1}$$

$$Let,\ V_p = |V_p| e^{j\delta p}$$

$$V_q = |V_q| e^{j\delta q}$$

$$\delta_{pq} = \delta_p - \delta_q \text{ and}$$

$$Y_{pq} = |Y_{pq}| e^{j\theta pq}$$

In polar co-ordinates, the power on p^{th} bus is given as,

$$S_p = P_p + jQ_p = \sum_{q=1}^{n} |V_p||V_q|\; e^{j\delta\, p\, q}\; |\, Y_{pq} \,|\, e^{j\theta pq} \tag{2}$$

Separating the Real and Imaginary parts we get,

$$P_p = \sum_{q=1}^{n} |V_p||V_q||Y_{pq}| \cos(\delta_p + \theta_{pq} - \delta_q)$$

$$Q_p = \sum_{q=1}^{n} |V_p||V_q||Y_{pq}| \sin(\delta_p + \theta_{pq} - \delta_q) \tag{3}$$

The Newton –Raphson method requires that a set of linear equations be formed expressing the relationship between the changes in real and reactive powers and the components of the bus voltages as follows:

$$\begin{bmatrix} \Delta P_2^{(r)} \\ \vdots \\ \vdots \\ \vdots \\ \Delta P_n^{(r)} \\ --- \\ \Delta Q_2^{(r)} \\ \vdots \\ \vdots \\ \vdots \\ \Delta Q_n^{(r)} \end{bmatrix} = \left[\begin{array}{ccc|ccc} \dfrac{\partial P_2}{\partial \delta_2}^{(r)} & \cdots & \dfrac{\partial P_2}{\partial \delta_n}^{(r)} & \dfrac{\partial P_2}{\partial |V_2|}^{(r)} & \cdots & \dfrac{\partial P_2}{\partial |V_n|}^{(r)} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \dfrac{\partial P_n}{\partial \delta_2}^{(r)} & \cdots & \dfrac{\partial P_n}{\partial \delta_n}^{(r)} & \dfrac{\partial P_2}{\partial |V_2|}^{(r)} & \cdots & \dfrac{\partial P_n}{\partial |V_n|}^{(r)} \\ \hline \dfrac{\partial Q_2}{\partial \delta_2}^{(r)} & \cdots & \dfrac{\partial Q_2}{\partial \delta_n}^{(r)} & \dfrac{\partial Q_2}{\partial |V_2|}^{(r)} & \cdots & \dfrac{\partial Q_2}{\partial |V_n|}^{(r)} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \dfrac{\partial Q_n}{\partial \delta_2}^{(r)} & \cdots & \dfrac{\partial Q_2}{\partial \delta_n}^{(r)} & \dfrac{\partial Q_n}{\partial |V_2|}^{(r)} & \cdots & \dfrac{\partial Q_n}{\partial |V_n|}^{(r)} \end{array} \right] \begin{bmatrix} \Delta \delta_2^{(r)} \\ \vdots \\ \vdots \\ \vdots \\ \Delta \delta_n^{(r)} \\ ---- \\ \Delta |V|_2^{(r)} \\ \vdots \\ \vdots \\ \vdots \\ \Delta |V_n^{(r)}| \end{bmatrix} \tag{4}$$

where, the coefficient matrix is known as Jacobian matrix.

In the above equation, bus 1 is assumed to be the slack bus. The Jacobian matrix gives the linearized relationship between small changes in voltage angle $\Delta\delta_i^{(r)}$ and voltage magnitude

$\Delta\left|V_i^{(r)}\right|$ with the small changes in real and reactive power $\Delta P_i^{(r)}$ and $\Delta Q_i^{(r)}$. Elements of the Jacobian matrix are the partial derivatives of (2) and (3) evaluated at $\Delta\delta_i^{(r)}$ and $\Delta\left|V_i^{(r)}\right|$.
The above relationship can be written in a compact form as,

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix}=\begin{bmatrix}J_{11} & J_{12}\\ J_{21} & J_{22}\end{bmatrix}\begin{bmatrix}\Delta\delta\\ \Delta|V|\end{bmatrix} \tag{5}$$

The elements of Jacobian matrix are defined as,

J_{11} :

$$\frac{\partial P_p}{\partial\delta_q}=|V_p||V_q||Y_{pq}|\sin(\delta_p+\theta_{pq}-\delta_q) \qquad q\neq p \tag{6}$$

$$\frac{\partial P_p}{\partial\delta_p}=-\sum_{\substack{q=1\\ q\neq p}}^{n}|V_p||V_q||Y_{pq}|\sin(\delta_p+\theta_{pq}-\delta_q) \tag{7}$$

J_{22} :

$$\frac{\partial Q_p}{\partial|V_q|}=|V_p||Y_{pq}|\sin(\delta_p+\theta_{pq}-\delta_q) \qquad q\neq p \tag{8}$$

$$\frac{\partial Q_p}{\partial|V_p|}=2|V_pY_{pp}|\sin\theta_{pp}+\sum_{\substack{q=1\\ q\neq p}}^{n}|V_q||Y_{pq}|\sin(\delta_p+\theta_{pq}-\delta_q) \tag{9}$$

J_{12} :

$$\frac{\partial P_p}{\partial|V_q|}=|V_p||Y_{pq}|\cos(\delta_p+\theta_{pq}-\delta_q) \qquad q\neq p \tag{10}$$

$$\frac{\partial P_p}{\partial|V_p|}=2|V_pY_{pp}|\cos\theta_{pp}+\sum_{\substack{q=1\\ q\neq p}}^{n}|V_q||Y_{pq}|\cos(\delta_p+\theta_{pq}-\delta_q) \tag{11}$$

J_{21} :

$$\frac{\partial Q_p}{\partial\delta_q}=-|V_p||V_q||Y_{pq}|\cos(\delta_p+\theta_{pq}-\delta_q) \qquad q\neq p \tag{12}$$

$$\frac{\partial Q_p}{\partial\delta_p}=\sum_{\substack{q=1\\ q\neq p}}^{n}|V_p||V_q||Y_{pq}|\cos(\delta_p+\theta_{pq}-\delta_q) \tag{13}$$

All quantities in the linear Equation (4) pertain to iteration *r*. The linear equation when solved for $\Delta\delta$, ΔV gives the correction to be applied to $|V|$ and δ, i.e.

$$|V|^{(r+1)} = |V|^{(r)} + \Delta|V|^{(r)} \tag{14}$$

$$\delta^{(r+1)} = \delta^{(r)} + \Delta\delta^{(r)} \tag{15}$$

Next we get a new set of linear equations evaluated at $(r+1)^{th}$ iteration and the process is repeated. Convergence is tested by the power mismatch criteria. This method converges to high accuracy nearly always in 2 to 5 iterations from a flat start ($|V| = 1$ p.u. and $\theta = 0$) for all buses where $|V|$, θ are unknown, independent of system size.

4.5 PROGRAM

4.6 VIVA QUESTIONS

1. What are the various methods of power flow study?
2. Classify the buses.
3. Can the bus voltage magnitude vary within specified limits for a load bus?
4. State any two advantages of NR method over GS method.
5. What is Jacobian matrix?

Preparation (2)	**Model calculation/Execution(5)**	**Viva (3)**

4.7 RESULT

Thus the power flow analysis by Newton-Raphson was performed using MATLAB and the results were verified.

Ex. No.:	FAULT ANALYSIS
Date:	

5.1 AIM

To become familiar with modeling and analysis of power systems under faulted condition and to compute the fault level, post-fault voltages and currents for different types of faults, both symmetrical and unsymmetrical.

5.2 OBJECTIVES

i. To carryout fault analysis for symmetrical and unsymmetrical faults in small systems using the Thevenin's equivalent circuit in the sequence and phase domains at the faulted bus but without the use of software.

ii. To conduct fault analysis on a given system using software available and obtain fault analysis report with fault level and current at the faulted point and post-fault voltages and currents in the network for the following faults

(a) Three-phase-to- ground
(b) Line-to-ground
(c) Line-to-Line
(d) Double-line-to-ground

5.3 SOFTWARE REQUIRED

The software required is **MATLAB.**

5.4 THEORETICAL BACKGROUND

5.4.1 Symmetrical Faults:

The symmetrical fault occurs when all the three conductors of a three-phase line are brought together simultaneously into a short–circuit condition as shown in Figure 1.

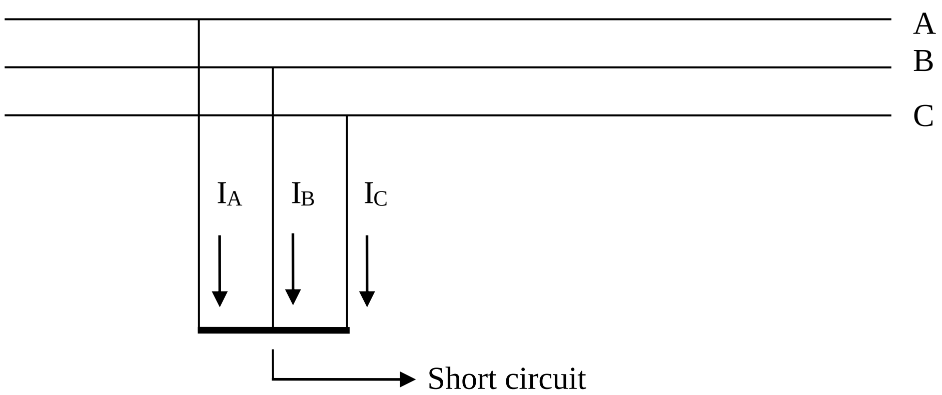


Fig 1 Symmetrical Fault on Three-Phase system

EXERCISE

1. The one-line diagram of a simple power system is shown in figure. The neutral of each generator through a current limiting reactor of 0.25/3 per unit on a 100 MVA base. The system data expressed in per unit on a common 100 MVA base is tabulated below. The generator are running on no-load at their rated voltage and rated frequency with their emfs in phase.

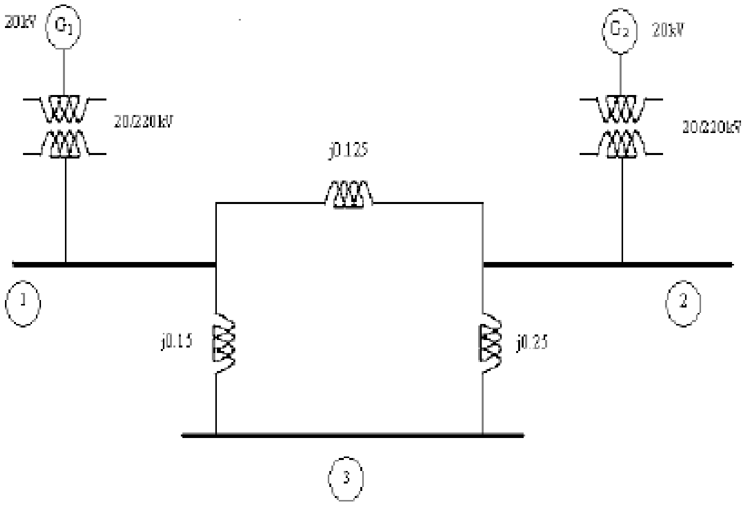
Determine the fault current for the following faults

(a) A balanced three-phase fault at bus 3 through a fault impedance Zf=j0.1 pu

(b) A single line to ground fault at bus 3 through a fault impedance Zf=j0.1 pu

(c) A line to line fault at bus 3 through a fault impedance Zf=j0.1 pu

(d) A double line to ground fault at bus 3 through a fault impedance Zf=j0.1 pu



Item	Base MVA	Voltage Rating Kv	X1	X2	X3
G1	100	20	0.15	0.15	0.05
G2	100	20	0.15	0.15	0.05
T1	100	20/220	0.1	0.1	0.1
T2	100	20/220	0.1	0.1	0.1
L12	100	220	0.125	0.125	0.3
L13	100	220	0.15	0.15	0.35
L23	100	220	0.25	0.25	0.7125

This type of fault gives rise to symmetrical currents i.e. equal fault currents with 120^0 displacement. Fault currents of I_A, I_B and I_C will be equal in magnitude with 120^0 displacement among them. Because of balanced nature of fault, only one phase needs to be considered in calculations since condition in the other two phases will also be similar.

A three-phase short circuit occurs rarely but it is most severe type of fault involving largest currents. For this reason, the balanced short-circuit calculations are performed to determine these large currents to be used to determine the rating of the circuit breakers.

Formula Used:

i) Fault Current, $I_f = \dfrac{V}{Z_f + Z_{pp}}$

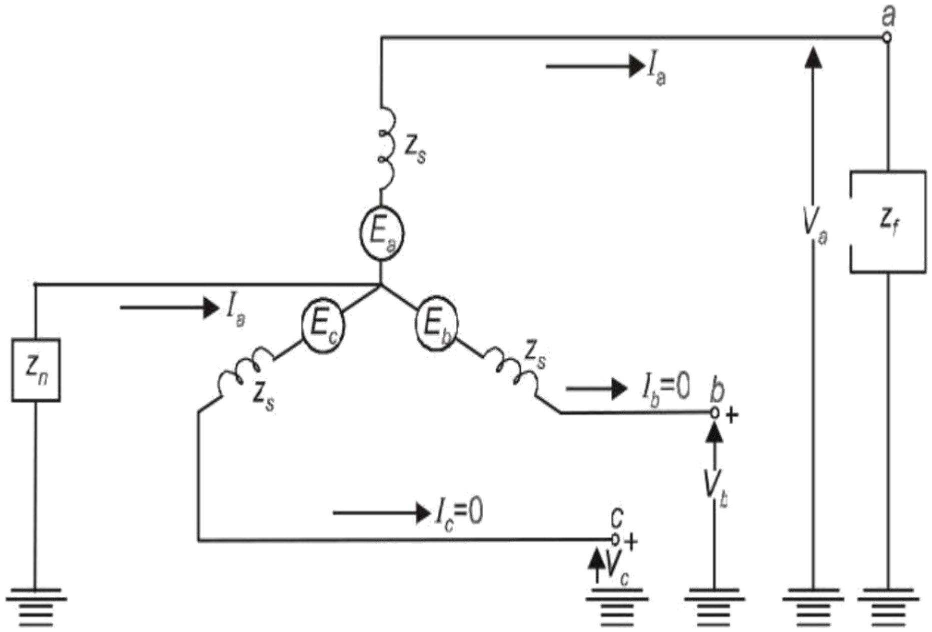
ii) Fault Voltage, $V_f = V(1 - \dfrac{Z_{bus}}{Z_f + Z_{pp}})$

where Z_f – Fault impedance
Z_{pp} – Line impedance

5.4.2 Unsymmetrical Faults:

Single line- to- ground fault:

Generally, a single line-to-ground fault on a transmission line occurs when one conductor drops to the ground or comes in contact with the neutral conductor.

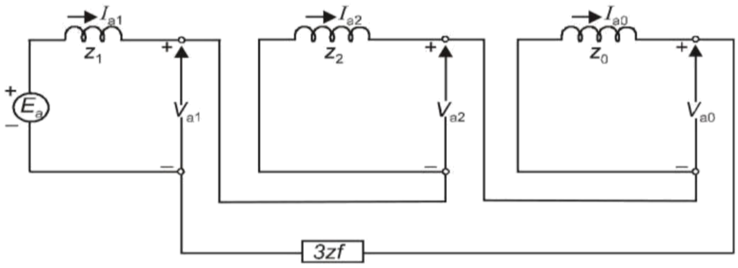


$I_b = 0$

$I_c = 0$

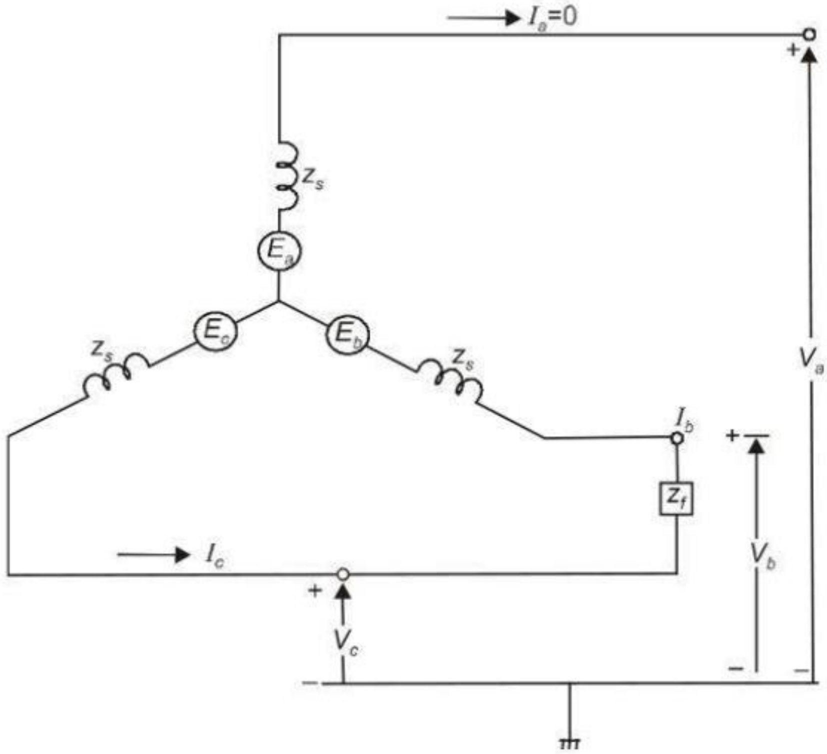
$V_a = Z_f I_a$

Sequence Network of Single line-to-ground-fault



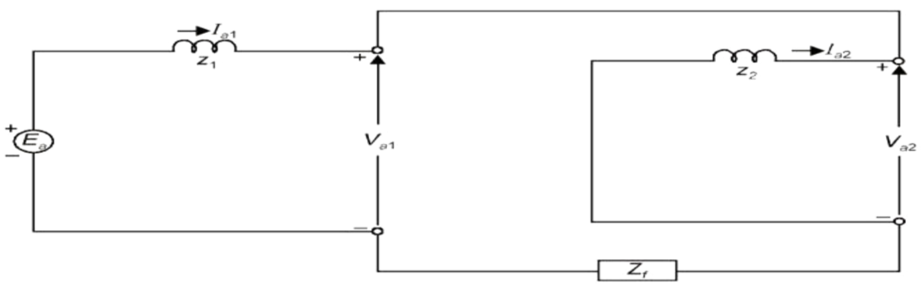
Fault Current = $$I_a = 3I_{a1} = \frac{3E_a}{(Z_1 + Z_2 + Z_0) + 3Z_f}$$

Line-To-Line Fault



$$V_b - V_c = Z_f . I_b$$
$$I_b + I_c = 0$$
$$I_a = 0$$

Sequence Network of Line-to-Line Fault



$$I_{a1} = \frac{E_a}{(Z_1 + Z_2 + Z_f)}$$

$$I_b = -I_c = \frac{-j\sqrt{3}\,E_a}{(Z_1 + Z_2 + Z_f)}$$

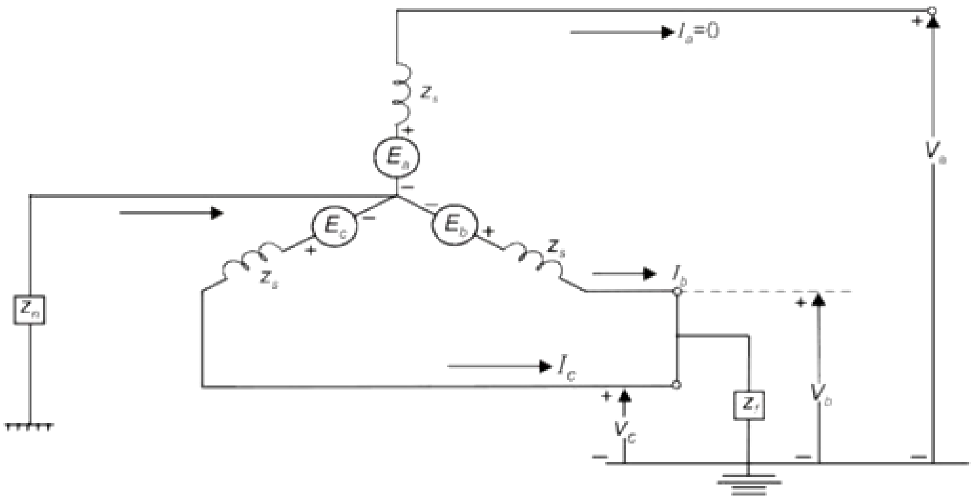
Double Line-To-Ground Fault

The open circuit or short circuits of transmission or distribution lines will lead to unsymmetrical or symmetrical faults in the system. Double line to ground fault occurs when two lines are short circuited and is in contact with the ground

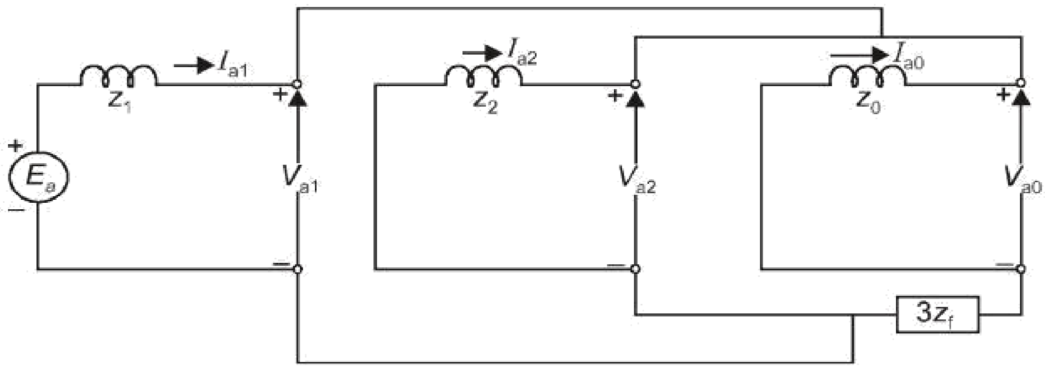
$$I_a = 0$$

$$I_{a1} + I_{a2} + I_{a0} = 0$$

$$V_b = V_c = (I_b + I_c)\ Z_f = 3Z_f I_{a0}$$



Sequence of Double line-to-ground fault



$$I_{a0} = \frac{-(E_a - Z_1 I_{a1})}{(Z_0 + 3Z_f)}$$

$$I_{a1} = \frac{E_a}{Z_1 + \dfrac{Z_2(Z_0 + 3Z_f)}{(Z_2 + Z_0 + 3Z_f)}}$$

$$I_{a2} = \frac{-(E_a - Z_1 I_{a1})}{Z_2}$$

5.5 PROGRAM

5.6 VIVA QUESTIONS

1. What are the types of faults?
2. What are the symmetrical components of a 3 phase system?
3. What are the positive, negative and zero sequence components?
4. What are sequence impedance and sequence network?
5. What is the need for short circuit studies or fault analysis?

Preparation (2)	**Model calculation/Execution(5)**	**Viva (3)**

5.7 RESULT

Thus the fault analysis was carried out using MATLAB.

Ex. No.:	TRANSIENT AND SMALL SIGNAL STABILITY ANALYSIS: SINGLE-MACHINE INFINITE BUS SYSTEM
Date:	

6.1 AIM

To become familiar with various aspects of the transient stability analysis of Single-Machine Infinite Bus (SMIB) system.

6.2 OBJECTIVES

i. To understand modelling and analysis of transient signal stability of a SMIB power system.

ii. To examine the transient stability of a SMIB and determine the critical clearing time of the system through simulation by trial and error method and by direct method.

6.3 SOFTWARE REQUIRED

The software required is MATLAB.

6.4 THEORETICAL BACK GROUND

6.4.1. Stability:

Stability of power systems has been a major concern in system operation. In steady state, the average electrical speed of all the generators must remain the same anywhere in the system. This is termed as the synchronous operation of a system. Any disturbance of small or large can affect the synchronous operation. The disturbance can be in the form of a sudden increase in the load, loss of generation or switching out of a transmission line. Power system stability may be defined may be defined as that property of the system which enables the synchronous machines of the system to respond to a disturbance from a normal operating condition so as to return to a condition where their operation is again normal. The duration of the fault has a critical influence on system stability. Although stability of a system is an integral property of the system, for purposes of the system analysis, it is divided into two broad classes as Steady state or small signal stability and Transient stability

6.4.2 Swing Equation

During any disturbance in the system, the rotor will accelerate or decelerate with respect to synchronously rotating axis and the relative motion begins. The equation describing the relative motion is called as swing equation.

$$P_m - P_e = (\pi H/f) \times d^2\delta/dt^2 \qquad (1)$$

Where P_m is the mechanical power input in MW and P_e is the electrical power output in MW.

6.4.3 Solution of Swing Equation by Fourth order Runge-Kutta Method

The general Runge Kutta fourth order approximation is

$$y_1 = y_0 + a_1k_1 + a_2k_2 + a_3k_3 + a_4k_4 \qquad (2)$$

EXERCISES

1. A 20 MVA, 3 phase, 50 Hz generator delivers rated output power at UPF via a double circuit transmission line to an infinite bus bar. The generator unit has a kinetic energy of 2.5 MJ/MVA at rated speed. It's X_d' =0.3 p.u. The resistance of the transformer circuit is negligible. The transformer resistance has each a reactance of 0.3 p.u. on 20 MVA base. The voltage behind transient reactance is 1.05 p.u. and the voltage of the infinite bus is 1 p.u. A 3 phase short circuit occurs at the middle of one of the transformer circuits. It involves ground. The fault is cleared in 0.4 sec by simultaneous opening of CB's at both ends of the faulted transmission line. Calculate and plot the swing curve for the system and ascertain whether the system is stable or not. Take Δt =0.05 sec and t_{max}=1 sec.

where

$$k_1 = f(x_0, y_0)h$$
$$k_2 = f(x_0 + b_1 h, y_0 + b_2 k_1)h$$
$$k_3 = f(x_0 + b_3 h, y_0 + b_4 k_2)h$$
$$k_4 = f(x_0 + b_5 h, y_0 + b_6 k_3)h$$

Following the same procedure used for the second order approximation, the coefficients in the eq are determined. Thus the Runge Kutta fourth order approximation becomes

$$y_1 = y_0 + \frac{1}{6}(k_1 + 2k_2 + 2k_3 + k_4) \tag{3}$$

where

$$k_1 = f(x_0, y_0)h$$
$$k_2 = f(x_0 + \frac{h}{2}, y_0 + \frac{k_1}{2})h$$
$$k_3 = f(x_0 + \frac{h}{2}, y_0 + \frac{k_2}{2})h$$
$$k_4 = f(x_0 + h, y_0 + k_3)h$$

In application of the Runge Kutta fourth order approximation, the changes in the internal voltage angles and machine speeds again for the simplified machine representation, are determined from

$$\Delta\delta_{i(t+\Delta t)} = \frac{1}{6}\left(k_{1i} + 2k_{2i} + 2k_{3i} + k_{4i}\right) \tag{4}$$

$$\Delta\omega_{i(t+\Delta t)} = \frac{1}{6}\left(l_{1i} + 2l_{2i} + 2l_{3i} + l_{4i}\right) \tag{5}$$

The k's and l's are the changes in δ_i and ω_i respectively, obtained using derivatives evaluated at predetermined points. Then,

$$\delta_{i(t+\Delta t)} = \delta_i(t) + \frac{1}{6}\left(k_{1i} + 2k_{2i} + 2k_{3i} + k_{4i}\right) \tag{6}$$

$$\omega_{i(t+\Delta t)} = \omega_i(t) + \frac{1}{6}\left(l_{1i} + 2l_{2i} + 2l_{3i} + l_{4i}\right) \tag{7}$$

Algorithm for Runge-Kutta method

1. Obtain a load flow solution for the prefault conditions and determine the generator internal voltages behind transient reactances. Calculate P_{max1} under prefault conditions.

2. The state variables δ has initial value given by $\delta_0 = \sin^{-1}\left(\frac{P_i}{P_{\max 1}}\right)$ but ω=0 under prefault conditions.
3. Assume the occurrence of the fault and calculate the reduced admittance matrix for this condition and hence calculate P_{max2} during fault conditions.
4. Initialize iteration count k=0.
5. Determine the eight constants k_1, k_2, k_3, k_4 and l_1, l_2, l_3, l_4.
6. Calculate the change in state variables

$$\Delta\delta^k = \frac{1}{6}\left(k_1^k + 2k_2^k + 2k_3^k + k_4^k\right)$$

$$\Delta\omega^k = \frac{1}{6}\left(l_1^k + 2l_2^k + 2l_3^k + l_4^k\right)$$

7. The new state variables are

$$\delta^{k+1} = \delta^k + \Delta\delta^k \quad and \quad \omega^{k+1} = \omega^k + \Delta\omega^k$$

8. Evaluate the internal voltage behind transient reactance using the relation

$$E^{k+1} = \left|E^k\right| \cos\delta^{k=}1 + j\left|E^k\right| \sin\delta^{k+1}$$

9. Check if $t < t_c$. If yes, increment time count and iteration count as k=k+1 and go to step 5.
10. If $t \geq t_c$, modify the network data and obtain a new reduce admittance matrix corresponding to post fault condition. Set k=k+1.
11. Check if $k<k_{max}$. If yes, go to step 5.
12. Terminate the process.

6.4.4. Determination of Critical Creating Angle and Time

Critical clearing time is the maximum allowable time between the occurrence of a fault and clearing of the fault for which the system will be stable. An expression for critical clearing angle is,

$$\cos\delta_{cr} = \frac{P_m(\delta_{max} - \delta_o) + P_{3max}\cos\delta_{max} - P_{2max}\cos\delta_o}{P_{3max} - P_{2max}}$$

The corresponding critical clearing time is given by $t_{cr} = \sqrt{[2H(\delta_{cr} - \delta_o) / (\pi f_o P_m)]}$

6.5 PROGRAMS

6.6 VIVA QUESTIONS

1. Define power system stability?
2. What are the types of power system stability?
3. What are the assumptions made in steady state stability analysis?
4. What are the methods to improve the steady state stability?
5. Draw the power angle curve of a synchronous machine?

Preparation (2)	Model calculation/Execution(5)	Viva (3)

6.7 RESULT

Thus the transient signal stability analysis of Single-Machine Infinite Bus (SMIB) system was analyzed using MATLAB.

Ex. No.:	TRANSIENT STABILITY ANALYSIS OF MULTI MACHINE POWER SYSTEMS
Date:	

7.1 AIM:

(i) To become familiar with modelling aspects of synchronous machines and network for transient stability analysis of multi-machine power systems.

(ii) To become familiar with the state-of-the-art algorithm for simplified transient stability simulation involving only classical machine models for synchronous machines.

(iii) To understand system behaviour when subjected to large disturbances in the presence of synchronous machine controllers.

(iv) To become proficient in the usage of the software to tackle real life problems encountered in the areas of power system planning and operation.

7.2 OBJECTIVES

(i) To assess the transient stability of a multi machine power system when subjected to a common disturbance sequence: fault application on a transmission line followed by fault removal and line opening.

(ii) To determine the critical clearing time.

(iii) To observe system response and understand its behaviour during a full load rejection at a substation with and without controllers.

(iv) To observe system response and understand its behaviour during loss of a major generating station.

(v) To understand machine and system behaviour during loss of excitation.

(vi) To study the effect of load relief provided by under frequency load shedding scheme.

7.3 SOFTWARE REQUIRED

The software required is **Matlab.**

7.4 THEORETICAL BACKGROUND

7.4.1. Mult-imachine Transient Stability

Transient stability analysis is essential both for power system planning and operation. The ability of the generators to remain in synchronism under conceivable disturbance scenario must be assessed. Also, transient stability simulations are essential for proper design of protection system. This calls for accurate modeling of the components such as generators and their control systems, static var compensators etc., involved in the dynamics triggered by

PROBLEM:

For bus 1, the voltage is given as $V_1=1.06\angle 0$ and it is taken as slack bus. The base value is 100MVA.

LOAD DATA		
BUS NO	LOAD	
	MW	Mvar
1	0	0
2	0	0
3	0	0
4	100	70
5	90	30
6	160	110

GENERATION SCHEDULE				
BUS NO	VOLTAGE MAG	GENERATION MW	Mvar LIMITS	
			Min	Max
1	1.06	------	-----	------
2	1.04	150	0	140
3	1.03	100	0	90

LINE DATA				
LINE NO (START)	LINE NO(END)	R(PU)	X(PU)	1/2B(PU)
1	4	0.035	0.225	0.0065
1	5	0.025	0.105	0.0045
1	6	0.040	0.215	0.0055
2	4	0.000	0.035	0.0000
3	5	0.000	0.042	0.0000
4	6	0.028	0.125	0.0035
5	6	0.026	0.175	0.0300

MACHINE DATA			
GEN	Ra	Xd'	H
1	0	0.20	20
2	0	0.15	4
3	0	0.25	5

A three phase occurs on line 5-6 near bus 6 and is cleared by the simultaneous opening of breakers at both ends of the line. Perform the transient stability analysis and determine the system stability for a) when the fault is cleared in 0.4 second b) when the fault is cleared in 0.5 second c) Repeat the simulation to determine the critical clearing angle a disturbance. The machines and their control systems are characterized by differential equation while the transmission system is represented by algebraic equations.

7.4.2. Modeling of Components for Transient Stability Simulation

Assumptions for Simplified Transient Stability Simulation

(i) Generator saliency neglected i.e, Xd = Xq, Xd’ = Xq’, where the unprimed quantities are the synchronous reactances and the primed quantities are transient reactances.

(ii) Generators are represented by constant internal voltage behind transient reactance.

(iii) The turbine mechanical power outputs are assumed to be constant. That is, the governor corrective action is ignored.

(iv) All resistances are neglected.

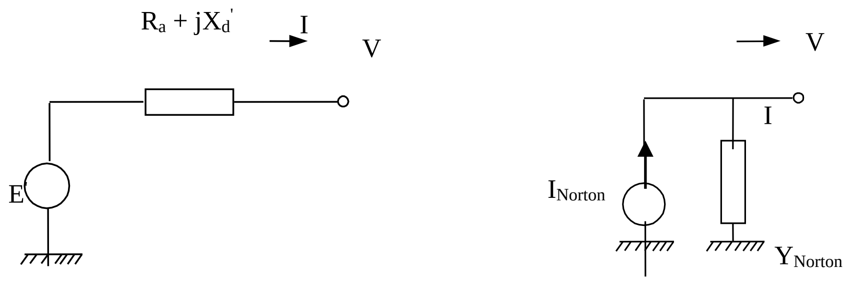
(v) Damping is neglected.

(vi) Loads are represented as constant admittances evaluated at the initial load flow solution. Dependence of load on voltage and frequency is ignored.

(vii) The system is balanced during normal operation and disturbance and after disturbance has been removed.

Generators

The equivalent circuit for classical model of the generator is given in Fig.1.a. This equivalent circuit is the Thevenin form. The Norton form of the equivalent circuit is shown in Fig. 1.b



$E' = V + (R_a + jX_d')\, I$ $\qquad$ $I_{Norton} = Y_{Norton}V + I$

(a) Thevenin equivalent **(b) Norton equivalent**

Fig. 1 Modelling of Generators and Representation for Network Solution

I_{Norton} in the above figure is the Norton current source. The expressions for the current source and the admittance is given by

$$I_{Norton} = E^{'} / (R_a + jX_d^{'}) \qquad (1)$$

$$Y_{Norton} = 1 / (R_a + jX_d^{'}) \qquad (2)$$

Loads

The loads are modelled as admittances. The admittances are computed from the initial load flow solution as shown below.

$$Y_L = (P_L - j\,Q_L) / \ |V_L|2 \qquad (3)$$

where,

P_L and Q_L are the active and reactive powers of the load
$|V_L|$ is the magnitude of the voltage of the load bus computed by load flow analysis
Y_L is the load admittance and it gets added to the diagonal of bus admittance matrix **Y** corresponding to the node where the load is connected.

Transmission lines

The transmission lines are modeled as π-circuits using positive sequence parameters: series resistance, series reactance and half line charging.

Transformers

Transformers are modeled by a series reactance, which is nothing, but its leakage reactance if the turns ratio is unity. For nonunity turns ratio i.e, for off nominal turns ratio, they are modeled by π-circuits and the elements of the π are functions of the tap ratio. The model for transformers is also identical to that for load flow analysis.

Network equations

The algebraic equations (4) describe the network performance

$$\mathbf{Y}\,\mathbf{V} = \mathbf{I} \qquad (4)$$

where,

Y is the bus admittance matrix with following modifications:

a. Admittances representing the loads are added to the diagonal elements corresponding to the buses where the loads are connected

b. The Norton admittances of the generators (see Fig.7.1.b) which are represented by classical machines are added to the diagonal elements corresponding to buses where generators are connected.

V is the vector of bus voltage phasors

I is the vector of Norton current injections occurring in the Norton equivalent of the generators. The vector I contains nonzero entries corresponding to generator nodes and zero's for non-generator nodes

7.4.3. MATHEMATICAL MODEL OF MULTIMACHINE TRANSIENT STABILITY ANALYSIS

The first step in the transient stability analysis is to solve the initial load flow and to determine the initial bus voltage magnitudes and phase angles. The machine currents prior to disturbance are calculated from,

$$I_i = \frac{S_i^*}{V_i^*} = \frac{P_i - jQ_i}{V_i^*}, i = 1, 2, \ldots, m \qquad (1)$$

Where
m= is the number of generators
Vi- is the terminal voltage of the ith generator
Pi and Qi are the generator real and reactive powers.

All unknown values are determined from the initial power flow solution. The generator armature resistances are usually neglected and the voltages behind the transient reactance are then obtained,

$$E_i^{'} = V_i + jX_d^{'} I_i \qquad (2)$$

Next, all load are converted to equivalent admittances by using the relation

$$y_{i0} = \frac{S_i^*}{|V_i|^2} = \frac{P_i - jQ_i}{|V_i|^2} \qquad (3)$$

To include voltages behind transient reactance, m buses are added to the n bus power system network. The equivalent network with all load converted to admittances is shown in Fig.2 ,

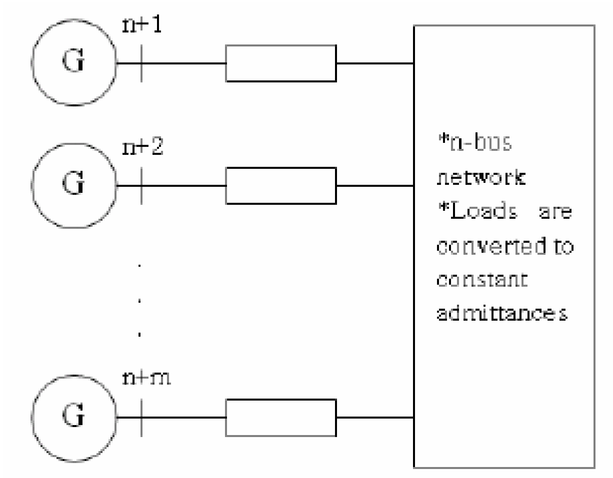


Fig. 2 Power system representation for transient stability analysis

Nodes n+1, n+2, . . ., n+m are the internal machine buses, i.e., the buses behind the transient reactances. The node voltage equation with node 0 as reference for this network, is

$$\begin{bmatrix} I_1 \\ I_2 \\ \cdot \\ \cdot \\ \cdot \\ I_n \\ \hline I_{n+1} \\ \cdot \\ \cdot \\ \cdot \\ I_{n+m} \end{bmatrix} = \begin{bmatrix} Y_{11} & \cdots & Y_{1n} & Y_{1(n+1)} & \cdots & Y_{1(n+m)} \\ Y_{21} & \cdots & Y_{2n} & Y_{2(n+1)} & \cdots & Y_{2(n+m)} \\ \cdot & \cdots & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdots & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdots & \cdot & \cdot & \cdots & \cdot \\ Y_{n1} & \cdots & Y_{nn} & Y_{n(n+1)} & \cdots & Y_{n(n+m)} \\ Y_{(n+1)1} & \cdots & Y_{(n+1)n} & Y_{(n+1)(n+1)} & \cdots & Y_{(n+1)(n+m)} \\ \cdot & \cdots & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdots & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdots & \cdot & \cdot & \cdots & \cdot \\ Y_{(n+m)1} & \cdots & Y_{(n+m)n} & Y_{(n+m)(n+1)} & \cdots & Y_{(n+m)(n+m)} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ \cdot \\ \cdot \\ \cdot \\ V_n \\ \hline E'_{n+1} \\ \cdot \\ \cdot \\ \cdot \\ E'_{n+m} \end{bmatrix} \quad (4)$$

Or

$$I_{bus} = Y_{bus} V_{bus} \quad (5)$$

Where

Ibus is the vector of the injected bus currents Vbus is the vector of bus voltages measured from the reference node.

The diagonal elements of the bus admittance matrix are the sum of admittances connected to it, and the off-diagonal elements are equal to the negative of the admittance between the nodes. The reference is that additional nodes are added to include the machine voltages behind transient reactances. Also, diagonal elements are modified to include the load admittances.

To simplify the analysis, all nodes other than the generator internal nodes are eliminated using Kron reduction formula . To eliminate the load buses, the bus admittance matrix in (4) is partitioned such that the n buses to be removed are represented in the upper n rows. Since no current enters or leaves the load buses, currents in the n rows are zero. The generator currents are denoted by the vector Im and the generator and load voltages are represented by the vector E' m and Vn, respectively. Then, Equation (4), in terms of sub matrices, becomes

$$\begin{bmatrix} 0 \\ I_m \end{bmatrix} = \begin{bmatrix} Y_{nn} & Y_{nm} \\ Y_{nm}^t & Y_{mm} \end{bmatrix} \begin{bmatrix} V_n \\ E_m' \end{bmatrix} \qquad (6)$$

The voltage vector Vn may be eliminated by substitution as follows.

$$0 = Y_{nn} V_n + Y_{nm} E_m' , \qquad (7)$$
$$I_m = Y_{nm}^t V_n + Y_{mm} E_m' . \qquad (8)$$

From (7),

$$V_n = -Y_{nn}^{-1} Y_{nm} E_m' \qquad (9)$$

Now substituting into (8), we have

$$I_m = [Y_{mm} - Y_{nm}^t Y_{nn}^{-1} Y_{nm}] E_m' = Y_{bus}^{red} E_m' \quad (10)$$

The reduced admittance matrix is

$$Y_{bus}^{red} = Y_{mm} - Y_{nm}^t Y_{nn}^{-1} Y_{nm} \qquad (11)$$

The reduced bus admittance matrix has the dimensions *(m x m)*, where m is the number of generators. The electrical power output of each machine can now be expressed in terms of the machine's internal voltages

$$S^*_{ei} = E'^*_i I_i ,$$

Or

$$P_{ei} = \mathrm{Re}(E_i'^* I_i) , \qquad (12)$$

Where

$$I_i = \sum_{j=1}^{m} E_j' Y_{ij} . \qquad (13)$$

Expressing voltages and admittances in polar form, i.e., I

$$E_i' = |E_i'| \angle \delta_i \quad \text{and} \quad Y_{ij} = |Y_{ij}| \angle \theta_{ij} ,$$

and substituting for Ii in (12), result in

$$P_{ei} = \sum_{j=1}^{m} |E_i'||E_j'||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \qquad (14)$$

The above equation is the same as the power flow equation. Prior to disturbance, there is equilibrium between the mechanical power input and the electrical power output, and we have

$$P_{mi} = \sum_{j=1}^{m} |E_i'||E_j'||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \qquad (15)$$

The classical transient stability study is based on the application of a three-phase fault. A solid three-phase fault at bus k in the network results in Vk = 0. This is simulated by removing the kth row and column from the prefault bus admittance matrix. The new bus admittance matrix is reduced by eliminating all nodes except the internal generator nodes. The generator excitation voltages during the fault and postfault modes are assumed to remain constant. The electrical power of the ith generator in terms of the new reduced bus admittance matrices are obtained from (14). The swing equation with damping neglected, for machine i becomes

$$\frac{H_i}{\pi f_0}\frac{d^2\delta_i}{dt^2} = P_{mi} - \sum_{j=1}^{m} \left|E_i'\right|\left|E_j'\right|\left|Y_{ij}\right| \cos(\theta_{ij} - \delta_i + \delta_j) \tag{16}$$

Where

Yij are the elements of the faulted reduced bus admittance matrix Hi is the inertia constant of machine I expressed on the common MVA base SB. If HGi is the inertia constant of machine I expressed on the machine rated MVA SGi, then Hi is given by

$$H_i = \frac{S_{G_i}}{S_{cb}} H_{Gi} \tag{17}$$

Showing the electrical power of the ith generator by Pef and transforming (16) into state variable mode yields

$$\frac{d\delta_i}{dt} = \Delta\omega_i\,, \tag{18}$$

$$\frac{d\Delta\omega_i}{dt} = \frac{\pi f_0}{H_i}(P_{mi} - P_{ei}^f)\,. \tag{19}$$

In transient stability analysis problem, we have two state equations for each generator. When the fault is cleared, which may involve the removal of the faulty line, the bus admittance matrix is recomputed to reflect the change in the networks. Next the post-fault reduced bus admittance matrix is evaluated and the post-fault electrical power of the ith generator shown by Ppf i is readily determined from (14). Using the post-fault power Ppf i, the simulation is continued to determine the system stability, until the plots reveal a definite trend as to stability or instability. Usually the slack generator is selected as the reference machines are plotted. Usually, the solution is carried out for two swings to show that the second swing is not greater than the first one. If the angle differences do not increase, the system is stable. If any of the angle differences increase indefinitely, the system is unstable.

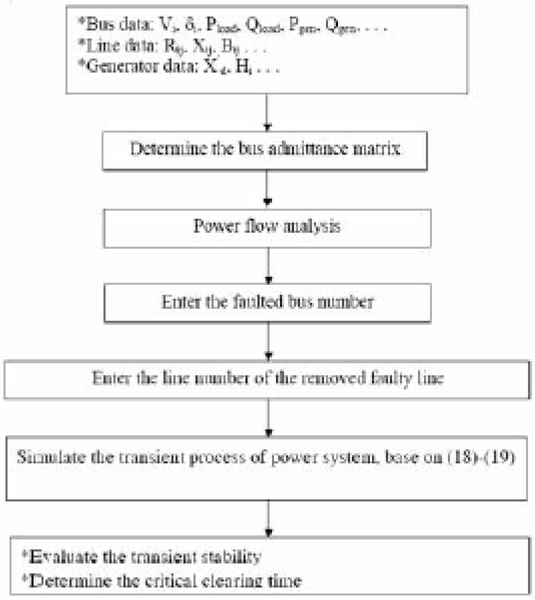


Fig. 3Flow chart of transient stability analysis for a multimachine power system

7.5 PROGRAM

7.6 VIVA QUESTIONS:

1. Define transient stability analysis?
2. Give some examples for large disturbances?
3. What is swing equation?
4. Distinguish single area and multi area systems?

Preparation (2)	Model calculation/Execution(5)	Viva (3)

7.7 RESULT :

Thus the transient stability of Multi machine power system was analysed using Matlab.

Ex. No.:	ELECTROMAGNETIC TRANSIENTS IN POWER SYSTEMS
Date:	

8.1 AIM

To study and understand the electromagnetic transient phenomena in power systems caused due to switching and faults by using Electromagnetic Transients Program (EMTP).

8.2 OBJECTIVES

i. To study the transients due to energization of a single-phase and three-phase load from a non-ideal source with line represented by π model.
ii. To study the transients due to energization of a single-phase and three-phase load from a non-ideal source and line represented by distributed parameters.
iii. To study the transient over voltages due to faults for a SLG fault at far end of a line.
iv. To study the Transient Recovery Voltage (TRV) associated with a breaker for a three-phase fault.

8.3 SOFTWARE REQUIRED:

The software required is PSCAD-EMTDC.

8.4 ALGORITHM

Step 1: To create a project window.

To start PSCAD, double click on the PSCAD available on the desktop. This will open the main window available on the PSCAD. Click on the file menu. Then click the create new or click a new project icon.

Step 2: For adding Component.

From the electrical parable displayed at the right side of the window select the element by click on the same, then while click on the workspace the corresponding will be appeared.

Otherwise right click within the project window, then click add available in the pop menu appeared and then select the required component from one drop menu. For illustration the components Resistor, Inductor, Capacitor, Voltmeter and Ammeter can be added. To get voltage source another main library link menu can be accessed by pressing control and right click simultaneously.

Step 3: For editing the component parameter.

To view/edit component parameters simply double click on it to edit the parameter like magnitude of voltage and frequency. Select signal parameter from the drop down list. Click on the corresponding parameter data and edit the same.

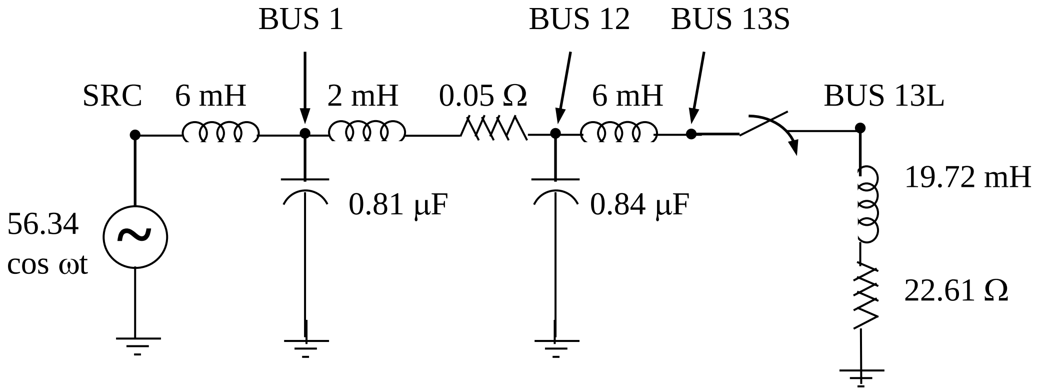
Step 4: For assembling the components:

Components are to be related to the left by 90 degree by selecting the component, then press ‘R’ button.

EXCERCISE

1. Prepare the data for the network given and run EMTP. Obtain the plots of source voltage, load bus voltage and load current following the energization of a Single-phase load. Comment on the results. Double the source inductance and obtain the plots of the variables mentioned earlier. Comment on the effect of doubling the source inductance. Energization of a single phase 0.95 pf load from a non ideal source and a more realistic line representation (lumped R, L, C).

(i) Circuit Diagram



Locating the components:

To assemble the read circuits select the component by click and drag the mouse to desired position and release the left circle click button.

Resizing the wires:

The wire components is a special button in component which can be resized by pressing the left circle button close to either end of the wire and drag the mouse. By pressing as above, the actual circuit can be assembled.

Step 5: To display the output time response curve.

Add the component channel from the pop menu, then add the data label from the channel after editing the signal have as Itr which represent current measurement. Right click on the channel select input/output reference from the pop up menu then select create a new plot with signal in the menu which displays a plot.

Step 6: to simulate the assembled circuit.

Right click from any blank working space of the window select properties to display property window of the project. Here we can edit duration of run time user EMTDC time slope and PSCAD plot. Stop if required.

8.5 SIMULINK

8.6 VIVA QUESTIONS

1. Define transients?
2. Give the examples for when transient occur in a systems?
3. Which software is best to study the transients?
4. Name any two effects of transients in power system
5. Classify the types of power system transient.

Preparation (2)	Model calculation/Execution(5)	Viva (3)

8.7 RESULT

Thus the electromagnetic transient phenomena in power systems caused due to switching and faults by using Electromagnetic Transients Program (EMTP) was analyzed.

Ex. No.:	LOAD – FREQUENCY DYNAMICS OF SINGLE- AREA AND TWO-AREA POWER SYSTEMS
Date:	

9.1 AIM

To become familiar with the modelling and analysis of load-frequency and tie-line flow dynamics of a power system with load-frequency controller (LFC) under different control modes and to design improved controllers to obtain the best system response.

9.2 OBJECTIVES

i. To study the time response (both steady state and transient) of area frequency deviation and transient power output change of regulating generator following a small load change in a single-area power system with the regulating generator under “free governor action”, for different operating conditions and different system parameters.
ii. To study the time response (both steady state and transient) of area frequency deviation and turbine power output change of regulating generator following a small load change in a single- area power system provided with an integral frequency controller, to study the effect of changing the gain of the controller and to select the best gain for the controller to obtain the best response.

9.3 SOFTWARE REQUIRED

The software required is MATLAB.

9.4 THEORETICAL BACKGROUND

9.4.1 Introduction:

Active power control is one of the important control actions to be performed during normal operation of the system to match the system generation with the continuously changing system load in order to maintain the constancy of system frequency to a fine tolerance level. This is one of the foremost requirements in providing quality power supply. A change in system load causes a change in the speed of all rotating masses (Turbine – generator rotor systems) of the system leading to change in system frequency. The speed change from synchronous speed initiates the governor control (Primary control) action resulting in all the participating generator – turbine units taking up the change in load, stabilizing the system frequency. Restoration of frequency to nominal value requires secondary control action which adjusts the load-reference set points of selected (regulating) generator – turbine units. The primary objectives of automatic generation control (AGC) are to regulate system frequency to the set nominal value and also to regulate the net interchange of each area to the scheduled value by adjusting the outputs of the regulating units. This function is referred to as load – frequency control (LFC)

9.4.2 Single-Area Load-Frequency Control:

The block diagram for single-area load-frequency control is given in Figure 1.

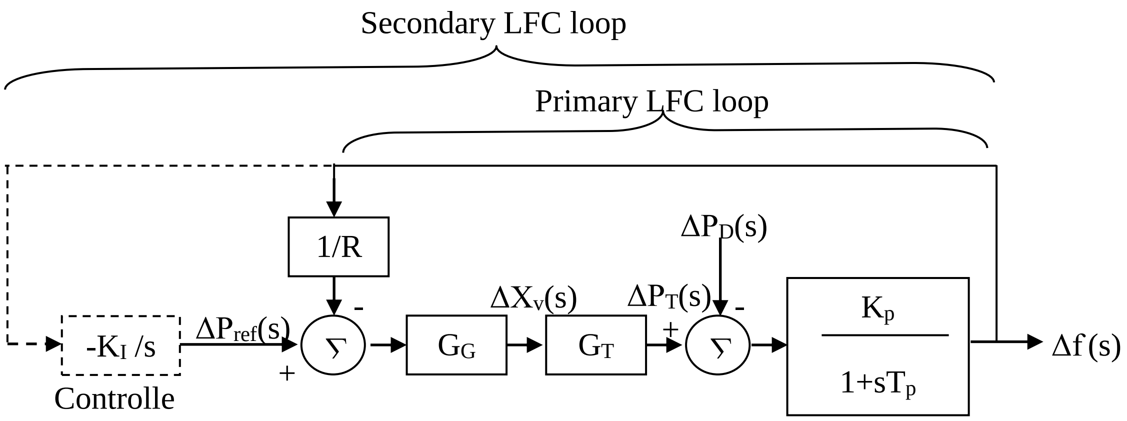


Fig 1 Block Diagram for Single-Area Load – Frequency Control

In the above diagram, all powers are in per unit to area rated capacity and the frequency deviation is in hertz.

$K_p = 1/D$ Hz / p.u.MW

$T_p = (2H/f^0 D)$ sec

The load damping constant D is normally expressed in percent and typical values of D are 1 to 2 percent. A value of D = 1.5 means that 1.0 percent change in frequency would cause a 1.5 percent change in load.

The dashed portion of the diagram marked as the secondary loop represents the integral controller whose gain is K_I. This controller actuates the load reference point until the frequency deviation becomes zero.

9.4.3 Two-Area Load-Frequency Control:

The block diagram for two-area load-frequency control is given in Figure 2

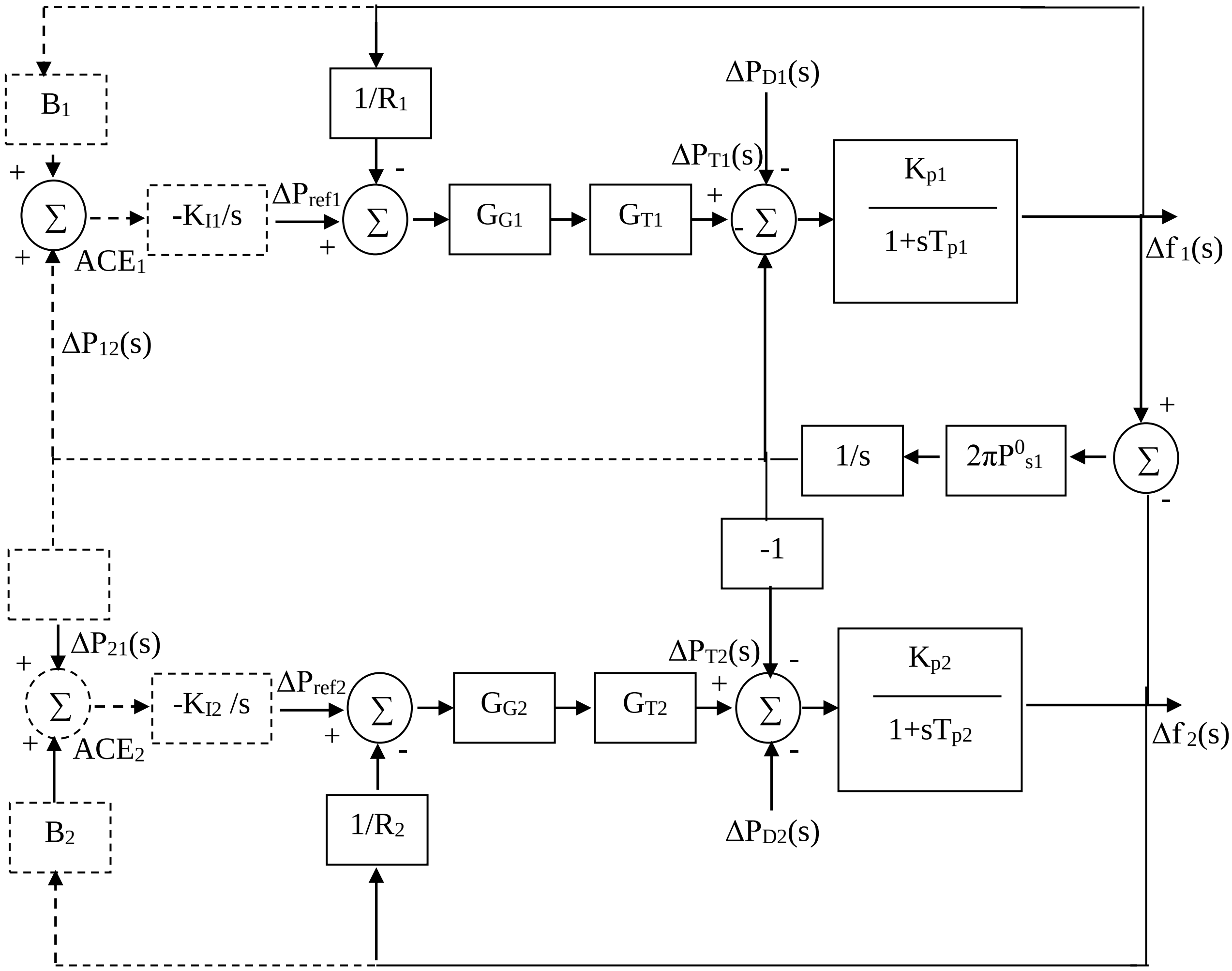


Fig 2 Block Diagram for Two-Area Load Frequency Control

From Fig 2 the following points are to be noted:

i. While in single-area diagram the powers and parameters R,D and H are expressed in per unit of area rating, in two-area diagram since their ratings may be different, we must refer all powers and parameters to the common chosen base power.

ii. The dashed portion of the diagram gives one integral controller for each area. Since the objective of the controller is to maintain the frequency and tie-line power at scheduled values, the input signal to the controller is the Area Control Error (ACE) which is given by

$$ACE_1 = \Delta P_{12} + B_1\, \Delta f_1$$

$$ACE_2 = \Delta P_{21} + B_2\, \Delta f_2$$

where B_1 and B_2 are frequency-bias parameters, which should be selected optimally to achieve better dynamic response.

Exercise:

1. A two area system connected by a tie line has the following parameters on a 1000MVA common base.

Area	1	2
Speed regulation	$R_1 = 0.05$	$R_2 = 0.0625$
Frequency-sens. load coeff.	$D_1 = 0.6$	$D_2 = 0.9$
Inertia constant	$H_1 = 5$	$H_2 = 4$
Base power	1000 MVA	1000 MVA
Governor time constant	$\tau_{g1} = 0.2$ sec	$\tau_{g2} = 0.3$ sec
Turbine time constant	$\tau_{T1} = 0.5$ sec	$\tau_{T2} = 0.6$ sec

The units are operating in parallel at the nominal frequency of 60Hz. The synchronizing power coefficient is computed from the initial operating condition and is given to be Ps = 2 p.u. A load change of 187.5 MW occurs in area1.

(a) Determine the new steady state frequency and the change in the tie-line flow.

(b) Construct the SIMULINK block diagram and obtain the frequency deviation response for the condition in part (a).

9.5 PROGRAMS

9.6 VIVA QUESTIONS

1. Define load frequency control?
2. Define speed regulation?
3. What is damping constant?
4. Why an integral control is added to Speed Governor System?
5. What are the functions of ALFC?

Preparation (2)	**Model calculation/Execution(5)**	**Viva (3)**

9.7 RESULT

Thus the modeling and analysis of load-frequency and tie-line flow dynamics of a power system with load-frequency controller (LFC) under different control modes was simulated and system response was obtained.

Ex. No.:	ECONOMIC DISPATCH IN POWER SYSTEMS
Date:	

10.1 AIM

To understand the basics of the problem of Economic Dispatch (ED) of optimally adjusting the generation schedules of thermal generating units to meet the system load which are required for economic operation of power systems.

10.2 OBJECTIVES

i. To write a program for solving ED problem without and with transmission losses for a given load condition / daily load cycle using

a. Direct method
b. Lambda-iteration method

ii. To study the effect of change in fuel cost on the economic dispatch for a given load.

10.3 SOFTWARE REQUIRED

The software required is **MATLAB.**

10.4 THEORETICAL BACKGROUND

10.4.1 Statement of Economic Dispatch Problem:

In a power system, with negligible transmission loss and with N number of spinning thermal generating units the total system load PD at a particular interval can be met by different sets of generation schedules

$$\left\{PG_1^{(k)}, PG_2^{(k)}, \text{-----------} PG_N^{(k)}\right\};\quad k = 1, 2, \text{------}NS$$

Out of these NS sets of generation schedules, the system operator has to choose that set of schedule which minimizes the system operating cost which is essentially the sum of the production costs of all the generating units. This economic dispatch problem is mathematically stated as an optimization problem.

Given: the number of available generating units N, their production cost functions, their operating limits and the system load PD,

To determine: the set of generation schedule,

$$PG_i\ ;\quad i = 1,2,\ldots\ldots N \qquad (1)$$

which minimizes the total production cost,

$$\text{Min}:\ F_T = \sum_{i=1}^{N} F_i(PG_i) \qquad (2)$$

EXERCISE

1. The input output curve for the three generating units are given below.

Unit I:Coal –fired unit:

$$H_1(\text{MBtu/h}) = 510 + 7.2P_1 + 0.00142P_1^2 \qquad 150 \leq P_1 \leq 600 \text{ MW}$$

Unit II: Oil-fired steam unit :

$$H_2(\text{MBtu/h}) = 310 + 7.85P_2 + 0.00194P_2^2 \qquad 100 \leq P_2 \leq 400 \text{ MW}$$

Unit III:Oil-fired steam unit:

$$H_3(\text{MBtu/h}) = 78 + 7.97P_3 + 0.00482P_3^2 \qquad 50 \leq P_2 \leq 200 \text{ MW}$$

The fuel costs are

Unit I =1.1 Rs./MBtu

Unit II= 1.0 Rs./MBtu

Unit III = 1.0 Rs./MBtu

Obtain (i) the optimum schedule for a total load of 850MW neglecting the losses

(ii) the optimum schedule assuming a power loss given by the expression

$$P_L = 0.00003\, P_1^2 + 0.00009\, P_2^2 + 0.00012\, P_3^2$$

and satisfies the power balance constraint

$$\Phi = \sum_{i=1}^{N} PG_i - PD = 0 \qquad (3)$$

and the operating limits

$$PG_{i,min} \leq PG_i \leq PG_{i,max} \qquad (4)$$

The unit production cost function is usually approximated by a quadratic function

$$F_i\,(PG_i) = a_i\, PG^2_i + b_i\, PG_i + c_i \quad ; \quad i = 1,2, \ldots\ldots N \qquad (5)$$

Algorithm for ED with loss (For quadratic production cost function)

Step 1: Choose the appropriate value of Lagrangian multiplier λ

Step 2: Start iteration iter=0

Step 3: Iteration iter =iter+1

Step 4: Calculate the power using $P_i(k) = \dfrac{\lambda(k) - b_i}{2(a_i + \lambda(k))B_{ii}}$

Step 5: Check for the limits of P_i

Step 6: Find losses using $P_L(k) = \sum_{i=1}^{Ng} B_{ii} P_i^2(k)$

Step 5: Find power mismatch using $\Delta.P(k) = P_D + P_L - \sum_{i=1}^{Ng} P_i(k)$

Step 6: Check the power mismatch P(k).Find if it is less than or equal to tolerance limit.

Step 7: Find the value of new λ

$$\lambda(k+1) = \lambda(k) + \lambda(k) \text{ If } \Delta.P(k) > 0$$

$$\lambda(k+1) = \lambda(k) - \Delta\lambda(k) \text{ If } \Delta.P(k) < 0$$

Step 8: Substitute λ equal to new λ value and repeat from step 2.

10.5 PROGRAM

10.6 VIVA QUESTIONS

1. Define economic dispatch?
2. What is known as equality and inequality constraints?
3. Differentiate economic dispatch and unit commitment?
4. What is a Lagrangian multiplier?.
5. Write the co-ordination equation considering losses

Preparation (2)	Model calculation/Execution(5)	Viva (3)

10.7 RESULT

Thus the Economic dispatch problem was solved and verified using MATLAB.

Ex. No.:	STUDY OF VARIABLE SPEED WIND ENERGY CONVERSION SYSTEM USING –PMSG
Date:	

11.1 AIM:

To study of variable speed wind energy conversion system using –PMSG

11.2 THEORY

Wind energy is a prominent area of application of variable-speed generators operating on the constant grid frequency. This generator is connected to the grid by means of an IGBT rectifier, a DC bus, an IGBT inverter and a filter. The modeling of the converters is made by using the concept of instantaneous average value. We have used an aerator profile of wind speed in order to illustrate the different controls realized, especially with maximum power point tracking algorithm (MPPT) and Pitch control at wind turbine level. To control the voltage of the continuous bus and the exchanges of active and reactive powers, we have used proportional integral correctors. Nowadays, the extraction of power from wind at a large scale became a well-recognized industry. This fast development of the wind power industry was possible due to several reasons, like: the increasing resistance regarding the use of coal, oil or uranium, the high price of oil and the climate change problem. Because of the rapid development of power electronic devices and thus decreasing equipment costs, the variable speed wind turbine concept with full-scale frequency converter has an increasing market share. The most common generators used in this topology, the doubly fed induction generators (DFIGs) and permanent magnet synchronous generators (PMSGs), allow the extraction of maximum power from a large wind speed interval. The PMSG with a high pole number for low speed, are also used in order to avoid having a mechanical gearbox. It has some valuable advantages over the DFIG such as : better efficiency, easier controllability, no need for reactive magnetizing current and they are smaller in size.The PMSG wind turbine, in general, is connected to the power grid using a full-size, properly controlled frequency converter technology. Two types of converter topologies are available these days. One, in which, the frequency converter is composed of a diode-rectifier, DC-chopper, DC bus, and DC/AC inverter. In the other topology, the frequency converter is composed of an IGBT-rectifier, DC bus, and DC/AC inverter.

1.3 SIMULATION METHODS OF THE TYPE 4 WIND TURBINE

Depending on the range of frequencies to be represented, three simulation methods are currently available in SimPowerSystems™ to model VSC based energy conversion systems connected on power grids.

The detailed model (discrete) : In order to achieve an acceptable accuracy with the 2000 Hz and 3000 Hz switching frequencies used in this demo, the model must be discretized at a relatively small time step (2 microseconds).

The average model (discrete) :In this type of model the IGBT Voltage-sourced converters (VSC) are represented by equivalent voltage sources generating the AC voltage averaged over one cycle of the switching frequency. A similar method is used for DC-DC converter. The average model does not represent harmonics, but the dynamics resulting from control system and power system interaction is preserved. This model allows using much larger time steps (typically 50 microseconds), thus allowing simulations of several seconds.

The phasor model (continuous) :This model is better adapted to simulate the low frequency electromechanical oscillations over long periods of time (tens of seconds to minutes). In the phasor simulation method, the sinusoidal voltages and currents are replaced by phasor quantities (complex numbers) at the system nominal

11.4 CIRCUIT DESCRIPTION

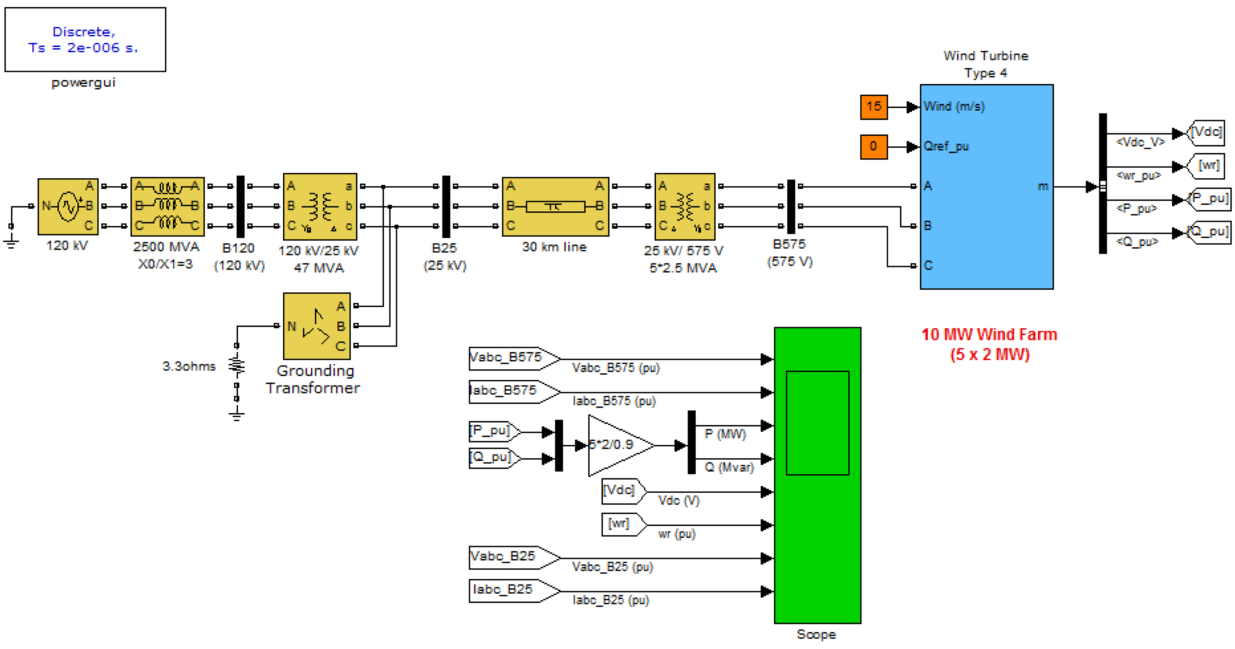
A 10 MW wind farm consisting of five 2 MW wind turbines connected to a 25 kV distribution system exports power to a 120 kV grid through a 30 km, 25 kV feeder.

The Type 4 wind turbine presented in this demo consists of a synchronous generator connected to a diode rectifier, a DC-DC IGBT-based PWM boost converter and a DC/AC IGBT-based PWM converter. The Type 4 technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind.

The wind speed is maintained constant at 15 m/s. The control system of the DC-DC converter is used to maintain the speed at 1 pu. The reactive power produced by the wind turbine is regulated at 0 Mvar.

Right-click on the “Wind Turbine Type 4” block and select “Look Under Mask” to see how the model is built. The sample time used to discretize the model (Ts= 2 microseconds)is specified in the Initialization function of the Model Properties.

Open the “Wind Turbine Type 4” block menu to see the data of the generator, the converter, the turbine, the drive train and the control systems. In the Display menu select “Turbine data for 1 wind turbine”, check "Display wind turbine power characteristics" and then click Apply. The turbine Cp curves are displayed in Figure 1. The turbine power, the tip speed ratio ambda and the Cp values are displayed in Figure 2 as function of wind speed. For a wind speed of 15 m/s, the turbine output power is 1 pu of its rated power, the pitch angle is 8.8 deg and the generator speed is 1 pu.



Wind Farm
Synchronous Generator and Full Scale Converter (Type 4) Detailed Model

Preparation (2)	Model calculation/Execution(5)	Viva (3)

11.5 RESULT

Thus the PMSG based wind energy conversion system was successfully studied.

Ex. No.:	AUTOMATIC VOLTAGE REGULATOR
Date:	

12.1 AIM

To construct a Simulink model for Automatic Voltage Regulator and to obtain the step response.

12.2 SOFTWARE REQUIRED

The software required is MATLAB.

12.3 THEORY

The Generator excitation system maintains generator voltage and controls the reactive power flow. The sources of reactive power are Generators, Capacitors, and reactors. The generator reactive powers are controlled by field excitation and other supplementary methods of improving the voltage profile on electric transmission systems are transformer load-tap changers, switched capacitors, step-voltage regulators and static-var control equipment. The primary means of generator reactive power control is the excitation control using Automatic Voltage Regulator(AVR). The role of an AVR is to hold the terminal voltage magnitude of a synchronous generator at a specified level.

Mathematical Model of AVR:

The mathematical modeling of AVR is derived as follows:

a) Amplifier Model

The excitation system amplifier may be magnetic amplifier, rotating amplifier or modern electronic amplifier. The amplifier is represented by a gain K_A and time constant τ_T and the transfer function is

$$V_R(s)/ V_e(s) = K_A /(1+ s\tau_A)$$

Typical values of K_A are in the range of 10 to 400, time constant τ_T is very small in the range of 0.02 to 0.1 sec and often neglected.

b) Exciter Model

Assume that for some reason the terminal voltage $|V|$ would decrease. This immediately results in an increased "error voltage" e which, in turn, causes increased values of v_R, i_e, v_f, and i_f. The d axis generator flux increases as result of the boost in i_f, thus raising the magnitude of the internal generator emf E and terminal voltage V.

$$V_F(s)/ V_R(s) = K_E /(1+ s\tau_E)$$

The time constants τ_E values in the range of 0.5 – 1.0 sec.

c) Generator Model

The synchronous machine generator emf is a function of the machine magnetization curve, and its terminal voltage is dependent on the generator load.

In the linearized model, the transfer function relating the generator terminal voltage to its field voltage can be represented by a gain K_G and a time constant T_G and the transfer function is

$$V_t(s)/ V_F(s) = K_G/(1+ s\tau_G)$$

These time constant are load dependent. K_G varies from 0.7 to 1 and τ_G between 1.0 to 2.0sec from full-load to no-load

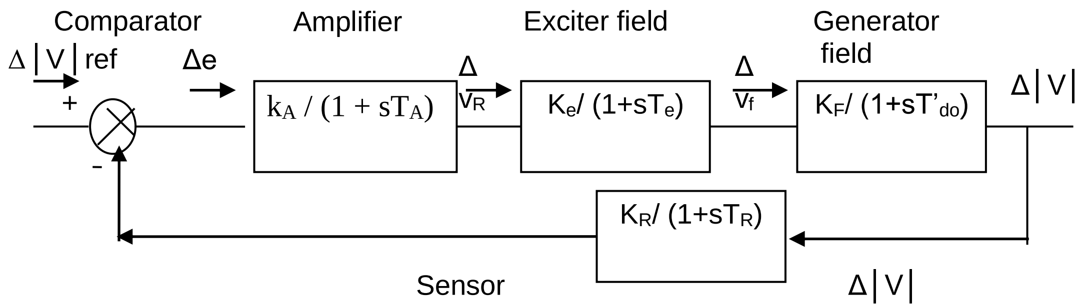
d) Sensor Model

The voltage sensed through a potential transformer and, in one form, it is rectified through a bridge rectifier. The sensor modeled be a simple first order transfer function, given by

$$V_S(s)/ V_t(s) = K_R/(1+ s\tau_R)$$

τ_R is small and range lies between 0.01 to 0.06sec

The overall block diagram for Automatic Voltage Regulator is given below:



12.4 SIMULINK

Preparation (2)	Model calculation/Execution(5)	Viva (3)

12.5 RESULT

The Simulink block diagram for Automatic Voltage Regulator is constructed and the step response is also obtained for a given specified gain and time constants.