MAILAM ENGINEERING COLLEGE
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(Approved by AICTE, New Delhi, Affiliated to Anna University Chennai& Accredited by TCS)
Department of Electrical & Electronics Engineering

SUB CODE/ NAME : EE6501/ POWER SYSTEM ANALYSIS
YEAR / SEC : III / A & B

SYLLABUS

UNIT I INTRODUCTION
Need for system planning and operational studies – basic components of a power system.-Introduction to restructuring - Single line diagram – per phase and per unit analysis – Generator - transformer – transmission line and load representation for different power system studies.- Primitive network - construction of Y- bus using inspection and singular transformation methods – z-bus.

UNIT II POWER FLOW ANALYSIS
Importance of power flow analysis in planning and operation of power systems - statement of power flow problem - classification of buses - development of power flow model in complex variables form - iterative solution using Gauss-Seidel method - Q-limit check for voltage controlled buses – power flow model in polar form iterative solution using Newton-Raphson method .

UNIT III FAULT ANALYSIS – BALANCED FAULTS
Importance of short circuit analysis - assumptions in fault analysis - analysis using Thevenin's theorem - Z-bus building algorithm - fault analysis using Z-bus – computations of short circuit capacity, post fault voltage and currents.

UNIT IV FAULT ANALYSIS – UNBALANCED FAULTS
Introduction to symmetrical components – sequence impedances – sequence circuits of synchronous machine, transformer and transmission lines - sequence networks analysis of single line to ground,line to line and double line to ground faults using Thevenin's theorem and Z-bus matrix.

UNIT V STABILITY ANALYSIS
Importance of stability analysis in power system planning and operation - classification of power system stability - angle and voltage stability – Single Machine Infinite Bus (SMIB) system: Development of swing equation - equal area criterion - determination of critical clearing angle and time solution of swing equation by modified Euler method and Runge-Kutta fourth order method.

TEXT BOOKS:

1. Nagrath I.J. and Kothari D.P., 'Modern Power System Analysis', Tata McGraw-Hill, Fourth Edition, 2011.
2. John J. Grainger and W.D. Stevenson Jr., 'Power System Analysis', Tata McGraw-Hill, Sixth reprint, 2010.

REFERENCES:

1. Hadi Saadat, 'Power System Analysis', Tata McGraw Hill Education Pvt. Ltd., New Delhi, 21st reprint, 2010.

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UNIT-I

PART-A

1. What is single line diagram and what are the advantages of it? (Nov/Dec-2011)(AU NOV/DEC 2015)

A single line diagram is a diagrammatic representation of power system in which the components are represented by their symbols and interconnection between them are shown by a single straight line. The ratings and the impedances of the components are also marked on the single line diagram.

The advantages (or purpose) of the single line diagram is to supply the significant information about the system in concise form.

2. What are the components of power system? (May/Jun-2012)

The components of power system are generators, power transformers, transmission lines, substation transformers, distribution transformers and loads.

3. Define per unit value?(Nov/Dec-2008, May/June-2013,2016)(AU NOV/DEC 2015)

The per unit value of any quantity is defined as the ratio of the actual value of the quantity to the base value expressed as a decimal. The base value is an arbitrary chosen value of the quantity.

$$\text{per unit value} = \frac{\text{Actual value}}{\textit{Base value}}$$

4. What is the need for base value? (Apr/May2018)

The components (or) various sections of power system may operate at different voltage and power levels. It will be components of power system are expressed with reference to a common value called base value. The all the voltage, power, current and impedance ratings of the components are expressed as a percent or per unit of the base value.

5. Write the equation for converting the p.u impedance expressed in one base to another? Or Write the equation for per unit impedance if change of base occurs?[AU MAY/JUNE 2016]

$$Z_{p.u,new} = Z_{p.u,old} \times \left(\frac{kV_{b,old}}{kV_{b,new}}\right)^2 \times \left(\frac{MVA_{b,new}}{MVA_{b,old}}\right)$$

6. What are the advantages of per unit computations? (May/Jun-2006) (OR) Why is P.U (Per Unit) system used in power system analysis? What is the need for per unit value? (Nov/Dec 2014,2016) (Apr/May2017)

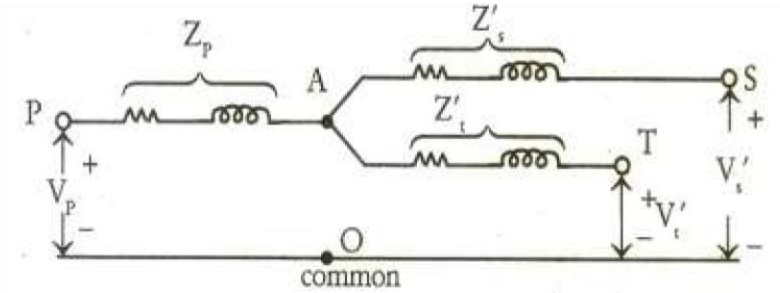
- Manufacturers usually specified the impedance of a device or machine in per unit on the base of the name plate rating.
- The P.U values of acidly different rating machines line within a narrow range.
- The P.U impedance of circuit element connected by transformers expressed on a proper base will be same if it is referred to either side of a transformer.
- The P.U impedance of a 3 phase transformer is in dependent of the type of winding connection.

7. **How the loads are represented in reactance or impedance diagram? (or) What are the types of load modeling?(Nov/Dec-2011,2016) ,(May/Jun 2014)**

The resistive and reactive loads can be represented by any one of the following representations.

- Constant power representation. Load power, $S = P + jQ$.
- Constant current representation. Load current, $I = \frac{\sqrt{(p^2 + Q^2}}{|V|} \angle S - \theta$
- Constant impedance representation. Load current, $Z = \frac{|V|^2}{P - jQ}$

8. **Draw the single phase equivalent circuit of a 3 winding transformer? (May/June-2013)**



9. If the reactance in ohms in 15 ohms, find the p.u value for a base of 15 kVA and 10kV? (May/Jun-06)

Solution:

Base impedance, $Z_b = \frac{kV^2}{MVA} = \frac{10^2}{\frac{15}{1000}} = 6666.67\Omega$.

P.u value of reactance = $\frac{reactance \quad in \ ohms}{base \quad impedance} = \frac{15}{6666.67} = 0.0022 p.u$

(Note: MVA= (KVA/1000))

10. A generator rated at 30MVA, 11kV has a reactance of 20% calculate its p.u reactance's for 50 MVA and 10 kV? (Nov/Dec-2004)

Solution:

New p.u reactance of generator,

$$X_{p.u,new} = X_{p.u,old} \times (\frac{kV_{b,old}}{kV_{b,new}})^2 \times (\frac{MVA_{b,new}}{MVA_{b,old}})$$

$$Xp.u,= 20\% = 0.2p.u$$

$$kVb,= 11kV$$

$$MVA_{b,old} = 30MVA$$

$$kV_{b,new} = 10kV$$

$$MVA_{b,new} = 50MVA$$

New p.u reactance of generator,

$$X_{p.u,new} = 0.2\times(\frac{11}{10})^2\times(\frac{50}{30}) = 0.403p.u$$

11. A Star connected generator rated at 300MVA, 33kV, has a reactance of 1.24 p.u. Find the ohmic value of reactance? (Apr/May 2017)

Solution:

Base impedance, $Z_b = \frac{kV^2}{MVA} = \frac{33^2}{300} = 3.63$ ohms/phase

P.u reactance per unit value $= \frac{\text{Actual value}}{2Base\ \ value}$

Reactance of generator = p.u reactance$\times Z_b = 1.24\times 3.63 = 4.5012\ \Omega/p$hase

12. The base kV and base MVA of a 3ph transmission line in 33kV and 10MVA respectively. Calculate the base current and base impedance?

Solution:

Base current, $I_b = \frac{kVA_b}{\sqrt{3kV_b}} = \frac{10\times 1000}{\sqrt{3}\times 33} = 174.95A$

Base impedance, $Z_b = \frac{kV}{MVA} = \frac{33}{10} = 108.9$ ohms/ph.

13. What are the approximations made in impedance diagram?

The following approximations are made while forming impedance diagram.

- The current limiting impedance connected between the generator neutral and ground are neglected since under balanced conditions no current flows through neutral.
- The shunt branches in the equivalent circuit of induction motor are neglected.
- All the resistances in the equivalent circuit of various components of the system are neglected.

14. Give equations for transforming base kV on LV side to HV side of transformer and vice-versa? (Nov/Dec 2017)

Base kV on HT side=Base kV on LT side$\times \frac{HT\ voltage\ \ rating}{LT\ voltage\ \ rating}$

Base kV on LT side=Base kV on HT side$\times \frac{LT\ voltage\ \ rating}{HT\ voltage\ \ rating}$

15. Define Bus?

The meeting point of various components in a power system is called a bus. The conductor is made up of copper or aluminum having negligible resistance. The buses are considered as point of constant voltage in a power system. At some of the buses power is being injected into the network, whereas at other buses it is being tapped by the system loads.

16. What is bus admittance matrix? (May/June-2012)

The matrix consisting of the self and mutual admittances of the network of a power system is called bus admittance matrix. It is denoted as Y_{bus}. The bus admittance matrix is symmetrical.

$$[Y][V] = [I]$$

$$\begin{bmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & Y_{23} \\ Y_{31} & Y_{32} & Y_{33} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} = \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix}$$

Where

V = Bus voltage

I = Injected bus currents.

Y = Bus admittance matrix

Y_{ii} = Sum of the admittance of all elements connected to the i^{th} node. It is called as self admittance at the i^{th} bus.

Y_{ij} = Negative of the sum of the admittance of all elements connected between the nodes i and j. It is called as mutual admittance between i^{th} and j^{th} bus.

17. Name the diagonal and off diagonal elements of bus admittance matrix?

The diagonal elements of bus admittance matrix are called self admittance of the buses and off diagonal elements are called mutual admittance of the buses.

18. What is bus impedance matrix? (May/June-2012)

The matrix consisting of driving point impedance and transfer impedance of the network of a power system is called bus impedance matrix. It is denoted as Z_{bus}. It is also symmetrical.

19. Draw a simple per phase model for a cylindrical rotor synchronous machine? (Apr/May-2011)

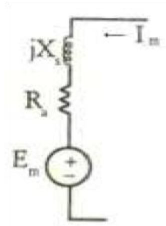


Fig. Impedance Diagram

20. What are the functions of power system analysis?

- To monitor the voltage at various buses, real and reactive power flow between buses.
- To design the circuit breakers.
- To plan future expansion of the existing system.
- To analysis the system under different fault conditions.
- To study the ability of the system for large disturbances and small disturbances.

21. Draw the impedance and reactance diagram for the given single line representation of the power system?

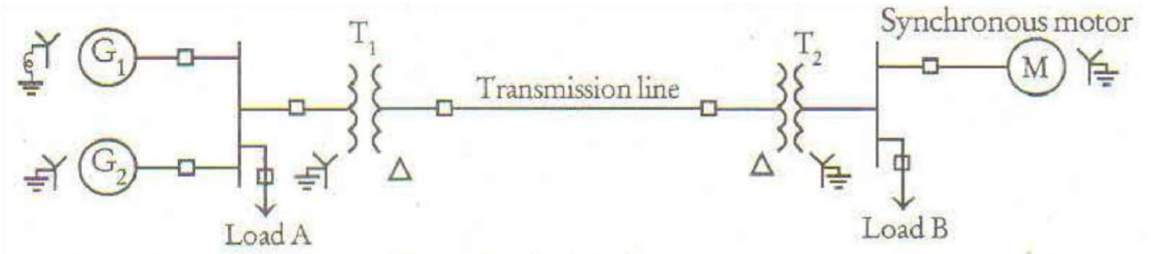


Fig a : Single line diagram

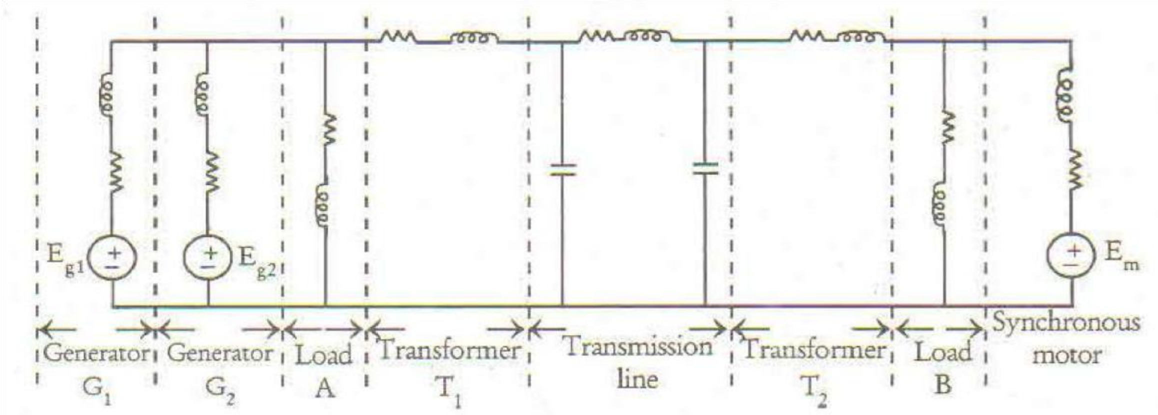


Fig b : Impedance diagram

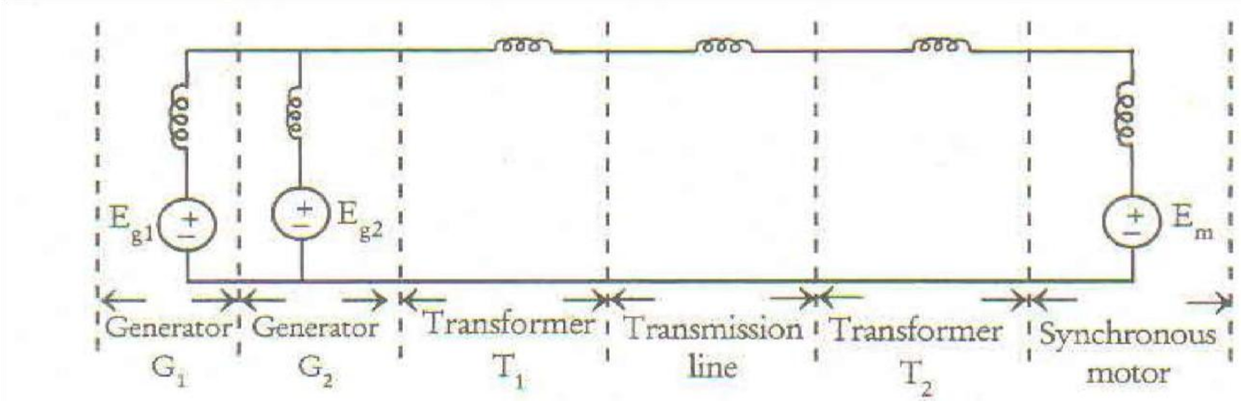
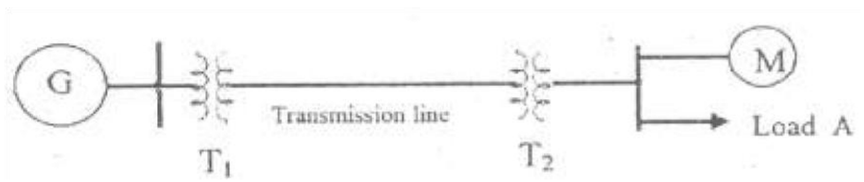


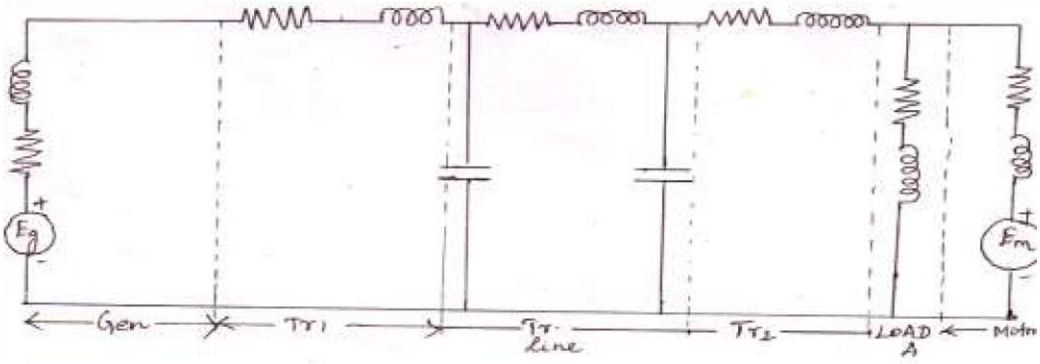
Fig. Reactance Diagram

22. Draw the impedance diagram for the given single line representation of the power system?(May/Jun 2014)

<u>Single line Diagram</u>



Solution: <u>Impedance Diagram</u>



23. What are the main divisions of power system? (Nov/Dec 2014)

The main divisions of power system are

- Generating system
- Transmission system
- Distribution system

24. What is the importance of power system analysis? (or) What is the need of power system analysis in planning and operation of power system?

- The generation should be such a way that to meet out the required demand. When this relation is satisfied, it gives good economy and security.
- The operation of a power system must be reliable and uninterrupted.
- The loads must be fed at constant voltage and frequency.
- Importance of power system planning and operational analysis covers the maintenance of generation, transmission and distribution facilities.

25. For the power system shown in fig., by taking generator rating as base values, specify the base values of the transmission line and motor circuit.

40MVA,25KV 33/220KV 220/11KV 25 MVA,10KV

35 MVA 30 MVA

Solution:

Generator circuit (selected base):

Base kilovolt =25KV

Base megavolt ampere =40 MVA

Transmission line:

Base kilovolt = 25x (220/33) =166.67 KV

Base megavolt ampere =40 MVA

Motor Circuit:

Base kilovolt = 166.67x (11/220) =8.33 KV

Base megavolt ampere =40 MVA

26. Determine Z_{bus} **when** $Y_{bus} = \begin{bmatrix} -j_1 & j_2 \\ j_2 & -j_5 \end{bmatrix}$

Solution:

$$Z_{bus} = Y_{bus}^{-1} = \frac{Adjo\text{int}\,ofY_{bus}}{Deter\min antofY_{bus}}$$

$$Deter\min antofY_{bus} = \begin{vmatrix} -j_1 & j_2 \\ j_2 & -j_5 \end{vmatrix} = (-j_1)(-j_5) - (j_2)^2$$

$$= -5+4 = -1$$

$$\text{Adjoint of } Y_{bus} = \begin{bmatrix} -j_5 & -j_2 \\ -j_2 & -j_1 \end{bmatrix}^T = \begin{bmatrix} -j_5 & -j_2 \\ -j_2 & -j_1 \end{bmatrix}$$

$$Y_{bus} = -1\begin{bmatrix} -j_5 & -j_2 \\ -j_2 & -j_1 \end{bmatrix} = \begin{bmatrix} j_5 & j_2 \\ j_2 & j_1 \end{bmatrix}$$

27. A 400 KV transmission line has a surge impedance 400 ohms. What would be its surge impedance loading? (Apr/May 2015)

Given data: surge impedance, Z_0 = 400 Ohms Line voltage ,V_L = 400 KV

To find :

Surge Impedance loading, P_{SIL}

Formula:

$P_{SIL} = V_{L2} / Z_0$

Soluion:

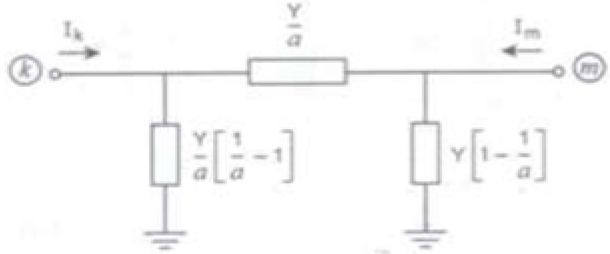
$P_{SIL} = 400^2 / 400 \quad (KV^2 / \Omega)$

$= 400$ MVA

Result:

Surge impedance loading = 400 MVA.

28. Draw the Π model of equivalent circuit of transformer with off nominal tap ratio?[Au May/June 2016]



Where

a = Off nominal tap ratio.

y = Admittance of the transformer.

29. Define per unit value of an electrical quantity and write the equation for base impedance for a three phase system? (Nov/Dec 2017)

The per unit value of any quantity is defined as the ratio of actual quantity to its base quantity expressed as a decimal. The ratio in percent is 100 times the value in per unit.

$$Z_b = \frac{kV_b \times 1000}{\sqrt{3} \times \frac{kVA_b}{\sqrt{3} kV_b}} = \frac{kV_b^2}{\frac{kVA_b}{1000}} = \frac{kV_b^2}{MVA_b}$$

30. Mention the requirements of planning the operation of a power system. (Apr/May2018)

Planning the operation of power system requires load studies, fault calculations, the design of means for protecting the system against lightning and switching surges and against short circuits and studies of the stability of the system.

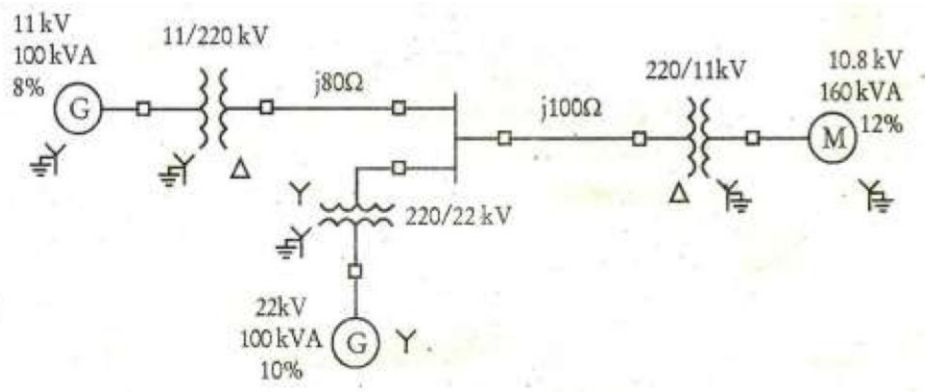
<u>16 Marks</u>

1. **With the help of single line diagram explain the basic components of a power system?(Apr/May-11)**

An electric power system consists of three main divisions namely,

i) The generating system ii) The transmission system iii) The distribution system

- **Transmission lines** are the links between the generating system and the distribution system and lead to other power system over interconnection.
- A **distribution system** connects all the individual loads to the transmission lines at substations which perform voltage transformation and switching functions.
- The components of power system are generating stations (Alternators), power transformers, Transmission lines substations (substation transformers), Distribution transformers and loads.
- The various types of **loads** are synchronous motors, Induction motor, Heating coils, Lights etc.,
- The various components of power system and their interconnection are usually represented by ***single line diagram***.In a single line diagram the components are represented by standard symbols and their interconnections are shown by single line even though are they are 3phase circuits.
- The ***Advantage*** of the one line diagram is to supply in concise form the significant information about the system. A typical single line diagram in shown in fig,



Symbols used in single line diagram:

Machine or rotating armature		Power circuit breaker, (oil/gas filled)	
Two-winding power transformer		Air circuit breaker	
Three-winding power transformer		Three-phase, three-wire delta connection	
Fuse		Three-phase star, neutral ungrounded	
Current transformer		Three-phase star, neutral grounded	
Potential transformer	or	Ammeter and voltmeter	A V

2. **Write detailed notes on per phase model of single phase and three phase system? (Apr/May-2011)**

The electric power transmission lines are operated at very high voltage levels and transmits large amount of power. Hence the operating voltage of transmission line in expressed in kilo volt and power transmitted in expressed in kW (or) MW and KVA(or) MVA.

The various components of power system like alternators, motor, transformer have their voltage, power, current and impedance rating in kV, kVA, KA and ohm respectively.

Per unit value of any quantity in defined as the ratio of the actual value of the quantity to the base value expressed as a animal the base value in an arbitrary chosen value of the quantity.

$$\text{per uint value} = \frac{\text{Actual value}}{base\ value}$$

$$\%\text{per uint value} = \frac{\text{Actual value}}{base\ value} \times 100$$

<u>Single phase system</u>:

Let,

kVA_b = Base kVA

kV_b = Base voltage in kV

I_b = Base current in Amp

Z_b = Base impedance in ohms

The following formulae relate the various quantities

Base current, $I_b = \dfrac{kVA_b}{kV_b}$ in amps (1)

Base impedance $Z_b = \dfrac{kV_b \times 1000}{I_b}$ in ohms (2)

On substituting for I_b from equation (1) in equ (2) we get

$$\text{Base impedance } Z_b = \frac{kV_b \times 1000}{\frac{kVA_b}{kV_b}} = \frac{kV_b^2}{\frac{kVA_b}{1000}} = \frac{kV_b^2}{MVA_b} \qquad (3)$$

$$\text{Per unit impedance} = \frac{\text{Actual impedance}}{base\ \ impedance}$$

Three phase system:

- The per-unit value of a line- to- neutral(V_{LN}) on the line-to-neutral voltage base ($V_{b,LN}$) is equal to the per-unit value of the line-to-line voltage(V_{LL}) at the same point on the line-to-line voltage base($V_{b,LL}$) if the system is balanced,

$$\frac{V_{LN}}{B_{b,LN}} = \frac{V_{LL}}{V_{b,LL}}$$

- The per unit value of a 3 phase kVA on 3 phase kVA base is identical to the per unit value of the kVA per phase on the kVA per phase base.

$$\frac{3-\text{phase kVA}}{3-phase\ base\ kVA} = \frac{\text{kVA per phase}}{base\ kVA\ per\ phase}$$

- The base impedance and base current of 3phase system can be computed directly from 3 phase value of base kVA and line value of base kV.

Let,

kV_b = Line to line base kV

kVA_b = 3phase kVA

I_b = Line value of base current

Now, $kVA_b = \sqrt{3} \times kV_b \times I_b$ (4)

(In 3 phase system, $kVA = \sqrt{3} V_L I_L \times 10^{-3} = \sqrt{3}(kV_L) I_L$)

Base current $I_b = \dfrac{kVA_b}{\sqrt{3} kV_b}$ (5)

In balanced power system the phase voltage in $\frac{1}{\sqrt{3}}$ times the line voltage.

$$\text{Base impedance per phase } Z_b = \frac{\frac{kV_b}{\sqrt{3}} \times 1000}{I_b} = \frac{kV_b \times 1000}{\sqrt{3} I_b} \qquad (6)$$

Substitute I_b value,

$$Z_b = \frac{kV_b \times 1000}{\sqrt{3} \times \frac{kVA_b}{\sqrt{3} kV_b}} = \frac{kV_b^2}{\frac{kVA_b}{1000}} = \frac{kV_b^2}{MVA_b} \qquad (7)$$

Here the equ (3) and (7) looks similar, but in 3-phase system, the kV_b is a line value and MVA_b is a 3-phase MVA.

3. Derive the expression for changing the base of per unit quantities? (Apr/May-2008)

- When a system is formed by interconnecting various devices for convenient for analysis the impedances are converted to common base. All impedance in any one part of a system must be expressed on the common impedance base. Hence it is necessary for converting per unit impedances from one base to another.

Let,

Z = Actual impedance, ohms

Z_b = Base impedance, ohms

Per unit impedance of a circuit element $= \frac{Z}{Z_b} = \frac{Z}{\frac{kV_b^2}{MVA_b}} = \frac{Z \times MVA_b}{(kV_b)^2}$ (1)

Let $kV_{b,}$ and $MVA_{b,old}$ represents old base values $kV_{b,new}$ and $MVA_{b,new}$ represents new base

$$Z_{p.u,old} = \frac{Z \times MVA_{b,old}}{kV_{b,old}^{\;2}} \qquad (2)$$

$$Z = Z_{p.u,old} \times \frac{kV_{b,old}^{\;2}}{Z \times MVA_{b,old}} \qquad (3)$$

If the new base values are used to compute the p.u impedance of a circuit element with impedance Z, then equ(1) can be written as

$$Z_{p.u,new} = \frac{Z \times MVA_{b,new}}{kV_{b,new}^{\;2}} \qquad (4)$$

On substituting for Z from equ (3) in (4) we get,

$$Z_{p.u,new} = Z_{p.u,old} \times \frac{kV_{b,old}^{\;2}}{MVA_{b,old}} \times \frac{MVA_{b,new}}{kV_{b,new}^{\;2}}$$

$$Z_{p.u,new} = Z_{p.u,old} \times \left(\frac{kV_{b,old}}{kV_{b,new}}\right)^2 \times \frac{MVA_{b,new}}{MVA_{b,old}} \qquad (5)$$

The equ (5) can be used to convert the p.u impedance expressed on one base value to another base.

4. A 3phase generator with rating 1000 KVA 33KV has its armature resistance and synchronous reactance as 20ohms/phase and 70ohms/phase. Calculate P.U impedance of the generator.

Solution:

Given data:

Power = 1000 kVA = kVA_b

Voltage = 33kV = kV_b

R_a = 20ohms/phase

X_s = 70ohms/phase

1000kVA_b = $1*10^3*kVA_b$ = 1 MVA_b

Solution:

The generator ratings are chosen as base kV and base kVA.

Per unit impedance of the generator = $Z_{p.u,gen}$

$$Z_{p.u,gen} = \frac{Z_{actual}}{Z_{base}}$$

$$Z_{actual} = (R_a + jX_s) = (20 + j70)$$

$$Z_{base} = Z_b = \frac{kV_b^2}{MVA_b} = \frac{33^2}{1} = 1089 ohms$$

$$Z_{p.u,gen} = \frac{Z_{actual}}{Z_{base}} = \frac{20 + j70}{1089} = 0.018 + j0.064 p.u$$

5. A 3phase star to delta transformer with rating 100kVA, 11kV/400V has its primary and secondary leakage reactance as 12ohms/ph and 0.05ohms/ph respectively. Calculate the p.u reactance of transformer. (Nov/Dec-2011)

Solution: **Case:1**

The high voltage winding primary ratings are chosen as base values.

Base kilovolt, kV_b = 11kV

kVA_b = 100kVA = (100/1000)*10^3 kVA

Base impedance per phase $Z_b = \frac{kV_b^2}{MVA_b} = \frac{11^2}{0.1} = 1210 ohms$

Transformer line voltage ratio, K = (400/11000)=0.0364

Total leakage reactance referred to primary

$$X_{01} = X_1 + X_2^{'} = X_1 + \frac{X_2}{K^2} = 12 + \frac{0.05}{(0.0364)^2} = 12 + 37.737$$

$$= 49.737\Omega / phase$$

p.u reactance per phase, Xpu = Total leakage reactance/Base impedance

$$= \frac{X_{01}}{Z_b} = \frac{49.737}{1210} = 0.0411 p.u.$$

Case(ii):

The low voltage winding(secondary) ratings are chosen as base values.

Base kilovolt, $kV_b = \frac{400}{1000} = 0.4kV$

Base kilovoltampere, $kVA_b = 100kVA$

Base impedance per phase $Z_b = \frac{(kV_b)^2}{MVA_b} = \frac{(0.4)^2}{100/1000} = 1.6 ohms$

Transformer line voltage ratio, $K = \frac{400}{11{,}000} = 0.0364$

Total leakage reactance referred to secondary $X_{02} = X_1' + X_2 = K^2 X_1 + X_2$

$$= (0.0364)^2 \times 12 + 0.05 = 0.0159 + 0.05$$

$$= 0.0659\Omega / phase$$

p.u reactance per phase, X_{pu} = Total leakage reactance / Base impedance

$$= \frac{X_{02}}{Z_b} = \frac{0.0659}{1.6} = 0.0411 \text{p.u}$$

6. A three phase star delta transformer in constructed using three identical single phase transformer of rating 200kVA, 63.51 kV/11kV transformer. The impedance of primary and secondary are 20+j45 and 0.1+j0.2 ohms respectively. Calculate the p.u impedance of the transformer?

Solution:

The 3phase transformer in formed using 3 number of identical single phase transformers. Hence the kVA rating of 3phase transformer in 3 times that of single phase transformer.

kVA rating of 3phase transformer = 3*200 = 600 kVA

Line voltage rating of star delta transformer = $63.51 * \frac{\sqrt{3}kV}{11kV} = 110kV / 11kV$

Case (i):

The high voltage winding (Primary) rating are chosen as base values.

Base value, kV_b = 110 kV

Base kilovoltampere, kVA_b= 600kVA

Base impedance/Phase $Z_b = \frac{kV_b^2}{MVA_b} = \frac{110^2}{\frac{600}{1000}} = 20166.7\Omega$

Transformer Line voltage ratio, K=11/110=0.1

Total impedance referred to primary $Z_{01} = Z_1 + Z_2' = Z_1 + \frac{Z_2}{K^2} = 20 + j45 + \frac{0.1 + j0.2}{(0.1)^2}$

$$= 20 + j45 + 10 + j20$$

$$= 30 + j65\Omega / phase$$

$$\text{p.u.impedance per phase, Zpu} = \frac{\text{Total impedance}}{Base\ impedance}$$

$$= \frac{30 + j65}{20166.7} = 0.0015 + j0.0032 p.u.$$

Case ii:

The low voltage winding (secondary) ratings are chosen as base values.

Base kilovolt, kV_b = 11 kV

Base kilovoltampere, kVA_b= 600kVA

Base impedance/Phase $Z_b = \frac{kV_b^2}{MVA_b} = \frac{11^2}{\frac{600}{1000}} = 201.67\Omega$

$$K = \frac{11}{110} = 0.1$$

Total impedance referred to Secondary $Z_{02} = Z_1{}' + Z_1 = k^2 Z_1 + Z_2$

$$= (0.1)^2 \times (20 + j45) + 0.1 + j0.2$$
$$= 20 + j45 + 0.1 + j0.2$$
$$= 0.3 + j0.65\Omega / phase$$

$$\text{p. u. reactance per phase, Zpu} = \frac{\text{Total impedance}}{Base\ impedance}$$

$$= \frac{0.3 + j0.65}{201.67}$$
$$= 0.0015 + j0.0032 p.u$$

7. A 50kW, 3ph star connected load in fed by a 200kVA transformer with voltage rating 11kV/400V through a feeder. The length of the feeder in 0.5 km and the impedance of the feeder in 0.1+j0.2ohm/km.If the load Power factor in 0.8 calculate the p.u impedance of the load and feeder.

Solution:

Let us chose the secondary winding rating of transformer as base values.

Base kilovolt, kV_b = 400/100=0.4 kV

Base kilovoltampere, kVA_b= 200kVA

Base impedance/Phase $Z_b = \frac{kV_b^2}{MVA_b} = \frac{0.4^2}{\frac{200}{1000}} = 0.8\Omega$

Actual impedance of feeder $Z_{feed} = (0.1 + j0.2) \times 0.5 = 0.05 + j0.1\Omega / phase$

$$\text{p. u. impedance of feeder} = \frac{\text{Actual impedance}}{Base\ impedance}$$

$$= \frac{0.05 + j0.1}{0.8} = 0.0625 + j0.125 p.u.$$

Given that P=50kW and $pf = \cos\phi = 0.8$

$\sin\phi = \sin(\cos^{-1} 0.8) = 0.6$

Real power $Q = \frac{P}{\cos\phi} \times \sin\phi = \frac{50}{0.8} \times 0.6 = 37.5 kVAR$

Load impedance per phase, $Z_L = \frac{|V_L|^2}{P - jQ} = \frac{400^2}{(50 - j37.5)\times 10^3} = \frac{400^2 \times 10^{-3}}{50 - j37.5}$

$$= \frac{160}{62.5 < -36.87^{\circ}} = 2.56 < 36.87^{\circ} = 2.048 + j1.536W / phase$$

$$\text{p.u value of load impedance} = \frac{\text{load impedance}}{Base\ impedance}$$

$$= \frac{Z_L}{Z_b} = \frac{2.048 + j1.536}{0.8} = 2.56 + j1.92 p.u.$$

8. a) A generator is rated 500MVA, 22kV. Its star connection minding has a reactance of 1.1p.u. Find the ohmic value of the reactance of winding.

b) If the generator in working in a circuit for which the basses are specified as 100MVA, 20kV. Then find the p.u value of reactance of generator winding on the specified base.

Solution:

<u>Given data:</u>

kV_b =22 kV

MVA_b= 500MVA

a) The generator p.u reactance will be specified by taking its rating as base values.

$$Z_b = \frac{kV_b^2}{MVA_b} = \frac{22^2}{500} = 0.968\Omega$$

$$\text{p.u reactance,Xpu} = \frac{\text{Actual reactance}}{Base\ impedance}$$

$$= \frac{X}{Z_b}$$

Actual reactance, $X = X_{p.u} \times Z_b = 1.1 \times 0.968 = 1.0648 \text{ohm/phase}$

b) The formula in used to convert the p.u reactance specified on a base value to another base in given below.

$$\boxed{X_{p.u,new} = X_{p.u,old} \times \left(\frac{kV_{b,old}}{kV_{b,new}}\right)^2 \times \frac{MVA_{b,new}}{MVA_{b,old}}}$$

The new base values are,

$kV_{b,} = 20kV$

$MVA_{b,} = 100MVA$

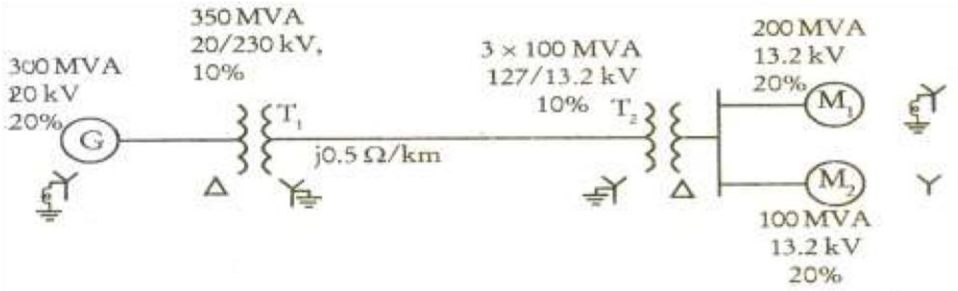
The old base values are

$kV_{b,old}$=22kV

$MVA_{b,old}$=500MVA

$$X_{pu,new} = 1.1 \times (\frac{22}{20})^2 \times (\frac{100}{500}) = 0.2662 p.u$$

9. A 300MVA, 20kV, 3phase generator has a sub transient reactance of 20%. The generator supplies 2 synchronous motors through a 64km transmission line having transformer at both ends as shown in fig. In this T1 in a 3phase transformer and T2 in made of 3 single phase transformer of rating 100MVA, 127/13.2kV, and 10% reactance. Series reactance of the transmission line in 0.5ohm/km. Draw the reactance marked in p.u. Select the generator rating as base values.(Nov/Dec 2014) (Apr/May 2017)



Solution:

$kV_{b,} = 20kV$

$MVA_{b,} = 300MVA$

Reactance of generator G:

Since the generator rating and the base value are same, the generator p.u reactance does not change, p.u reactance of generator = 20% = 0.2p.u

Reactance of transformer T1:

The new p.u reactance of transformer T1= $X_{pu,old} \times (\frac{kV_{b,old}}{kV_{b,new}})^2 \times (\frac{MVA_{b,new}}{MVA_{b,old}})$

$$= 0.1 \times (\frac{20}{20})^2 \times (\frac{300}{350}) = 0.0857 p.u$$

Reactance of transmission line:

Reactance of Tr line =0.5ohm/km

Total reactance of Tr line = 0.5*64 = 32ohms

Base kV on HT side of transformer T_1 = Base kV on LT side $\times \frac{\text{HT voltage rating}}{\text{LT voltage rating}}$

$$= 20 \times \frac{230}{20} = 230kV$$

Base impedance, $Z_b = \frac{kV_b^2}{MVA_b} = \frac{230^2}{300} = 176.33\Omega$

$$Z_{p.u,Tr.line} = \frac{Z_{actual}}{Z_b} = \frac{32}{176.33} = 0.1815 p.u$$

Reactance of transformer T2:

The transformer T2 is a 3phase transformer bank formed using three number of single phase transformer with voltage rating 127/13.2kV.

In this case high voltage side in star connected and low voltage side in delta connected. Voltage ratio of line voltage 3phase transformer Bank

$$= \frac{\sqrt{3}\times 127}{13.2} = \frac{220}{13.2} kv$$

Base kV on LT side of transformer

$$T_2 = \text{Base kV on HT side} \times \frac{\text{LT voltage rating}}{\text{HT voltage rating}}$$

$$= 230 \times \frac{13.2}{220} = 13.8$$

$$X_{p.u,T2} = X_{pu,old} \times (\frac{kV_{b,old}}{kV_{b,new}})^2 \times (\frac{MVA_{b,new}}{MVA_{b,old}})$$

$$= 0.1 \times (\frac{13.2}{13.8})^2 \times (\frac{300}{3\times 100}) = 0.0915 p.u$$

Reactance of M1:

$$X_{p.u,M1} = X_{pu,old} \times (\frac{kV_{b,old}}{kV_{b,new}})^2 \times (\frac{MVA_{b,new}}{MVA_{b,old}})$$

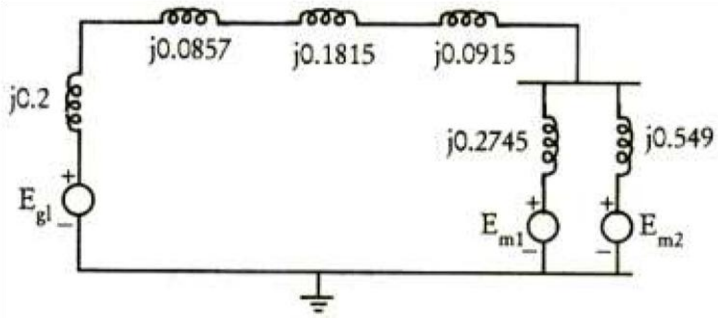
$$= 0.2 \times (\frac{13.2}{13.8})^2 \times (\frac{300}{200}) = 0.2745 p.u$$

Reactance of M2:

$$X_{p.u,M2} = X_{pu,old} \times (\frac{kV_{b,old}}{kV_{b,new}})^2 \times (\frac{MVA_{b,new}}{MVA_{b,old}})$$

$$= 0.2 \times (\frac{13.2}{13.8})^2 \times (\frac{300}{100}) = 0.549 p.u$$

Reactance diagram:



10. **A 120 MVA,19.5 KV generator has a synchronous reactance of 0.15p.u and it is connected to a transmission line through a transformer rated 150 mva,230/18 kv(Y/Δ) with X=0.1 P.U.**

a) Calculate the p.u reactances by taking generator rating as base values.

b) Calculate the p.u reactances by taking transformer rating as base values.

c) Calculate the p.u reactances for a base value of 100 MVA and 220 KV on HT side of transformer.

Solution:

a) Base megavoltampere, $MVA_{b,new}$=120MVA

Base kilovolt, $KV_{b,new}$ = 19.5kV
Since the generator ratings are chosen as base values, its p.u reactance wil not change,
Reactance of generator=0.15p.u.

New p.u reactance of transformer = $X_{pu,old} \times (\frac{kV_{b,old}}{kV_{b,new}})^2 \times (\frac{MVA_{b,new}}{MVA_{b,old}})$

$$= 0.1 \times (\frac{18}{19.5})^2 \times (\frac{120}{150}) = 0.0682 p.u$$

b) Base megavoltampere, $MVA_{b,new}$=150MVA
Base kilovolt, $KV_{b,new}$ = 18kV
Since the transformer ratings are chosen as base values, its p.u reactance wil not change,
Reactance of Transformer=0.1p.u.

New p.u reactance of generator = $X_{pu,old} \times (\frac{kV_{b,old}}{kV_{b,new}})^2 \times (\frac{MVA_{b,new}}{MVA_{b,old}})$

$$= 0.15 \times (\frac{19.5}{18})^2 \times (\frac{150}{120}) = 0.22 p.u$$

c) Base megavoltampere, $MVA_{b,new}$=100MVA
Base kilovolt, $KV_{b,new}$ = 220kV
In this case the base values are neither generator ratings nor transformer ratings. Hence both the p.u reactances should be converted to new base.

New p.u reactance of generator = $X_{pu,old} \times (\frac{kV_{b,old}}{kV_{b,new}})^2 \times (\frac{MVA_{b,new}}{MVA_{b,old}})$

$$= 0.1 \times (\frac{230}{220})^2 \times (\frac{100}{150}) = 0.0729 p.u$$

The generator is connected to LT side of transformer,

Base kV on LT side of transformer = Base kV on HT side $\times \frac{\text{LT voltage rating}}{\text{HT voltage rating}}$

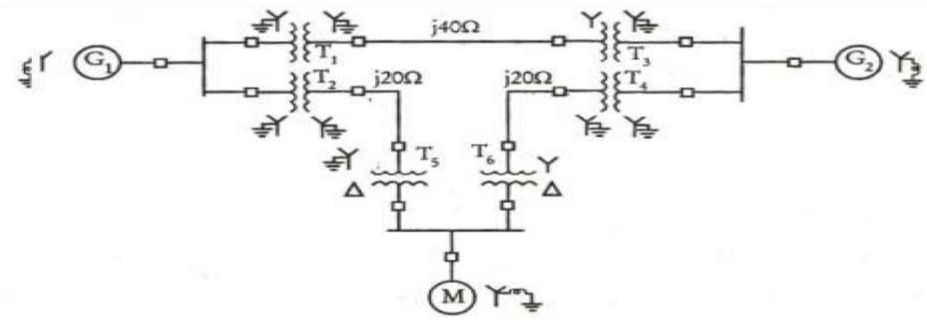
$$= 220 \times \frac{18}{230} = 17.22 kV$$

$$kV_{b,new} = 17.22 kV$$

The new p.u reactance of generator= $X_{pu,old} \times (\frac{kV_{b,old}}{kV_{b,new}})^2 \times (\frac{MVA_{b,new}}{MVA_{b,old}})$

$$= 0.15 \times (\frac{19.5}{17.22})^2 \times (\frac{100}{120}) = 0.1603 p.u.$$

11. Draw the reactance diagram for the power system shown in fig. The rating of generator motor and transformer are given below neglect resistance and use a base of 50MVA, 138kV in the 40ohms line.(April/May-2008)



Generator G1:20MVA, 18kV, X”=20%

Generator G2:20MVA, 18kV, X”=20%

Synchronous motor: 30MVA, 13.8kV, X”=20%

3ph, star-delta transformer: 20MVA, 138/20kV, X=10% 3ph, star-delta transformer: 15MVA, 138/20kV, X=10%

Solution:

$$MVA_{b,new} = 50MVA$$

$$kV_{b,new} = 138kV$$

Reactance of j40 ohms transmission line:

Base impedance, $Z_b = \frac{kV_{b,new}^2}{MVA_{b,new}} = \frac{138^2}{50} = 380.8\Omega$

$$X_{p.u.Tr.line} = \frac{X_{actual}}{Z_b} = \frac{40}{380.88} = 0.105p.u$$

Reactance of transformer T1:

Base kV on LT side of transformer T1 = Base kV on HT side $\times \frac{\text{LT voltage rating}}{\text{HT voltage rating}}$

$$= 138 \times \frac{20}{138} = 20kV$$

$$= X_{pu,old} \times (\frac{kV_{b,old}}{kV_{b,new}})^2 \times (\frac{MVA_{b,new}}{MVA_{b,old}})$$

$$= 0.1 \times (\frac{20}{20})^2 \times (\frac{50}{20}) = 0.25p.u.$$

Reactance of Generator G1:

$$X_{p.u,G1} = X_{pu,old,g1} \times (\frac{kV_{b,old}}{kV_{b,new}})^2 \times (\frac{MVA_{b,new}}{MVA_{b,old}})$$

$$= 0.2 \times (\frac{18}{20})^2 \times (\frac{50}{20}) = 0.405p.u.$$

Reactance of transformer T2:

$$X_{p.u,T2} = X_{pu,old,T2} \times (\frac{kV_{b,old}}{kV_{b,new}})^2 \times (\frac{MVA_{b,new}}{MVA_{b,old}})$$

$$= 0.1 \times (\frac{20}{20})^2 \times (\frac{50}{20}) = 0.25 p.u.$$

Reactance of j20 ohms transformer line:

Base kV on HT side of transformer T2 = Base kV on LT side $\times \frac{\text{HT voltage rating}}{\text{LT voltage rating}}$

$$= 20 \times \frac{138}{20} = 138 kV$$

$$\text{Base impedance, } Z_b = \frac{kV_{b,}^2}{MVA_{b,}} = \frac{138^2}{50} = 380.8\Omega$$

p.u reactance of 20Ω Transmission line = $\frac{\text{Actual reactance}}{\text{Base impedance}}$

$$= \frac{20}{380.88} = 0.0525 kV$$

Here it is observed that both the sections of j20Ω transmission lines have same values of reactances and base kV's. Hence their p.u reactances will be same.

Reactance of transformer T5:

$$X_{p.u,T2} = X_{pu,old,T2} \times (\frac{kV_{b,old}}{kV_{b,new}})^2 \times (\frac{MVA_{b,new}}{MVA_{b,old}})$$

$$= 0.1 \times (\frac{138}{138})^2 \times (\frac{50}{15}) = 0.333 p.u.$$

Reactance of synchronous motor:

Base kV on LT side of transformer T2 = Base kV on HT side $\times \frac{\text{LT voltage rating}}{\text{HT voltage rating}}$

$$= 138 \times \frac{13.8}{138} = 13.8 kV$$

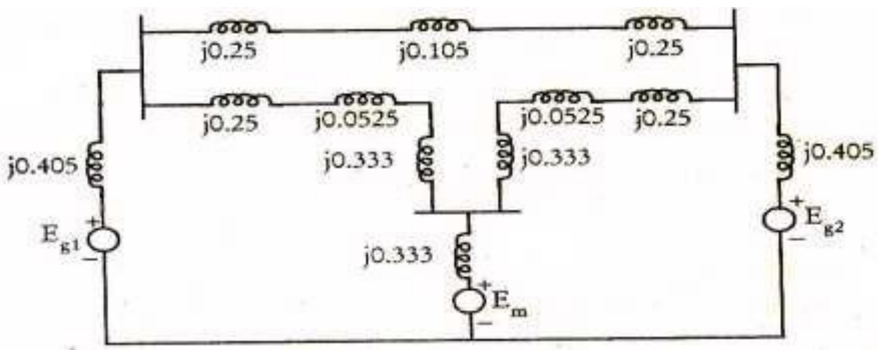
$$= X_{pu,old} \times (\frac{kV_{b,old}}{kV_{b,new}})^2 \times (\frac{MVA_{b,new}}{MVA_{b,old}})$$

$$= 0.2 \times (\frac{138}{13.8})^2 \times (\frac{50}{30}) = 0.333 p.u.$$

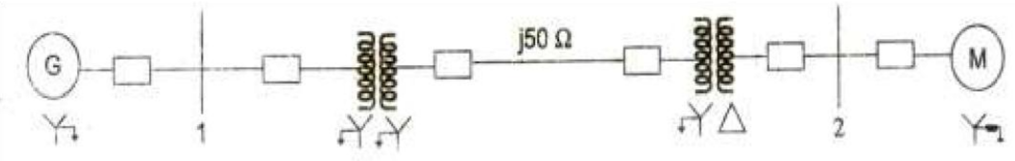
Reactance of T6, T4, T3 and G2:

1. The transformer T6 in identical to that T5. Hence p.u reactance of T5 and T6 are same.
2. The transformer T, T2, T3 and T4 are identical. Hence p.u reactance of T5 and T6 are same.
3. The generator G2 in identical to that of G1. Hence p.u reactance of T5 and T6 are same.

Reactance diagram:



12. Draw the reactance diagram for the power system shown in fig. Neglect resistance and use a base of 100MVA, 200kV in 50 ohms line. The ratings of the generator motor and transformer are given below.



Generator: 40MVA, 25kV, X"=20%
Synchronous motor: 50MVA, 11kV, X"=30%
3ph, star-star transformer: 40MVA, 33/220kV, X=15%
3ph, star-delta transformer: 30MVA, 11/220kV, X=15% (May/Jun-2012)

Solution:

$MVA_{b,} = 100MVA$

$kV_{b,} = 220kV$

Reactance of transmission line:

$$\text{Base impedance, } Z_b = \frac{kV_{b,new}^2}{MVA_{b,new}} = \frac{220^2}{100} = 484\Omega$$

$$\text{p.u reactance of Transmission line} = \frac{\text{Actual reactance}}{\text{Base impedance}}$$

$$= \frac{50}{484} = 0.1033 p.u$$

Reactance of transformer T1:

$$\text{Base kV on LT side of transformer T1} = \text{Base kV on HT side} \times \frac{\text{LT voltage rating}}{\text{HT voltage rating}}$$

$$= 220 \times \frac{33}{220} = 33kV$$

$$= X_{pu,old} \times \left(\frac{kV_{b,old}}{kV_{b,new}}\right)^2 \times \left(\frac{MVA_{b,new}}{MVA_{b,old}}\right)$$

$$= 0.15 \times \left(\frac{33}{33}\right)^2 \times \left(\frac{100}{40}\right) = 0.375 p.u.$$

Reactance of Generator G:

$$= X_{pu,old} \times \left(\frac{kV_{b,old}}{kV_{b,new}}\right)^2 \times \left(\frac{MVA_{b,new}}{MVA_{b,old}}\right)$$

$$= 0.2 \times (\frac{25}{33})^2 \times (\frac{100}{40}) = 0.287 p.u.$$

Reactance of transformer T2:

Base kV on LT side of transformer T2 = Base kV on HT side $\times \frac{\text{LT voltage rating}}{\text{HT voltage rating}}$

$$= 220 \times \frac{11}{220} = 11kV$$

$$= X_{pu,old} \times (\frac{kV_{b,old}}{kV_{b,new}})^2 \times (\frac{MVA_{b,new}}{MVA_{b,old}})$$

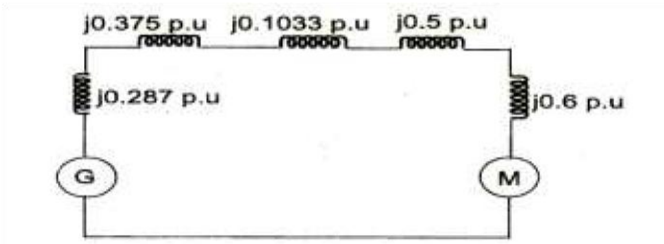
$$= 0.15 \times (\frac{11}{11})^2 \times (\frac{100}{30}) = 0.5 p.u.$$

Reactance of synchronous motor:

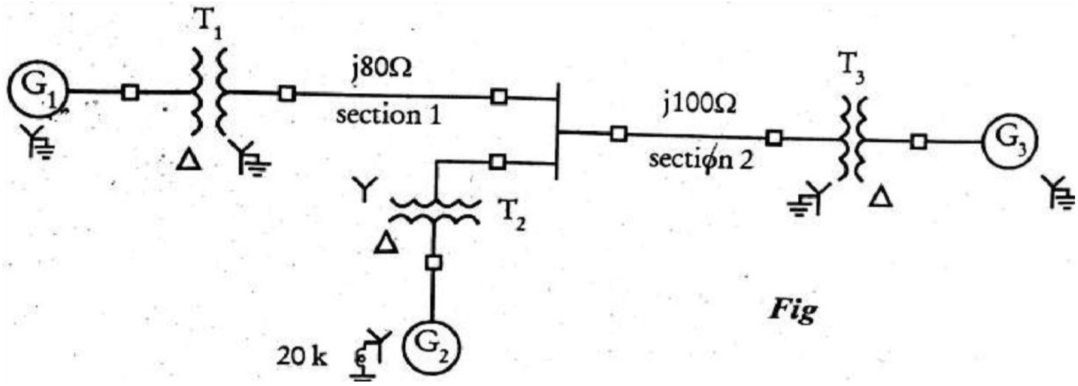
$$= X_{pu,old} \times (\frac{kV_{b,old}}{kV_{b,new}})^2 \times (\frac{MVA_{b,new}}{MVA_{b,old}})$$

$$= 0.3 \times (\frac{11}{11})^2 \times (\frac{100}{50}) = 0.6 p.u.$$

Reactance diagram:



13. Draw the reactance diagram for the power system is shown in fig. The generator and transformers are rated as follows.(May/Jun 2014) (AU NOV/DEC 2015,2017)



Fig

Generator G1:20MVA, 13.8kV, X"=20%
Generator G2:30MVA, 18kV, X"=20%
Generator G3:30MVA, 20kV, X"=20%
Transformer,T_1 = 25MVA, 220/13.8kV, X=10%
Transformer,T_2 = 3 single phase units each rated at 10MVA, 127/18kV, X=10%
Transformer,T_3 = 35MVA, 220/22kV, X=10%

Draw the reactance diagram using a base of 50MVA and 13.8kVon the generator G_1[AU NOV/DEC 2015]
Solution:

Base megavoltampere, $MVA_{b,new}$=50MVA
Base kilovolt, $kV_{b,new}$=13.8kV

Reactance of Generator G_1

$$X_{p.u,G1} = X_{pu,old,g1} \times (\frac{kV_{b,old}}{kV_{b,new}})^2 \times (\frac{MVA_{b,new}}{MVA_{b,old}})$$

$$= 0.2 \times (\frac{13.8}{13.8})^2 \times (\frac{50}{20}) = 0.5\,p.u.$$

Reactance of Transformer T_1

$$= X_{pu,old} \times (\frac{kV_{b,old}}{kV_{b,new}})^2 \times (\frac{MVA_{b,new}}{MVA_{b,old}})$$

$$= 0.1 \times (\frac{13.8}{13.8})^2 \times (\frac{50}{25}) = 0.2\,p.u.$$

Reactance of Transmission lines

$$\text{Base kV on HT side of transformer T1} = \text{Base kV on LT side} \times \frac{\text{HT voltage rating}}{\text{LT voltage rating}}$$

$$= 13.8 \times \frac{220}{13.8} = 220kV$$

$$\text{Base impedance, } Z_b = \frac{kV_{b,}^2}{MVA_{b,}} = \frac{220^2}{50} = 968\Omega$$

$$\text{p.u reactance of section 1 of Transmission line} = \frac{\text{Actual reactance}}{\text{Base impedance}}$$

$$= \frac{80}{968} = 0.0826kV$$

$$\text{p.u reactance of section 2 of Transmission line} = \frac{\text{Actual reactance}}{\text{Base impedance}}$$

$$= \frac{100}{968} = 0.1033p.u$$

Reactance of transformer T2:

$$= \frac{\sqrt{3} \times 127}{18} = \frac{220}{18}kV$$

$$\text{Base kV on LT side of transformer T2} = \text{Base kV on HT side} \times \frac{\text{LT voltage rating}}{\text{HT voltage rating}}$$

$$= 220 \times \frac{18}{220} = 18kV$$

New p.u reactance of transformer T_2

$$= X_{pu,old} \times (\frac{kV_{b,old}}{kV_{b,new}})^2 \times (\frac{MVA_{b,new}}{MVA_{b,old}})$$

$$= 0.1 \times (\frac{18}{18})^2 \times (\frac{50}{3 \times 10}) = 0.1667\,p.u.$$

Reactance of Generator G_2:

$$X_{p.u,G2} = X_{pu,old,g2} \times (\frac{kV_{b,old}}{kV_{b,new}})^2 \times (\frac{MVA_{b,new}}{MVA_{b,old}})$$

$$= 0.2 \times (\frac{18}{18})^2 \times (\frac{50}{30}) = 0.3333 p.u.$$

Reactance of transformer T3:

Base kV on LT side of transformer T3 = Base kV on HT side $\times \frac{\text{LT voltage rating}}{\text{HT voltage rating}}$

$$= 220 \times \frac{22}{220} = 22 kV$$

Now $kV_{b,new}$ = 22kV

New p.u reactance of transformer T_3

$$= X_{pu,old} \times (\frac{kV_{b,old}}{kV_{b,new}})^2 \times (\frac{MVA_{b,new}}{MVA_{b,old}})$$

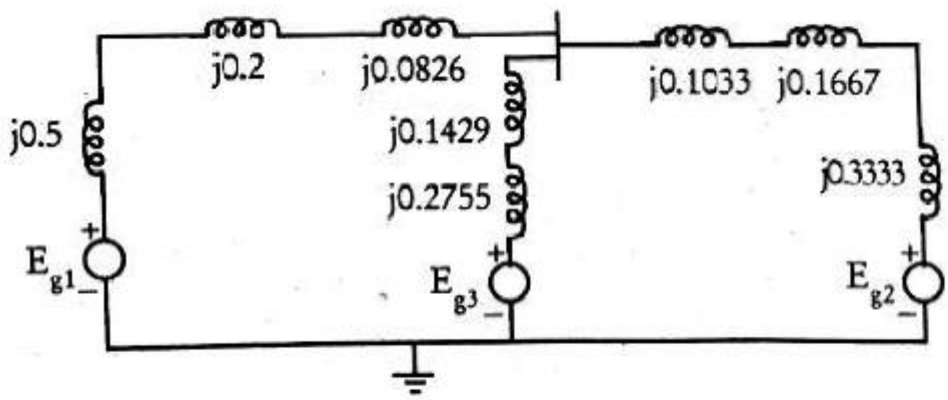
$$= 0.1 \times (\frac{22}{22})^2 \times (\frac{50}{35}) = 0.1429 p.u.$$

Reactance of Generator G_2:

$$X_{p.u,G3} = X_{pu,old,g2} \times (\frac{kV_{b,old}}{kV_{b,new}})^2 \times (\frac{MVA_{b,new}}{MVA_{b,old}})$$

$$= 0.2 \times (\frac{20}{22})^2 \times (\frac{50}{30}) = 0.2755 p.u.$$

Reactance Diagram



14. The data for the system whose single line diagram shown in fig

Generator G1:30MVA, 10.5kV, X"=1.6ohms

Generator G2:15MVA, 6.6kV, X"=1.2ohms

Generator G3:25MVA, 6.6kV, X"=0.56ohms

Transformer,T_1 = 15MVA, 33/11kV, X=15.2ohms/phase on H.T side

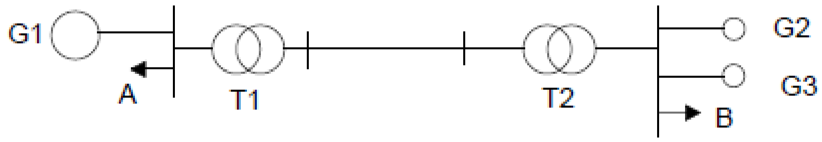
Transformer,T_2 = 15MVA,33/6.2kV, X=16.0 ohms/phase on L.T side

Transmission line: X=20.5 ohms/phase

Loads:A:40MW,11kV,0.9p.f lagging

B:40MW,6.6kV,0.85 p.f lagging

Choose the base power as 30MVA and approximate base voltages for different parts. Draw the reactance diagram. Indicate pu reactance on the diagram. [AU MAY/JUNE 2016]



Solution:

High tension side of T1 and high tension side of T2 is specified. So we start from transmission line.

Transmission Line:

Assume Base MVA_{new}=30MVA

Base kV_{new}=33kV

Actual impedance=j20.5Ω/ph

$$\text{P.u. impedance} = \frac{\text{Actual impedance}}{\text{Base impedance}}$$

$$= \frac{Actua\lim pedance}{(kV_b)^2} \times MVA_b$$

$$= \frac{j20.5}{(33)^2} \times 30 = j0.565 p.u$$

Transformer T1 (referred to secondary side or H.T. side):

$kV_{b\ new}$ = 33kV

$$Z_{p.u} = \frac{Z_{actual}}{KV_b^2} \times MVA_b = \frac{j15.2 \times 30}{33^2} = j0.418$$

Generator 1: Transformer T1 primary side change occurs, so calculate $kV_{b\ new}$ as

$$kV_{bnew} = kV_{bold} \times \frac{\text{LT side voltage rating of T1}}{\text{HT side voltage ratingof T1}}$$

$$= \frac{33 \times 11}{33} = 11kV$$

$$Z_{p.u} = \frac{Z_{actual}}{KV_b^2} \times MVA_b = \frac{j1.6 \times 30}{11^2} = j0.397 p.u$$

Load A:

$kV_{b\ new}$ = 11kV

P=15MW, 0.9p.f lagging

$S_L=40<\cos^{-1}0.9=36+j17.43$MVA

$$Z_L = \frac{kV_b^2}{S_L^*} = \frac{11^2}{36 - j17.43} = 2.722 + j1.3183\Omega$$

$$Z_{p.u} = \frac{Z_L}{Z_{base}} = \frac{Z_L}{kV_{bnew}^2} \times MVA_{bnew}$$

$$= \frac{36 + j17.43}{11^2} \times 30$$

$$= 8.925 + j4.32 p.u$$

Transformer T2(referred to primary or H.T side):

$kV_{b\ new}$ = kV_b of transmission line=33kV

$$Z_{p.u} = \frac{Z_{actual}}{KV_b^2} \times MVA_b = \frac{j16 \times 30}{33^2} = j0.44 p.u$$

Generator 2: Transformer T2 secondary side change occurs, so calculate $kV_{b\ new}$ as

$$kV_{bnew} = kV_{bold} \times \frac{\text{LT side voltage rating of T2}}{\text{HT side voltage ratingof T2}}$$

$$= \frac{33 \times 6.2}{33} = 6.2kV$$

$$Z_{p.u} = \frac{Z_{actual}}{KV_b^2} \times MVA_b = \frac{j1.2 \times 30}{6.2^2} = j0.936 p.u$$

Generator 3:

$$Z_{p.u} = \frac{Z_{actual}}{KV_b^2} \times MVA_b = \frac{j0.56 \times 30}{6.2^2} = j0.437 p.u$$

Load B:

$kV_{b\ new}$ = 6.6kV

P=40MW, 0.85p.f lagging

$S_L = 40 \angle \cos^{-1} 0.85 = 34 + j21.07$MVA

$$Z_L = \frac{kV_b^2}{S_L^*} = \frac{6.6^2}{34 - j21.07} = 0.9256 + j0.573$$

$$Z_{p.u} = \frac{Z_L}{Z_{base}} = \frac{Z_L}{kV_{bnew}^2} \times MVA_{bnew}$$

$$= \frac{0.925 + j0.573}{6.6^2} \times 30 = 0.6374 + j0.394 p.u$$

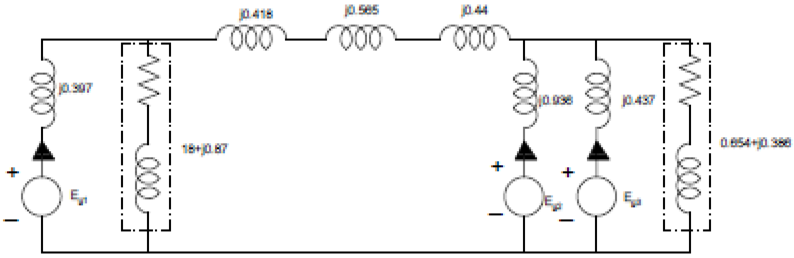


Fig. Impedance Diagram

Assuming reactance diagram is used for short circuit studies, Current drawn by the static loads can be neglected.

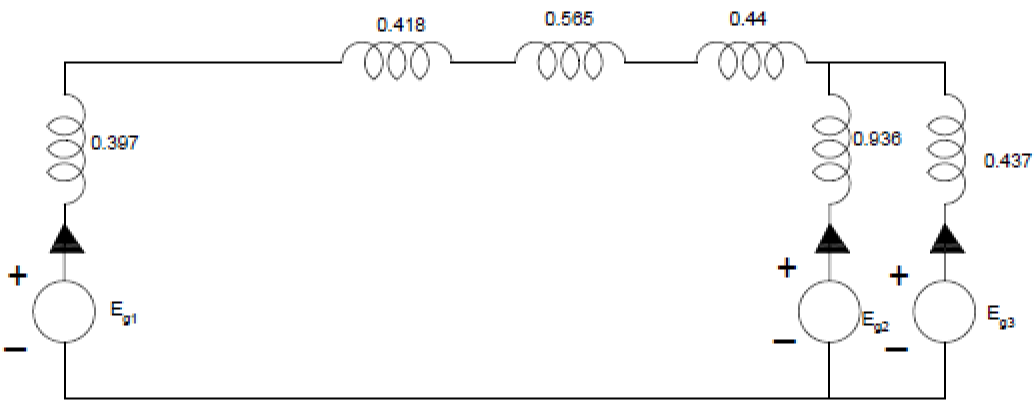
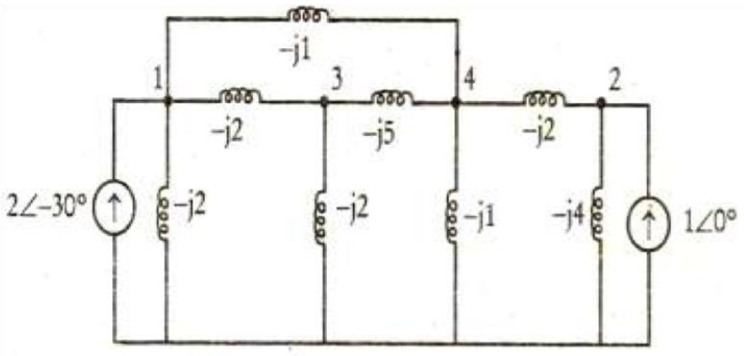


Fig. Reactance diagram

15. **Determine the bus admittance matrix of the system whose reactance diagram is shown in fig. The current and admittances are given in P.U. Determine the reduced bus admittance matrix after eliminating node 3. (May/June-2012)**



Solution:

The bus admittance matrix can be formed by inspection using the following guidelines.

- The diagonal element Y_{jj} is given by sum of all the admittances connected to node j.
- The off-diagonal element Y_{jk} is given by negative of the sum of all the admittances connected between node-j and node-k.

$$Y_{bus} = \begin{bmatrix} -j2-j2-j2 & 0 & j2 & j1 \\ 0 & -j2-j4 & 0 & j2 \\ j2 & 0 & -j2-j2-j5 & j5 \\ j1 & j2 & j5 & -j1-j5-j2-j1 \end{bmatrix}$$

$$Y_{bus} = \begin{bmatrix} -j5 & 0 & j2 & j1 \\ 0 & -j6 & 0 & j2 \\ j2 & 0 & -j9 & j5 \\ j1 & j2 & j5 & -j9 \end{bmatrix}$$

For eliminating node 3, the bus admittance matrix is rearranged by interchanged reow-3 & row-4, and then interchanging column-3 & column-4.

After interchanging row-3 & row 4 of Y_{bus} matrix of equal we get,

$$Y_{bus} = \begin{bmatrix} -j5 & 0 & j2 & j1 \\ 0 & -j6 & 0 & j2 \\ j1 & j2 & j5 & -j9 \\ j2 & 0 & -j9 & j5 \end{bmatrix}$$

After interchanging column-3 & column 4 of Y_{bus} matrix of equal we get,

$$Y_{bus} = \begin{bmatrix} -j5 & 0 & j1 & j2 \\ 0 & -j6 & j2 & 0 \\ j1 & j2 & -j9 & j5 \\ j2 & 0 & j5 & -j9 \end{bmatrix}$$

Now the last row and last column (i.e., 4th row and 4th column) of Ybus matrix of equal can be eliminated.

The elements of new bus admittance matrix after eliminating 4th row and 4th column is given by

$$Y_{jk,new} = Y_{jk} - \frac{Y_{jn}Y_{nk}}{Y_{nn}}$$

where n=4; j=1,2,3 and k=1,2,3

$$Y_{11,new} = Y_{11} - \frac{Y_{14}Y_{41}}{Y_{44}} = -j5 - \frac{(j2)\times(j2)}{(-j9)} = -j4.556$$

$$Y_{12,new} = Y_{12} - \frac{Y_{14}Y_{42}}{Y_{44}} = 0 - \frac{(j2\times 0)}{-j9} = 0$$

$$Y_{13,new} = Y_{13} - \frac{Y_{14}Y_{43}}{Y_{44}} = j1 - \frac{(j2\times j5)}{-j9} = j2.111$$

$$Y_{22,new} = Y_{22} - \frac{Y_{24}Y_{42}}{Y_{44}} = -j6 - \frac{(0\times 0)}{-j9} = -j6$$

$$Y_{23,new} = Y_{23} - \frac{Y_{24}Y_{43}}{Y_{44}} = j5 - \frac{(0\times j5)}{-j9} = j2$$

$$Y_{31,new} = Y_{13,new} = j2.111$$

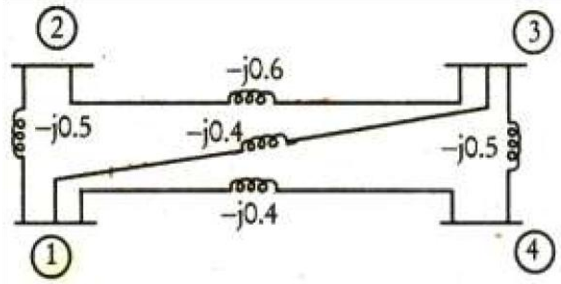
$$Y_{32,new} = Y_{23,new} = j2$$

$$Y_{33,new} = Y_{33} - \frac{Y_{34}Y_{43}}{Y_{44}} = -j9 - \frac{(j5\times j5)}{-j9} = -j6.222$$

The reduced bus admittance matrix after eliminating 3th is given by

$$Y_{bus} = \begin{bmatrix} -j4.556 & 0 & j2.111 \\ 0 & -j6 & j2 \\ j2.111 & j2 & -j6.222 \end{bmatrix}$$

16.For the network shown in fig from the bus admittance matrix. Determine the reduced admittance matrix by eliminating node 4. The values are market in p.u. (Nov/Dec-2008) (April/May-2018)



Solution:

The Y_{bus} matrix of the network in

$$Y_{bus}=\begin{bmatrix} -(j0.5+j0.4+j0.4) & j0.5 & j0.4 & j0.4 \\ j0.5 & -(j0.5+j0.6) & j0.6 & 0 \\ j0.4 & j0.6 & -(j0.6+j0.5+j0.4) & j0.5 \\ j0.4 & 0 & j0.5 & -(j0.5+j0.4) \end{bmatrix}$$

$$Y_{bus}=\begin{bmatrix} -j1.3 & j0.5 & j0.4 & j0.4 \\ j0.5 & -j1.1 & j0.6 & 0 \\ j0.4 & j0.6 & -j1.5 & j0.5 \\ j0.4 & 0 & j0.5 & -0.9 \end{bmatrix}$$

The elements of new bus admittance matrix after eliminating the 4^{th} row and 4^{th} column is given by

$$Y_{jk,new}=Y_{jk}-\frac{Y_{jn}Y_{nk}}{Y_{nn}}$$

The bus admittance matrix is symmetrical,

$$Y_{11,new}=Y_{11}-\frac{Y_{14}Y_{41}}{Y_{44}}=-j1.3-\frac{(j0.4)\times(j0.4)}{(-j0.9)}=-j1.12$$

$$Y_{12,new}=Y_{12}-\frac{Y_{14}Y_{42}}{Y_{44}}=j0.5-\frac{(j0.4\times 0)}{-j0.9}=j0.5$$

$$Y_{13,new}=Y_{13}-\frac{Y_{14}Y_{43}}{Y_{44}}=j0.4-\frac{(j0.4\times j0.5)}{-j0.9}=j0.622$$

$$Y_{22,new}=Y_{22}-\frac{Y_{24}Y_{42}}{Y_{44}}=-j1.1-\frac{(0\times 0)}{-j0.9}=-j1.1$$

$$Y_{23,new}=Y_{23}-\frac{Y_{24}Y_{43}}{Y_{44}}=j0.6-\frac{(0\times j0.5)}{-j0.9}=j0.6$$

$$Y_{31,new}=Y_{13,new}=j0.622$$

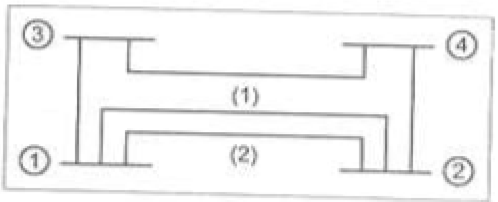
$$Y_{32,new}=Y_{23,new}=j0.6$$

$$Y_{33,new}=Y_{33}-\frac{Y_{34}Y_{43}}{Y_{44}}=-j1.5-\frac{(j0.5\times j0.5)}{-j0.9}=-j1.222$$

The reduced bus admittance matrix after eliminating 4^{th} row is shown below.

$$Y_{bus}=\begin{bmatrix} -j1.12 & j0.5 & j0.622 \\ j0.5 & -j1.1 & j0.6 \\ j0.622 & j0.6 & -j1.222 \end{bmatrix}$$

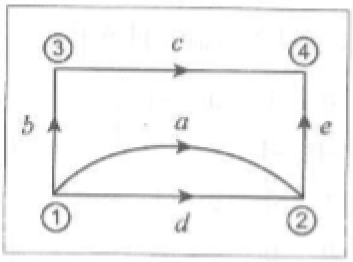
17. Form Y_{bus} by singular transformation for the network shown in Fig. The impedance data is given in Table. Take(1) as referance node?



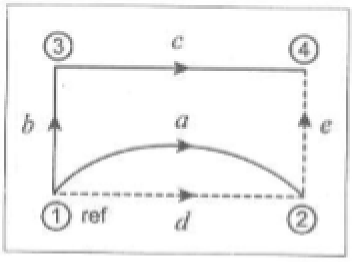
Element No.	Self	
	Bus code	Impedance
1	*1 – 2 (1)*	*0.6 .*
2	*1 – 3*	*0.5*
3	*3 – 4*	*0.5*
4	*1 – 2 (2)*	*0.4*
5	*2 – 4*	*0.2*

Solution:

Oriented Graph



Take (1) as referance. Draw a tree



Incidence matrix $[A]=\begin{bmatrix} -1 & 0 & 0 & -1 & 1 \\ 0 & -1 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 & -1 \end{bmatrix}$

$$[A]^T = \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 0 \\ 1 & 0 & -1 \end{bmatrix}$$

$$\text{Primittive impedance Matrix } \left[Z_{primittive}\right] = \begin{bmatrix} j0.6 & 0 & 0 & 0 & 0 \\ 0 & j0.5 & 0 & 0 & 0 \\ 0 & 0 & j0.5 & 0 & 0 \\ 0 & 0 & 0 & j0.4 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Primittive admittance matrix = $[Y_{primittive}] = [Z_{primittive}]^{-1}$

$$= \begin{bmatrix} -j1.667 & 0 & 0 & 0 & 0 \\ 0 & -j2.0 & 0 & 0 & 0 \\ 0 & 0 & -j2 & 0 & 0 \\ 0 & 0 & 0 & -j2.5 & 0 \\ 0 & 0 & 0 & 0 & -j5 \end{bmatrix}$$

$$Y_{bus} = [\grave{A}][Y_{primittive}][A]^T$$

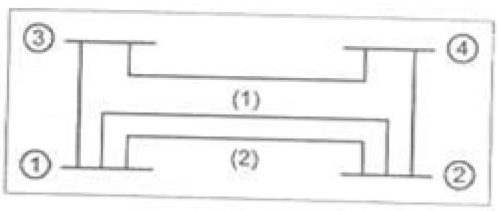
$$[Y_{primittive}][A]^T = \begin{bmatrix} j1.667 & 0 & 0 \\ 0 & j2 & 0 \\ 0 & -j2 & j2 \\ j2.5 & 0 & 0 \\ -j5 & 0 & j5 \end{bmatrix}$$

$$Y_{bus} = [\grave{A}][Y_{primittive}][A]^T = \begin{bmatrix} -j1.667 & 0 & j5 \\ 0 & -j2-j2 & j2 \\ j5 & j2 & -j2-j5 \end{bmatrix}$$

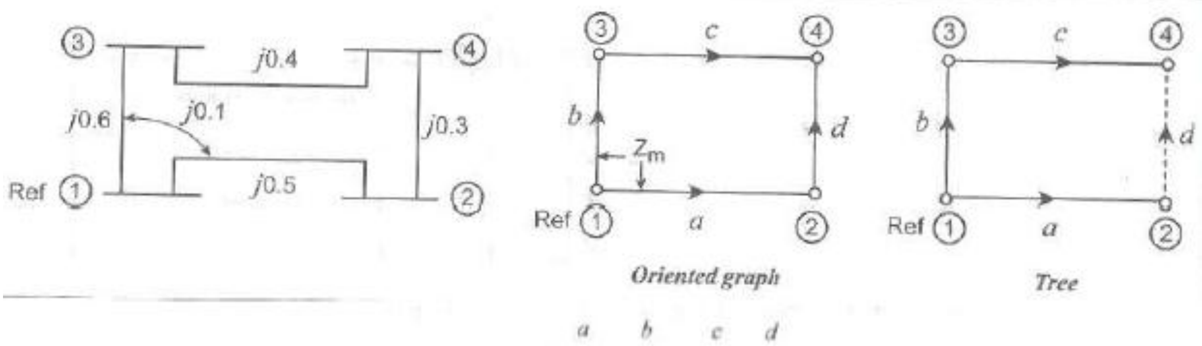
$$= \begin{bmatrix} -j9.167 & 0 & j5 \\ 0 & -j4 & j2 \\ j5 & j2 & -j7 \end{bmatrix}$$

18. Form Y_{bus} of the test system shown in fig by using singular transformation method.

The impedance data is given in Table. Take (1) as reference node. [AU NOV/DEC 2015]



S.No.	Self		Mutual	
	Bus code	Impedance	Bus code	Impedance
1	1 – 2	0.5	1 – 2	0.1
2	1 – 3	0.6		
3	3 – 4	0.4		
4	2 – 4	0.3		



Solution:

$$\text{Incidence matrix } = \begin{bmatrix} -1 & 0 & 0 & 1 \\ 0 & -1 & 1 & 0 \\ 0 & 0 & -1 & -1 \end{bmatrix}$$

Primittive impedance matrix [Zprimittive]

$$= \begin{bmatrix} j0.5 & j0.1 & 0 & 0 \\ j0.1 & j0.6 & 0 & 0 \\ 0 & 0 & j0.4 & 0 \\ 0 & 0 & 0 & j0.3 \end{bmatrix}$$

Primittive admittance matrix $[Y_{primittive}] = [Z_{primittive}]^{-1}$

Consider the matrix

$$\begin{bmatrix} j0.5 & j0.1 \\ j0.1 & j0.6 \end{bmatrix}^{-1} = \frac{1}{-0.29}\begin{bmatrix} j0.6 & -j0.1 \\ -j0.1 & j0.5 \end{bmatrix}$$

$$= \begin{bmatrix} -j2.0689 & j0.3448 \\ j0.3448 & -j1.724 \end{bmatrix}$$

$$Y_{primittive} = \begin{bmatrix} -j2.0689 & j0.3448 & 0 & 0 \\ j0.3448 & -j1.724 & 0 & 0 \\ 0 & 0 & -j2.5 & 0 \\ 0 & 0 & 0 & -j3.333 \end{bmatrix}$$

Bus admittance matrix $[Y_{bus}] = [A][Y_{primittive}][A]^T$

$$[Y_{\Pr imittive}][A]^T = \begin{bmatrix} -j2.0689 & j0.3448 & 0 & 0 \\ j0.3448 & -j1.724 & 0 & 0 \\ 0 & 0 & -j2.5 & 0 \\ 0 & 0 & 0 & -j3.333 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 1 & -1 \\ 1 & 0 & -1 \end{bmatrix}$$

$$= \begin{bmatrix} j2.0689 & -j0.3448 & 0 \\ -j0.3448 & j1.724 & 0 \\ 0 & -j2.5 & j2.5 \\ -j3.333 & 0 & j3.333 \end{bmatrix}$$

$$[Y_{bus}] = [A][Y_{\Pr imittive}][A]^T = \begin{bmatrix} -1 & 0 & 0 & 1 \\ 0 & -1 & 1 & 0 \\ 0 & 0 & -1 & -1 \end{bmatrix} \begin{bmatrix} j2.0689 & -j0.3448 & 0 \\ -j0.3448 & j1.724 & 0 \\ 0 & -j2.5 & j2.5 \\ -j3.333 & 0 & j3.333 \end{bmatrix}$$

$$Y_{bus} = \begin{bmatrix} -j5.4019 & j0.3448 & j3.333 \\ j0.3448 & -j4.224 & j2.5 \\ j3.333 & j2.5 & -j5.833 \end{bmatrix}$$

19. Describe the Bus Impedance Matrix ($\mathbf{Z_{bus}}$) building algorithm in detail by using a three bus system.(May/Jun 2014) (Nov/Dec 2017)

Modification of an existing Bus Impedance Matrix :

Let us denote the original $\mathbf{Z_{bus}}$ of a system with n- number of independent buses as $\mathbf{Z_{orig}}$ .When a branch of impedance Z_b is added to the system the Z_{orig} gets modified**.** The **branch impedance** Z_b can be added to the original system in the following 4 ways.

(1) Adding a branch of impedances from a new bus- p to the reference bus.

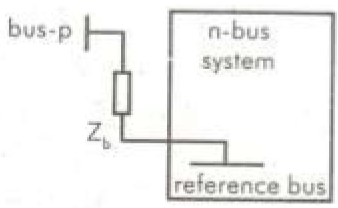
(2). Adding a branch of impedance Z_b from a new bus p to an existing bus-q.

(3). Adding a branch of impedance Z_b from an existing bus-q to the reference b us.

(4). Adding a branch of impedance Z_b between two existing buses h and q.

Case 1: Adding $\mathbf{Z_b}$ from a new bus p to the reference bus:

Consider a n-bus system shown in fig. Let us add a bus-p through an impedance Z_b to the reference bus. The addition of a bus will increase the order of the bus impedance matrix by one.



$$Z_{bus,\,new} = \left[\begin{array}{ccc|c} & & & 0 \\ & & & 0 \\ & Z_{orig} & & \vdots \\ & & & 0 \\ \hline 0 & 0 & \ldots\ldots 0 & Z_b \end{array}\right] \qquad (1)$$

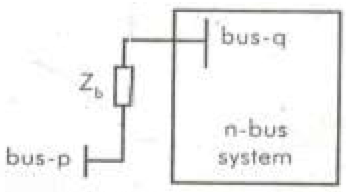
Fig. Adding a new bus through an impedance to reference bus

In this case the elements of $(n+1)^{th}$ column and row are all zeros except the diagonal. The diagonal element is the added branch impedance Z_b. The elements of orginal Z_{bus} matrix are not altered. The new bus impedance matrix will be as shown in equ 1.

Case 2: Adding Z_b from a new bus p to the existing bus q:

Consider a n-bus system as shown in fig. In which a new bus p is added through an impedance Z_b to an existing bus q. The addition of a bus will increase the order of the bus impedance matrix by one.

In this the elements of $(n+1)^{th}$ column are the elements of q^{th} column and elements of $(q+1)^{th}$ row are the elements q^{th} row. The diagonal element is given by sum of Z_{qq} and $Z_{b.}$ The elements of orginal Z_{bus} matrix are not altered. The new bus impedance matrix will be as shown in equ 2.



$$Z_{bus,\ new} = \left[\begin{array}{c|c} & Z_{1q} \\ Z_{orig} & Z_{2q} \\ & \vdots \\ & Z_{nq} \\ \hline Z_{q1} \quad Z_{q2} \ldots\ldots Z_{qn} & Z_{qq} + Z_b \end{array}\right] \qquad (2)$$

Fig. Adding a new bus through an impedance to an existing bus

Case 3: Adding Z_b from an existing bus-q to the reference bus:

Consider a n- bus system shown in fig. in which an impedance Z_b is added from an existing bus-q to the reference bus. Let us consider as if the impedance Z_b is connected from a new bus-p and existing bus –q.

Now it will be an addition as that of case 2.The bus impedance matrix order (n+1) can be formed that of case 2.Then we can short circuit the bus-q to the reference bus. This is equivalent to eliminating $(n+1)^{th}$ bus(i.e., bus-p in this case) and so the bus impedance matrix has to be modified by eliminating $(n+1)^{th}$ row and $(n+1)^{th}$ column. The reduced bus impedance matrix is the actual new bus impedance matrix. Every element of actual new bus impedance matrix can be determined by using this equation.

$$Z_{jk,act} = Z_{jk} - \frac{Z_{j(n+1)} Z_{(n+1)k}}{Z_{(n+1)(n+1)}}$$

- $Z_{jk,act}$ is the impedance corresponding to row-j and column-k of actual new bus impedance matrix.
- Z_{jk}, $Z_{(n+1)k}$,$Z_{j(n+1)}$,$Z_{(n+1)(n+1)}$ are impedances of new bus impedance matrix of order (n+1).

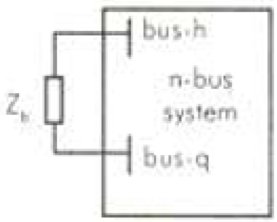
- Since bus impedance matrix is symmetrical.

$$Z_{jk,act} = Z_{kj,act}$$

Case 4: Adding Z_b between two existing buses h and q.

Consider a n- bus system shown in fig.1, in which an impedance Z_b is added between two existing buses h and q.

In this case the bus impedance matrix is formed as shown in equ(1). Hence the elements of $(n+1)^{th}$ column is the difference between the elements of column-h and column-q. The elements of $(n+1)^{th}$ row is the difference between the elements of row-h and row-q. The diagonal elements is given by eu 2



$$Z_{bus,\,new} = \left[\begin{array}{ccc|c} & & & Z_{1h}-Z_{1q} \\ & Z_{orig} & & Z_{2h}-Z_{2q} \\ & & & \vdots \\ & & & Z_{nh}-Z_{nq} \\ \hline Z_{h1}-Z_{q1} & Z_{h2}-Z_{q2} \;\ldots\ldots & Z_{hn}-Z_{qn} & Z_{(n+1)(n+1)} \end{array}\right] \qquad (1)$$

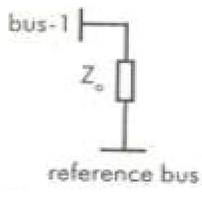
Fig. Adding an impedance between bus-h and bus-q.

$$Z_{(n+1)(n+1)} = Z_b + Z_{hh} + Z_{qq} - 2Z_{hq} \qquad (2)$$

Since the modification does not involve addition of new bus, the order of new bus impedance matrix has to be reduced to n×n by eliminating the $(n+1)^{th}$ column and $(n+1)^{th}$ row.

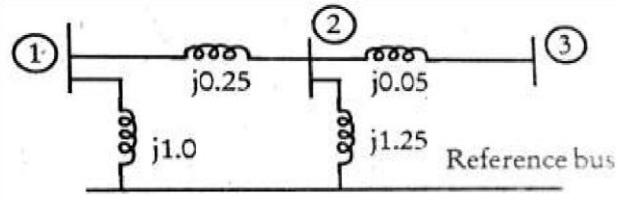
Direct determination of a bus impedance matrix:

The bus

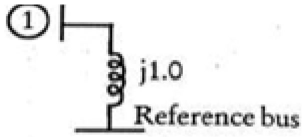


$$Z_{bus} = Z_a$$

20. Find the bus impedance matrix for the system whose reactance diagram is shown in fig.1.All the impedances are in p.u? (May/Jun 2012 & Apr/May 2015)

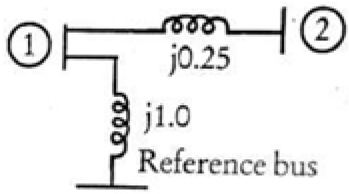


Step 1: Consider the branch with impedance j1 p.u. connected between bus-1 and reference as shown in fig. The system shown in fig. has a single bus and so the order of the bus impedance matrix is one, as shown below.



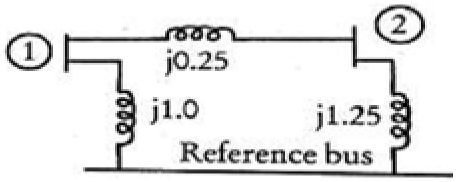
$$Z_{bus} = [j1.0]$$

Step 2:



$$Z_{bus} = \begin{bmatrix} j1.0 & j1.0 \\ j1.0 & j1.0 + j0.25 \end{bmatrix} = \begin{bmatrix} j1.0 & j1.0 \\ j1.0 & j1.25 \end{bmatrix}$$

Step 3:



$$Z_{bus} = \begin{bmatrix} j1.0 & j1.0 & j1.0 \\ j1.0 & j1.25 & j1.25 \\ j1.0 & j1.25 & j1.25 + j1.25 \end{bmatrix}$$

$$= \begin{bmatrix} j1.0 & j1.0 & j1.0 \\ j1.0 & j1.25 & j1.25 \\ j1.0 & j1.25 & j1.25 + j2.5 \end{bmatrix}$$

$$Z_{jk,act} = Z_{jk} - \frac{Z_{j(n+1)} Z_{(n+1)k}}{Z_{(n+1)(n+1)}} \quad \text{where n=2; j=1,2 and k=1,2}$$

$$Z_{11,act} = Z_{11} - \frac{Z_{13} Z_{31}}{Z_{33}} = j1.0 - \frac{j1.0 \times j1.0}{j2.5} = j0.6$$

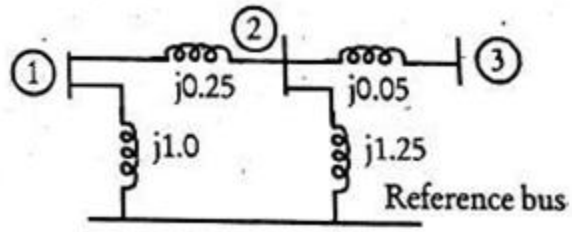
$$Z_{12,act} = Z_{11} - \frac{Z_{13} Z_{32}}{Z_{33}} = j1.0 - \frac{j1.0 \times j1.25}{j2.5} = j0.5$$

$$Z_{21,act} = Z_{12,act} = j0.5$$

$$Z_{22,act} = Z_{22} - \frac{Z_{23} Z_{32}}{Z_{33}} = j1.25 - \frac{j1.25 \times j1.25}{j2.5} = j0.625$$

$$Z_{bus} = \begin{bmatrix} j0.6 & j0.5 \\ j0.5 & j0.625 \end{bmatrix}$$

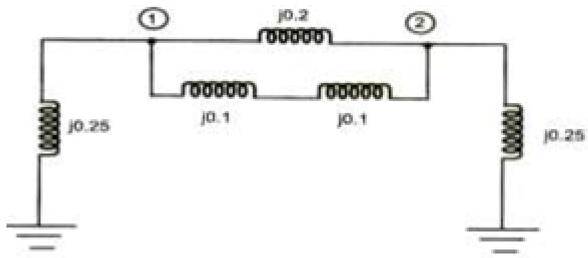
Step 4:



$$Z_{bus} = \begin{bmatrix} j0.6 & j0.5 & j0.5 \\ j0.5 & j0.625 & j0.625 \\ j0.5 & j0.625 & j0.625 + j0.05 \end{bmatrix}$$

$$Z_{bus} = \begin{bmatrix} j0.6 & j0.5 & j0.5 \\ j0.5 & j0.625 & j0.625 \\ j0.5 & j0.625 & j0.675 \end{bmatrix}$$

21. Form the bus impedance matrix for the network shown. (May/June 2013)



Solution:

Step 1:

Addition of element 0-1,p=0, q=1

Addition of a branch. No mutual coupling. P is the ref bus

$$Z_{bus} = \begin{bmatrix} Z_{00} & Z_{01} \\ Z_{10} & Z_{11} \end{bmatrix}$$

$Z_{qi}= 0$

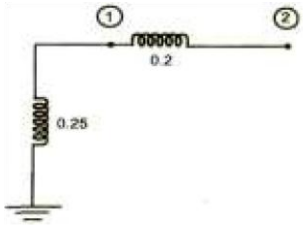
$Z_{qq}= z_{pq,pq}$

$Z_{11} = z_{01,01} = 0.25$

Neglecting the reference bus, we get $Z_{bus} = (1)[0.25]$

Step 2:

Addition of element 1-2. It is a branch p=1, q=2; No mutual coupling



$$Z_{bus} = \begin{bmatrix} 0.25 & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix}$$

$Z_{qi} = Z_{pi}$, $i = 1$

$Z_{21} = Z_{11} = 0.25$

$Z_{12} = Z_{21}$

$Z_{qq} = Z_{pq} + Z_{pq,pq}$

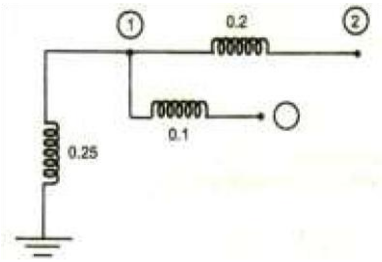
$Z_{22} = Z_{12} + z_{12,12}$

$= 0.25 + 0.2 = 0.45$

$$Z_{bus} = \begin{bmatrix} 0.25 & 0.25 \\ 0.25 & 0.45 \end{bmatrix}$$

Step 3:

Addition of element 1-3. It is a branch p=1, q=3; No mutual coupling



$$Z_{bus} = \begin{bmatrix} 0.25 & 0.25 & Z_{13} \\ 0.25 & 0.45 & Z_{23} \\ Z_{31} & Z_{32} & Z_{33} \end{bmatrix}$$

$Z_{qi} = Z_{pi}$, $i = 1, 2$

$Z_{3i} = Z_{1i}$

$Z_{31} = Z_{11} = 0.25 = Z_{13}$

$Z_{32} = Z_{12} = 0.25 = Z_{23}$

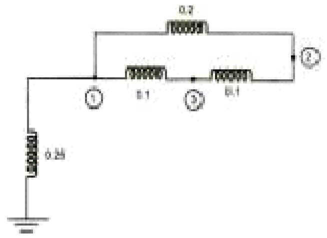
$Z_{qq} = Z_{pq} + z_{pq,pq}$

$Z_{33} = Z_{13} + z_{13,13} = 0.25 + 0.1 = 0.35$

$$Z_{bus} = \begin{bmatrix} 0.25 & 0.25 & Z_{13} \\ 0.25 & 0.45 & 0.25 \\ 0.25 & 0.25 & 0.35 \end{bmatrix}$$

Step 4:

Addition of element 3-2. It is a link p=3, q=2; No mutual coupling. This adds a fictitious node l.



$$Z_{bus} = \begin{bmatrix} 0.25 & 0.25 & 0.25 & Z_{1i} \\ 0.25 & 0.45 & 0.25 & Z_{2i} \\ 0.25 & 0.25 & 0.35 & Z_{3i} \\ Z_{i1} & Z_{i2} & Z_{i3} & Z_{ii} \end{bmatrix}$$

$$Z_{li} = Z_{pi} - Z_{qi},\ i = 1, 2, 3$$

$$Z_{li} = Z_{3i} = Z_{2i}$$

$$Z_{l1} = Z_{31} - Z_{21} = 0$$

$$Z_{l2} = Z_{32} - Z_{22} = 0.25 - 0.45 = -0.2$$

$$Z_{l3} = Z_{33} - Z_{23} = 0.35 - 0.25 = 0.1$$

$$Z_{ll} = Z_{pl} - Z_{ql} + z_{pq,pq}$$

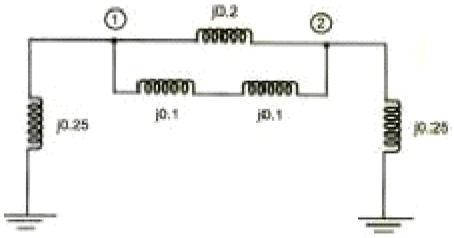
$$Z_{ll} = Z_{3l} - Z_{2l} + z_{32,32} = 0.1 - -0.2 + 0.1$$

$$Z_{bus} = \begin{bmatrix} 0.25 & 0.25 & 0.25 & 0 \\ 0.25 & 0.45 & 0.25 & -0.2 \\ 0.25 & 0.25 & 0.35 & 0.1 \\ 0 & -2 & 0.1 & 0.4 \end{bmatrix}$$

Eliminating the fictitious node, we get $Z_{bus} = \begin{bmatrix} 0.25 & 0.25 & 0.25 \\ 0.25 & 0.35 & 0.3 \\ 0.25 & 0.3 & 0.325 \end{bmatrix}$

Step 5:

Addition of element 0-2. It is a link p=0, q=2; No mutual coupling and p is the reference bus.



$$Z_{bus} = \begin{bmatrix} 0.25 & 0.25 & 0.25 & Z_{1i} \\ 0.25 & 0.35 & 0.3 & Z_{2i} \\ 0.25 & 0.3 & 0.325 & Z_{3i} \\ Z_{i1} & Z_{i2} & Z_{i3} & Z_{ii} \end{bmatrix}$$

$$Z_{li} = -Z_{qi},\ i = 1, 2, 3$$

$$Z_{l1} = -Z_{21} = -0.25$$

$$Z_{l2} = -Z_{22} = -0.35$$

$$Z_{l3} = -Z_{23} = -0.3$$

$$Z_{ll} = -Z_{ql} + z_{pq,pq}$$
$$= -Z_{2l} + z_{02,02} = -(-0.35)+0.25 = 0.6$$

$$Z_{bus} = \begin{bmatrix} 0.25 & 0.25 & 0.25 & -0.25 \\ 0.25 & 0.35 & 0.3 & -0.35 \\ 0.25 & 0.3 & 0.325 & -0.3 \\ -0.25 & -0.35 & -0.3 & 0.6 \end{bmatrix}$$

Eliminating the fictitious node, we get $Z_{bus} = \begin{bmatrix} 0.1458 & 0.1041 & 0.125 \\ 0.1041 & 0.1458 & 0.125 \\ 0.125 & 0.125 & 0.175 \end{bmatrix}$

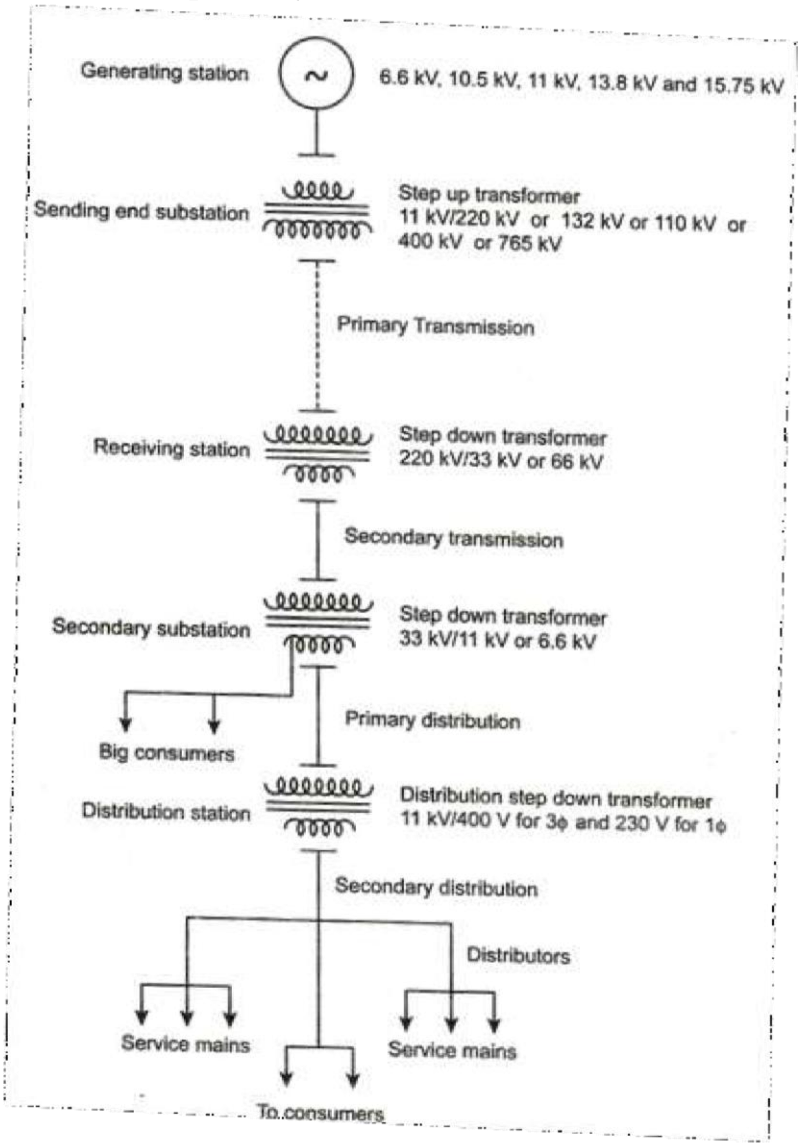
$$Z_{bus} = \begin{bmatrix} j0.1458 & j0.1041 & j0.125 \\ j0.1041 & j0.1458 & j0.125 \\ j0.125 & j0.125 & j0.175 \end{bmatrix}$$

As a check Y_{bus} is formed and is found to be

$$Y_{bus} = \begin{bmatrix} 19 & -5 & -10 \\ -5 & 19 & -10 \\ -10 & -10 & 20 \end{bmatrix}$$

$$Y_{bus} \times Z_{bus} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

22. Explain structure of modern power system with neat sketch? (Nov/Dec 2014)



An electrical power system consists of generation, transmission and distribution. The transmission system supply bulk power and the distribution system transfer electric power to ultimate consumer.

The generation of electric energy in the conversion of one form of energy into electrical energy. This energy is generated in hydrothermal and nuclear power stations sometimes electrical energy is generated from non-renewable energy resources like wind, waves, fossil fuels etc. The generating voltages are usually, 6.6kV,
10.5kV, 11kV, 13.8kV, 15.75kV etc

Components of an Electric Power System:

Generators - A device used to convert one form of energy into electrical energy.

Transformer - Transfer power from one circuit to another without change of frequency.

Transmission lines - Transfer power from one location to another

Control equipments - Used for protection purpose.

Regional grid:

The interconnected transmission system of a state or a region is called the grid of state or region. State grids are interconnected with the help of the lines and form the regional grid.

Transmission System:

It interconnects two or more generating stations. Tolerance of transmission line voltage is $+\underline{5}$ to $\pm$ 10% due to variation of loads.It can be divided into primary and secondary transmission system. The highest A.C transmission in India is 765kV.

Secondary Transmission:

The secondary transmission forms the link between the receiving end substation and the secondary substation. At the receiving end substation, the voltage is stepped down to a value of 66kv (or) 33kV (or) 22kV using step down transformer.

Distribution system:

The components of electric power system connecting all the consumers in an area to the bulk power sources or transmission lines are called distribution system.

A distribution station distributes the power to domestic commercial and relatively small consumers. It can be divided into primary and secondary system.

Primary Distribution:

At the primary substations the voltage in stepped down to 11kV or 6.6kV using step down transformer. It forms the link between secondary substations and distribution substation and power is fed into the primary distribution system. It uses 3phase 3wire system.

Secondary Distribution:

At the distribution substation the voltage is stepped down to 400V (for 3phase) or 230V (for single phase) using step down transformers. It uses 3phase 4wire system single phase loads connected between one phase wire and one neutral wire.

23.Describe about the representation of loads. (Nov/Dec 2014)

Single phase load:

Let P = Active power

And Q = Reactive power

The complex power, S = VI*= P+jQ

$$(VI^*)^* = (P+jQ)^*$$

$$V^*I=P-jQ$$

$$I = \frac{P - jQ}{V^*} \qquad (1)$$

Let $V = |V| < \delta \qquad V^* = |V| < -\delta$ (2)

And $P - jQ = \sqrt{P^2 + Q^2} < -\tan^{-1}\frac{Q}{P} = \sqrt{P^2 + Q^2} < -\theta$

Where $\theta = \tan^{-1}\frac{Q}{P}$ (3)

From equ (1), (2) and (3) we can write

$$I = \frac{\sqrt{P^2 + Q^2} < -\theta}{|V| < -\delta} = \frac{\sqrt{P^2 + Q^2}}{|V|} < \delta - \theta = |I| < \delta - \theta \qquad (4)$$

$$|I| = \frac{\sqrt{P^2 + Q^2}}{|V|}$$

Load impedance, $Z = \frac{V}{I}$ (5)

On substituting for I from equ(1) in equ (5) we get

Load impedance $Z = \frac{V}{(P - jQ)/V^*} = \frac{VV^*}{P - jQ} = \frac{|V|^2}{P - jQ}$

Load admittance $Y = \frac{1}{Z} = \frac{P - jQ}{|V|^2}$

Three phase load:

Balanced star connected load:

Let P = Three phase active power of star connected load in watts.

Q = Three phase reactive power of star connected load in VARs.

V, V_L = Phase & line voltage of load respectively

I, I_L = Phase & line current of load respectively

Three phase complex power, S=3VI* = P+jQ

(3VI*)* = (P+jQ)*

3V*I = P-jQ

$$I = \frac{P - jQ}{3V^*} \qquad (1)$$

Let $V = |V| < \delta \qquad V^* = |V| < -\delta$

$|V| = \frac{|V_L|}{\sqrt{3}}$ and $I=I_L$

$$V^* = \frac{|V_L|}{\sqrt{3}} < -\delta \qquad (2)$$

And $P - jQ = \sqrt{P^2 + Q^2} < -\tan^{-1}\frac{Q}{P} = \sqrt{P^2 + Q^2} < -\theta$

Where $\theta = \tan^{-1}\frac{Q}{P}$ (3)

Using equ (2) and (3), the equation (1) can be written as,

$$I = \frac{P - jQ}{3V^*} = \frac{\sqrt{P^2 + Q^2} < -\theta}{3\frac{|V_L|}{\sqrt{3}} < -\delta} = \frac{\sqrt{P^2 + Q^2}}{\sqrt{3}|V_L|} < \delta - \theta$$

$$I = |I_L| = \frac{\sqrt{P^2 + Q^2}}{\sqrt{3}|V_L|} < \delta - \theta \qquad (4)$$

$$I = |I_L| = \frac{\sqrt{P^2 + Q^2}}{\sqrt{3}|V_L|} \qquad (5)$$

Load impedance, $Z = \frac{V}{I}$ (6)

On substituting for I from equ(1) in equ (5) we get

Load impedance $Z = \frac{V}{(P - jQ)/3V^*} = \frac{3VV^*}{P - jQ} = \frac{3|V|^2}{P - jQ}$

$$= \frac{3([V_L]/\sqrt{3})^2}{P - jQ} = \frac{|V|^2}{P - jQ}$$

Load impedance per phase, $Z = \frac{|V|^2}{P - jQ}$

Load admittance $Y = \frac{1}{Z} = \frac{P - jQ}{|V|^2}$

Balanced Delta connected load:

Let P = Three phase active power of delta connected load in watts.

Q = Three phase reactive power of delta connected load in VARs.

V, V_L = Phase & line voltage of load respectively

I, I_L = Phase & line current of load respectively

$(3VI^*)^* = (P+jQ)^*$

$3V^*I = P-jQ$

$$I = \frac{P - jQ}{3V^*} \qquad (1)$$

Let $V = |V| < \delta$ $\qquad V^* = |V| < -\delta$

$V = V_L$ and $|I| = \frac{|I_L|}{\sqrt{3}}$ (2)

And $P - jQ = \sqrt{P^2 + Q^2} < -\tan^{-1}\frac{Q}{P} = \sqrt{P^2 + Q^2} < -\theta$

Where $\theta = \tan^{-1}\frac{Q}{P}$ (3)

Using equ (2) and (3), the equation (1) can be written as,

$$I = \frac{P - jQ}{3V^*} = \frac{\sqrt{P^2 + Q^2} < -\theta}{3|V| < -\delta} = \frac{\sqrt{P^2 + Q^2}}{3|V|} < \delta - \theta = \frac{\sqrt{P^2 + Q^2}}{3|V_L|} < \delta - \theta$$

$$= |I| < \delta - \theta$$

$$|I| = \frac{\sqrt{P^2 + Q^2}}{\sqrt{3}|V_L|}$$

$$|I_L| = \sqrt{3}|I| = \sqrt{3}\,\frac{\sqrt{P^2 + Q^2}}{3|V_L|} = \frac{\sqrt{P^2 + Q^2}}{\sqrt{3}|V_L|}$$

Load impedance per phase, $Z = \frac{V}{I}$ (4)

On substituting for I from equ(1) in equ (4) we get

Load impedance $Z = \dfrac{V}{(P - jQ)\big/3V^*} = \dfrac{3VV^*}{P - jQ} = \dfrac{3|V|^2}{P - jQ} = \dfrac{3|V_L|^2}{P - jQ}$

Load impedance per phase, $Z = \dfrac{3|V_L|^2}{P - jQ}$

Load admittance $Y = \dfrac{1}{Z} = \dfrac{P - jQ}{3|V_L|^2}$

24. Draw a one line diagram of a sample power system with 3-phase generator,synchronous motor,transformer ,induction motor,transmission lines?(Nov/Dec 2008) (or) Draw the per unit equivalent circuit of 3-phase generator,synchronous motor,induction motor,transmission lines, single-phase transformer?(Nov/Dec 2014)

<u>Equivalent circuits of components of power system:</u>

The equivalent circuit of a power system is needed to perform analysis like load flow analysis, fault level calculations, ete. It can be obtained from the equivalent circuit of the componenets of the power system. The various components of power system are generator, transformer, transmission line, induction motor, Synchronous motor, resistive and reactive loads. The equivalent circuits of various electrical machines developed in electrical machine theory can be used in power system modelling with or without approximations.

Equivalent circuit of generator:

The equivalent circuit of a 3 phase generator is shown in fig. It consists of a source representing induced emf per phase, a series reactance representing the armature reactance and leakage reactance and series resistance representing the armature winding resistance.

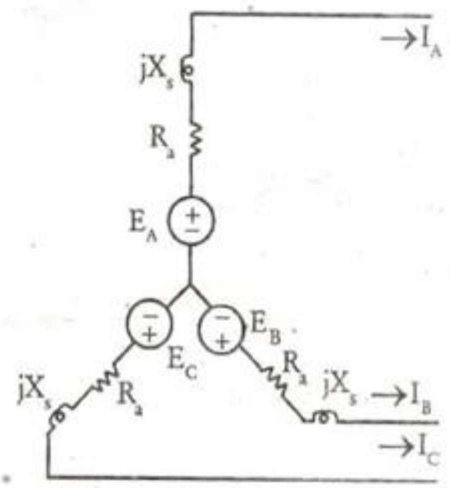


Fig a : 3-Phase equivalent circuit

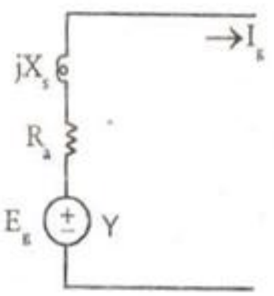


Fig b : Single phase equivalent circuit

Fig 1. : Equivalent circuit of generator (3-phase alternator)

Equivalent circuit of transformer:

The equivalent circuit of a single phase, two winding transformer referred to primary is shown in fig. It consists of shunt branches to represent magnetising current and core loss, series resistance representing winding resistance referred to primary and the series reactance representing leakage reactance referred to primary.

$$K = \frac{E_2}{E_1} = \frac{N_2}{N_1} \approx \frac{V_2}{V_1} = \frac{I_1}{I_2}$$

$$R_{01} = R_1 + R_2' = R_1 + \frac{R_2}{K^2}$$

$$X_{01} = X_1 + X_2' = X_1 + \frac{X_2}{K^2}$$

The three phase transformer is represented by its single phase equivalent and the equivalent circuit is similar to that of fig. In three phase transformers, the transformation ratio, K is taken as the ratio of line voltages. This will facilitate the direct conversion of star side impedances to delta side.

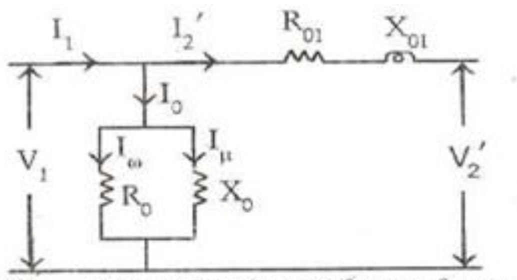


Fig : Equivalent circuit of a transformer

Equivalent circuit of synchronous motor:

The equivalent circuit of synchronous motor is shown in fig. The synchronous motor is similar to a generator in construction, but it performs the reverse action of the generator. Therefore the direction of current in motor is opposite to that of generator.

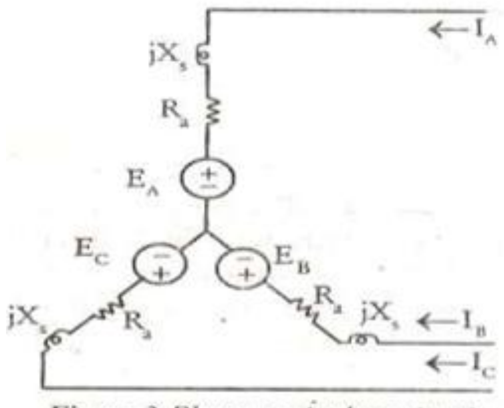


Fig a : 3-Phase equivalent circuit

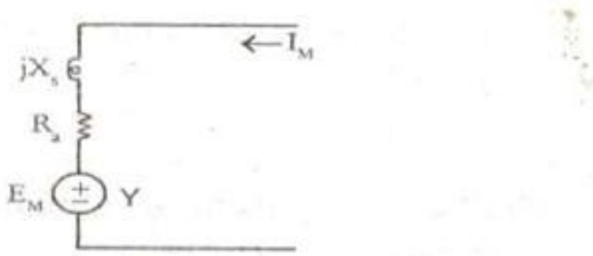


Fig b : Single phase equivalent circuit

Fig : Equivalent circuit of synchronous motor

Equivalent circuit of induction motor:

The single phase equivalent circuit of induction motor reffered to stator is shown in fig. It is similar to equivalent circuit of transformer. (The induction motor is also called rotating transformer).

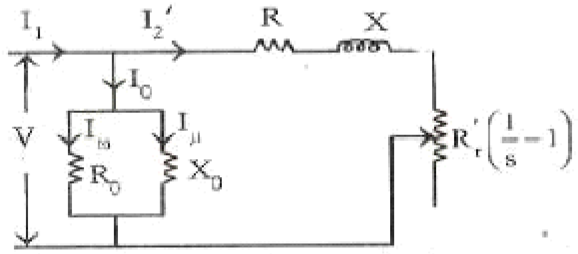


Fig : Equivalent circuit of induction motor

Equivalent circuit of transmission line:

The transmission line can be represented by its resistance, inductance and capacitance. The single phase equivalent π-type and T type model of the transmission lines is shown in fig. The elements are resistance, inductance and capacitive reactance per phase respectively.

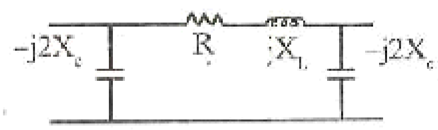


Fig a : π - type

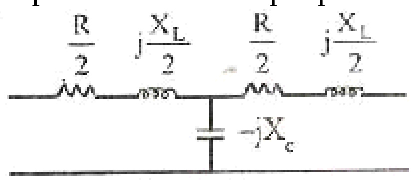


Fig b : T - type

25.Determine the Y_{bus} matrix by inspection method for the line specification as mentioned below [AU MAY/JUNE 2016]

Line p-q	Impedance in p.u	Half line charging Admittance in pu
1-2	0.04+j0.02	j0.05
1-4	0.05+j0.03	j0.07
1-3	0.025+j0.06	j0.08
2-4	0.8+j0.015	j0.05
3-4	0.035+j0.045	j0.02

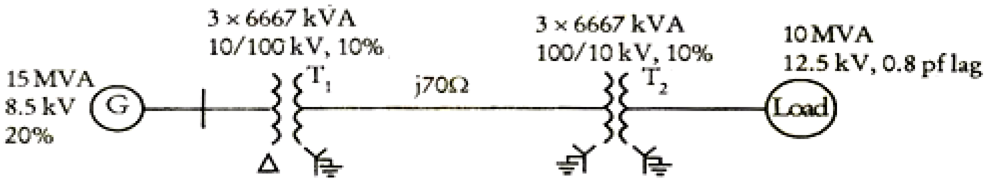
$$Y_{11} = Y_{12} + Y_{13} + Y_{14} + Y_{10}$$

$$= \frac{1}{0.04 + j0.02} + \frac{1}{0.025 + j0.66} + \frac{1}{0.05 + j0.03} + j0.05 + j0.07 + j0.08$$

$$= 20 - j10 + +0.0573 - j1.5129 + 14.705 - j8.823 + j0.05 + j0.07 + j0.08$$
$$= 34.7623 - j20.53$$
$$Y_{21} = Y_{12} = -\frac{1}{0.04 + j0.02} = -20 + j10$$
$$Y_{31} = Y_{13} = -\frac{1}{0.025 + j0.06} = -5.917 + j14.201$$
$$Y_{41} = Y_{14} = -\frac{1}{0.05 + j0.03} = -14.705 + j8.823$$
$$Y_{22} = Y_{21} + Y_{24} + Y_{20}$$
$$= \frac{1}{0.04 + j0.02} + \frac{1}{0.8 + j0.015} + j0.05 + j0.05$$
$$= 20 - j10 + 1.2495 - j0.023 + j0.05 + j0.05$$
$$= 21.2495 - j9.923$$
$$Y_{32} = Y_{23} = 0$$
$$Y_{42} = Y_{24} = -\frac{1}{0.8 + j0.015} = -1.2495 + j0.023$$
$$Y_{33} = Y_{31} + Y_{34} + Y_{30}$$
$$= \frac{1}{0.025 + j0.06} + \frac{1}{0.035 + j0.045} + j0.08 + j0.02$$
$$= 16.6863 - j27.9$$
$$Y_{34} = Y_{43} = -\frac{1}{0.035 + j0.045} = -10.7692 + j13.846$$
$$Y_{44} = Y_{41} + Y_{42} + Y_{43} + Y_{40}$$
$$= \frac{1}{0.05 + j0.03} + \frac{1}{0.8 + j0.015} + \frac{1}{0.035 + j0.045} + j0.02 + j0.07 + j0.05$$
$$= 14.705 - j8.823 + 1.2495 - j0.0234 + 10.769 - j13.846 + j0.02 + j0.07 + j0.05$$
$$= 26.723 - j22.5524$$

$$Y_{bus} = \begin{bmatrix} 34.762 - j20.53 & -20 + j10 & -5.917 + j14.201 & -14.705 + j8.823 \\ -20 + j10 & 21.249 - j9.923 & 0 & -1.249 + j0.023 \\ -5.917 + j14.201 & 0 & 16.683 - j27.9 & -10.769 + j13.846 \\ -14.705 + j8.823 & -1.249 + j0.023 & -10.769 + j13.846 & 26.723 - j22.5524 \end{bmatrix}$$

26. A 15MVA, 8.5kV, 3phase generator has a sub transient reactance of 20%. It in connected through a delta star transformer to a high voltage transmission line having a total series reactance of 70 ohms. The load end the line has star-star step down transformer. Both transformer banks are composed of single phase transformer connected for 3ph operators. Each of three transformer composing 3ph bank in rated 6667kVA,10/100kV, with a reactance of 10%. The load represented as impedance in drawing 10MVA at 12.5kV and 0.8pf lagging. Draw the single line diagram of the power network. Choose a base of 10MVA, 12.5kV in the load circuit and determine the reactance diagram. Determine also the voltage at the terminals of the generators? (April/May-2011) (Nov/Dec 2016) (April/May-2018)



Given Data:

Generator G1:15MVA, 8.5kV, X"=20%
Load: 10MVA at 12.5kV and 0.8pf lagging.
3ph, star-delta transformer: 6667kVA,10/100kV, X=10%
3ph, star-delta transformer: 6667kVA,100/10kV, X=10%
Transmission line: 70 ohms

To find: Z(pu) of various components., Draw the reactance diagram.

Formula used:

$$Z_b = \frac{kV_{b,new}^2}{MVA_{b,new}}$$

$$Base\ kV\ on\ LT\ side\ of\ transformer\ T1 = Base\ kV\ on\ HT\ side \times \frac{LT\ voltage\ rating}{HT\ voltage\ rating}$$

$$X_{p.u,new,T1} = X_{p.u,old} \times \left(\frac{kV_{b,old}}{kV_{b,new}}\right)^2 \times \left(\frac{MVA_{b,new}}{MVA_{b,old}}\right)$$

Solution:

$$MVA_{b,new} = 10MVA, \qquad kV_{b,new} = 12.5kV$$

<u>Reactance of transformer T2:</u>

Voltage ratio of line voltage of transformer $T_2 = \frac{100 \times \sqrt{3}kV}{10 \times \sqrt{3}kV} = \frac{173.2kV}{17.32kV}$

3ph kVA rating of transformer$T_2 = 3 \times 1\varphi\ rating\ of\ kVA = 3 \times 6667 = 20000kVA = 20MVA$

$MVA_{b,old} = 20MVA$

$kV_{b,old} = 17.32kV(on\ LT\ side)$

$$X_{p.u,new,T2} = X_{p.u,old} \times \left(\frac{kV_{b,old}}{kV_{b,new}}\right)^2 \times \left(\frac{MVA_{b,new}}{MVA_{b,old}}\right)$$

$$= 0.1 \times \left(\frac{17.32}{12.5}\right)^2 \times \left(\frac{10}{20}\right) = 0.096p.u$$

<u>Reactance of transmission line:</u>

$$Base\ kV\ on\ HT\ side\ of\ transformer\ T2 = Base\ kV\ on\ LT\ side \times \frac{HT\ voltage\ rating}{LT\ voltage\ rating}$$

$$= 12.5 \times \frac{173.2}{17.32} = 125kV$$

$$Z_b = \frac{kV_{b,new}^2}{MVA_{b,new}} = \frac{125^2}{10} = 1562.5\ ohms$$

$$X_{p.u,new,Tr,line} = \frac{Actual\ impedance}{Base\ impedance} = \frac{70}{1562.5} = 0.0448p.u$$

Reactance of transformer T1:

$$\text{Voltage ratio of line voltage of transformer } T_1 = \frac{10kV}{100 \times \sqrt{3}kV} = \frac{10kV}{173.2kV}$$

$$\text{3ph kVA rating of transformer } T_1 = 3 \times 6667 = 3 \times 6667 = 20{,}000kVA = 20MVA$$

$$MVA_{b,old} = 20MVA$$

$$kV_{b,old} = 173.2kV(on\ HT\ side)$$

$$X_{p.u,new,T1} = X_{p.u,old} \times \left(\frac{kV_{b,old}}{kV_{b,new}}\right)^2 \times \left(\frac{MVA_{b,new}}{MVA_{b,old}}\right)$$

$$= 0.1 \times \left(\frac{173.2}{125}\right)^2 \times \left(\frac{10}{20}\right) = 0.096p.u$$

Reactance of Generator G:

$$Base\ kV\ on\ LT\ side\ of\ transformer\ T1 = Base\ kV\ on\ HT\ side \times \frac{LT\ voltage\ rating}{HT\ voltage\ rating}$$

$$= 125 \times \frac{10}{173.2} = 7.217kV$$

$$kV_{b,new} = 7.217kV$$

$$X_{p.u,new,G} = X_{p.u,old} \times \left(\frac{kV_{b,old}}{kV_{b,new}}\right)^2 \times \left(\frac{MVA_{b,new}}{MVA_{b,old}}\right)$$

$$= 0.2 \times \left(\frac{8.5}{7.217}\right)^2 \times \left(\frac{10}{15}\right) = 0.185p.u$$

Load:

This can be represented as constant current load P.f of load = 0.8 lag

P.f angle = $-\cos^{-1}0.8 = -36.87^{o}$

Complex load power = $10\angle -36.87^{o}$ MVA

$$p.u\ value\ of\ load(power) = \frac{Actual\ load\ MVA}{Base\ value\ of\ MVA} = \frac{10\angle - 36.87^0}{10} = 1\angle - 36.87^0 p.u$$

$$p.u\ value\ of\ load\ voltage = \frac{Actual\ load\ voltage}{Base\ voltage} = \frac{12.5kV}{12.5kV} = 1p.u$$

Let,

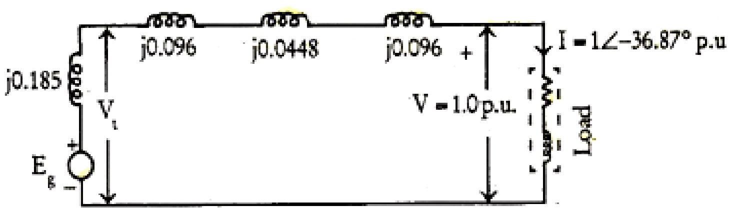
I = Load current in p.u

V = Load voltage in p.u

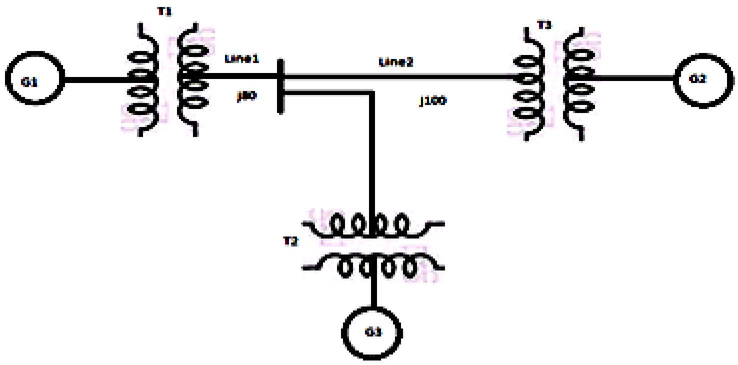
We know that, V*I = p.u value of load (power)

$$I = \frac{p.u\ value\ of\ load}{V} = \frac{1\angle - 36.87^0}{1} = 1\angle - 36.87^0$$

Reactance diagram:



27. Draw the reactance diagram for the power systemshow in fig .Neglect resistance and use a base of 50MVA and 13.8KV on generator G1.(Nov/Dec-2015)



Given Data

$$\text{G1: 20MVA, 13.8KV, X}'' = 20\%$$
$$\text{G2: 30MVA, 18.0KV, X}'' = 20\%$$
$$\text{G3: 30MVA, 20KV, X}'' = 20\%$$
$$\text{T1: 25MVA, 220/13.8KV, X} = 10\%$$
$$\text{T2: Single phase unit each rated 10MVA,} \frac{127}{18}\text{KV, X} = 10\%$$
$$\text{T3: 35MVA, 220/22KV, X} = 10\%$$

To Find

Determine the new values of per unit reactance of G1, T1, and Transmission line1, Transmission line2 G2, T2, G3 and T3.

Solution:

<u>Reactance of generator G1:</u>

$$Z_{New} = Z_{old} \times \left(\frac{MVA_{New}}{MVA_{Given}}\right) \times \left(\frac{KV_{Given}}{KV_{New}}\right)^2$$

$$Z_{old} = 0.2 \text{ pu}$$
$$MVA_{Given} = 20$$
$$MVA_{New} = 50$$
$$KV_{Given} = 13.8$$
$$KV_{New} = 13.8$$

$$Z_{New} = Z_{old} \times \left(\frac{MVA_{New}}{MVA_{Given}}\right) \times \left(\frac{KV_{Given}}{KV_{New}}\right)^2$$

$$= 0.2 \times \left(\frac{50}{20}\right) \times \left(\frac{13.8}{13.8}\right)^2 = j0.5pu$$

Reactance of Transformer T1(Primary side)

$$Z_{New} = Z_{old} \times \left(\frac{MVA_{New}}{MVA_{Given}}\right) \times \left(\frac{KV_{Given}}{KV_{New}}\right)^2$$

$$= 0.1 \times \left(\frac{50}{25}\right) \times \left(\frac{13.8}{13.8}\right)^2 = j0.5pu = j0.2pu$$

<u>Reactance of Transmission line j80Ω</u>

$$\text{per unit reactance of transmission line} = \frac{\text{Actual reactance } \Omega}{\text{Base reactance } \Omega}$$

$$\text{Actual reactance} = 80\Omega$$

$$\text{Base KV on HT side of transformer } T_1 = \text{Base KV on LT side } \times \frac{\text{HT voltage rating}}{\text{LT voltage rating}}$$

$$\text{Base KV on HT side of transformer } T_1 = 13.8 \times \frac{220}{13.8} = 220\text{KV}$$

$$KV_{new} = 220\text{KV}$$

$$\text{Base impedance} = \frac{KV^2}{MVA_{New}} = \frac{220^2}{50} = 968\Omega$$

$$\text{per unit reactance of transmission line} = \frac{\text{Actual reactance } \Omega}{\text{Base reactance } \Omega} = \frac{80}{968} = j0.0826 \text{ p.u}$$

Reactance of Transmission line j100Ω

$$\text{per unit reactance of transmission line} = \frac{\text{Actual reactance } \Omega}{\text{Base reactance } \Omega}$$

$$\text{Actual reactance} = 100\Omega$$

$$\text{Base KV on HT side of transformer } T_1 = \text{Base KV on LT side } \times \frac{\text{HT voltage rating}}{\text{LT voltage rating}}$$

$$\text{Base KV on HT side of transformer } T_1 = 13.8 \times \frac{220}{13.8}$$

$$KV_{new} = 220\text{KV}$$

$$\text{Base impedance} = \frac{KV^2}{MVA_{New}} = \frac{220^2}{50} = 968\Omega$$

$$\text{per unit reactance of transmission line} = \frac{\text{Actual reactance } \Omega}{\text{Base reactance } \Omega} = \frac{100}{968} = j0.1033 \text{ p.u}$$

Reactance of Transformer T2(Primary side)

$$Z_{New} = Z_{old} \times \left(\frac{MVA_{New}}{MVA_{Given}}\right) \times \left(\frac{KV_{Given}}{KV_{New}}\right)^2$$

$$Z_{old} = 0.1 \text{ p.u}$$

Y/Δ connection : voltage rating: $\sqrt{3} \times 127/18\text{KV} = 220/18\text{KV}$

$$Z_{New} = 0.1 \times \left(\frac{50}{30}\right) \times \left(\frac{220}{220}\right)^2 = j0.1667 \text{ p.u}$$

Reactance of generatorG2

$$Z_{New} = Z_{old} \times \left(\frac{MVA_{New}}{MVA_{Given}}\right) \times \left(\frac{KV_{Given}}{KV_{New}}\right)^2$$

$$\text{Base KV on LT side of transformer } T_2 = \text{Base KV on HT side } \times \frac{\text{LT voltage rating}}{\text{HT voltage rating}}$$

$$\text{Base KV on LT side of transformer } T_2 = 220 \times \frac{18}{220} = 18 \text{ KV}$$

$$Z_{New} = 0.2 \times \left(\frac{50}{20}\right) \times \left(\frac{13.8}{13.8}\right)^2 = j0.5 \text{ p.u}$$

$$Z_{New} = 0.2 \times \left(\frac{50}{30}\right) \times \left(\frac{18}{18}\right)^2 = j0.333 \text{ p.u}$$

Reactance of Transformer T3 (Secondary side)

$$Z_{New} = Z_{old} \times \left(\frac{MVA_{New}}{MVA_{Given}}\right) \times \left(\frac{KV_{Given}}{KV_{New}}\right)^2$$

$$= 0.1 \times \left(\frac{50}{35}\right) \times \left(\frac{220}{220}\right)^2 = j0.1429 \text{ p.u}$$

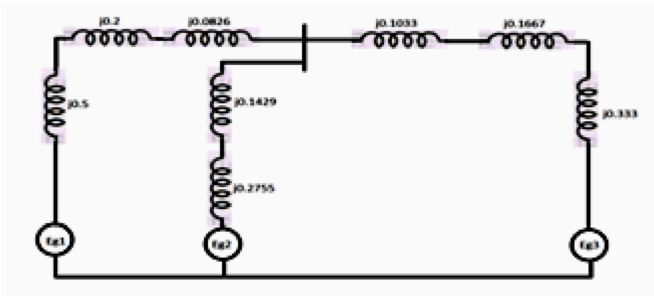
<u>Reactance of generatorG3</u>

$$Z_{New} = Z_{old} \times \left(\frac{MVA_{New}}{MVA_{Given}}\right) \times \left(\frac{KV_{Given}}{KV_{New}}\right)^2$$

$$\text{Base KV on LT side of transformer } T_2 = \text{Base KV on HT side} \times \frac{\text{LT voltage rating}}{\text{HT voltage rating}}$$

$$\text{Base KV on LT side of transformer } T_2 = 220 \times \frac{22}{220} = 22 \text{ KV}$$

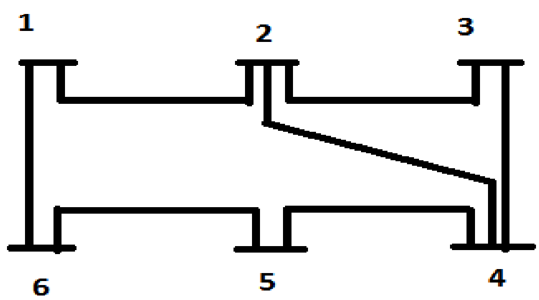
$$Z_{New} = 0.2 \times \left(\frac{50}{30}\right) \times \left(\frac{20}{22}\right)^2 = j02755 \text{ p.u}$$

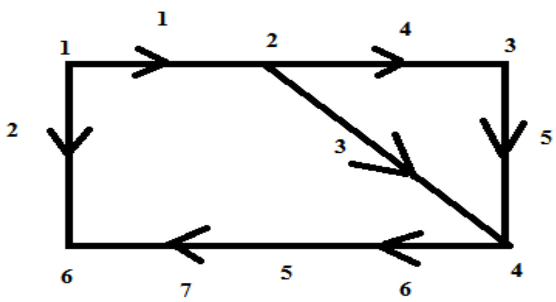


28.Form bus admittance matrix for the data given below using singular transformation method. Take node '6' as reference node.(Apr/May 2017)

Elements	Bus code	X(p.u)
1	**1-2**	**0.04**
2	**1-6**	**0.06**
3	**2-4**	**0.03**
4	**2-3**	**0.02**
5	**3-4**	**0.08**
6	**4-5**	**0.06**
7	**5-6**	**0.05**

Solution:





The incidance matrix

$$[A] = \begin{bmatrix} 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 & -1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 1 \end{bmatrix}$$

Matrix transpose

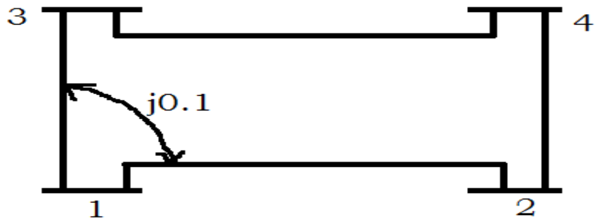
$$[A]^T = \begin{bmatrix} 1 & -1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & -1 & 0 \\ 0 & 1 & -1 & 0 & 0 \\ 0 & 0 & 1 & -1 & 0 \\ 0 & 0 & 0 & 1 & -1 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Ybus matrix

$$Y_{Bus} = [A]^T [y][A]$$

$$Y_{Bus} = -j\begin{bmatrix} 41.67 & -25 & 0 & 0 & 0 \\ -25 & 108.33 & -50 & -33.33 & 0 \\ 0 & -50 & 62.5 & -12.5 & 0 \\ 0 & -33.33 & -12.5 & 62.5 & -16.67 \\ 0 & 0 & 0 & -16.67 & 36.67 \end{bmatrix}$$

27. From Y_{Bus} of the test system shown in fig using singular transformation method. The impedance data is given in table take (1) as reference node.(Nov/Dec-2015) (Apr/May 2017)



Element No	Self		Mutual	
	Bus code	Impedance	Bus code	Impedance
1	1-2	0.5	1-2	0.1
2	1-3	0.6		
3	3-4	0.4		
4	2-4	0.3		

Solution:

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

Take (1) as reference node and eliminate it. Bus incidence matrix

$$\begin{array}{cc} \textbf{\textit{element/node}} & \begin{array}{ccc} \mathbf{2} & \mathbf{3} & \mathbf{4} \end{array} \\ A = \begin{array}{c} 1-2 \\ 1-3 \\ 3-4 \\ 2-4 \end{array} & \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 1 & -1 \\ 1 & 0 & -1 \end{bmatrix} \end{array}$$

$$A^t = \begin{bmatrix} -1 & 0 & 0 & 1 \\ 0 & -1 & 1 & 0 \\ 0 & 0 & -1 & -1 \end{bmatrix}$$

$$\begin{array}{cc} \textbf{\textit{element/element}} & \begin{array}{cccc} 1-2 & 1-3 & 3-4 & 2-4 \end{array} \\ Z_{Perimitive} = \begin{array}{c} 1-2 \\ 1-3 \\ 3-4 \\ 2-4 \end{array} & \begin{bmatrix} j0.5 & j0.1 & 0 & 0 \\ j0.1 & j0.6 & 0 & 0 \\ 0 & 0 & j0.4 & 0 \\ 0 & 0 & 0 & j0.3 \end{bmatrix} \end{array}$$

$$Y_{Perimitive} = Z_{Perimitive}{}^{-1}$$

Consider 2×2 matrix

$$\begin{bmatrix} j0.5 & j0.1 \\ j0.1 & j0.6 \end{bmatrix}^{-1} = \frac{1}{-0.29} \begin{bmatrix} j0.6 & -j0.1 \\ -j0.1 & j0.5 \end{bmatrix} = \begin{bmatrix} -j2.0689 & j0.3448 \\ j0.3448 & -j1.724 \end{bmatrix}$$

$$Y_{Perimitive} = \begin{bmatrix} -j2.0689 & j0.3448 & 0 & 0 \\ j0.3448 & -j1.724 & 0 & 0 \\ 0 & 0 & -j2.5 & 0 \\ 0 & 0 & 0 & -j3.333 \end{bmatrix}$$

$$Y_{Bus} = [A][Y_{Perimitive}][A^T]$$

$$[A][Y_{Perimitive}] = \begin{bmatrix} -j2.0689 & j0.3448 & 0 & 0 \\ j0.3448 & -j1.724 & 0 & 0 \\ 0 & 0 & -j2.5 & 0 \\ 0 & 0 & 0 & -j3.333 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 1 & -1 \\ 1 & 0 & -1 \end{bmatrix}$$

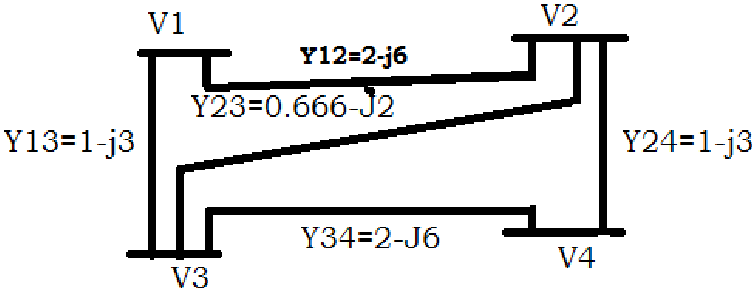
$$[A][Y_{Perimitive}] = \begin{bmatrix} j2.0689 & j0.3448 & 0 \\ -j0.3448 & j1.724 & 0 \\ 0 & -j2.5 & j2.5 \\ -3.333 & 0 & j3.333 \end{bmatrix}$$

$$A^t[Y_{Perimitive}][A] = \begin{bmatrix} -1 & 0 & 0 & 1 \\ 0 & -1 & 1 & 0 \\ 0 & 0 & -1 & -1 \end{bmatrix} \begin{bmatrix} j2.0689 & j0.3448 & 0 \\ -j0.3448 & j1.724 & 0 \\ 0 & -j2.5 & j2.5 \\ -3.333 & 0 & j3.333 \end{bmatrix}$$

$$Y_{Bus} = \begin{bmatrix} -j5.4019 & -j0.3448 & j3.333 \\ j0.3448 & -j4.22 & j2.5 \\ j3.333 & j2.5 & j5.833 \end{bmatrix}$$

30. Single line diagram of a simple four bus system. It gives line impedance by bus on which these terminate .the shunt admittance at all buses are assumed negligible calculate Y_{Bus} using1.Rule of Inspection method, 2.singular transformation method.

1.Rule of Inspection method,



Apply KCL At node V1

$$\begin{aligned} 0 &= (V_1 - V_2)Y_{12} + (V_1 - V_3)Y_{13} \\ &= Y_{12}V_1 - Y_{12}V_2 + Y_{13}V_1 - Y_{13}V_3 \\ &= (Y_{12} + Y_{13})V_1 - Y_{12}V_2 - Y_{13}V_3 \dots\dots\dots (1) \end{aligned}$$

Apply KCL At node V2

$$\begin{aligned} &= (V_2 - V_1)Y_{12} + (V_2 - V_3)Y_{23} + (V_2 - V_4)Y_{24} \\ &= Y_{12}V_2 - Y_{12}V_1 + Y_{23}V_2 - Y_{23}V_3 + Y_{24}V_2 - Y_{24}V_4 \\ &= -Y_{12}V_1 + (Y_{12} + Y_{23} + Y_{24})V_2 - Y_{23}V_3 - Y_{24}V_4 \dots\dots\dots (2) \end{aligned}$$

Apply KCL At node V3

$$\begin{aligned} &= (V_3 - V_1)Y_{13} + (V_3 - V_4)Y_{34} + (V_3 - V_2)Y_{32} \\ &= Y_{13}V_3 - Y_{13}V_1 + Y_{34}V_3 - Y_{34}V_4 + Y_{32}V_3 - Y_{32}V_2 \\ &= -Y_{13}V_1 - Y_{32}V_2 + (Y_{13} + Y_{32} + Y_{34})V_3 - Y_{34}V_4 \dots\dots\dots (3) \end{aligned}$$

Apply KCL At node V4

$$\begin{aligned} &= (V_4 - V_2)Y_{24} + (V_4 - V_3)Y_{34} \\ &= Y_{24}V_4 - Y_{24}V_2 + Y_{34}V_4 - Y_{34}V_3 \\ &= -Y_{24}V_2 - Y_{34}V_3 + (Y_{24} + Y_{34})V_4 \dots\dots\dots (4) \end{aligned}$$

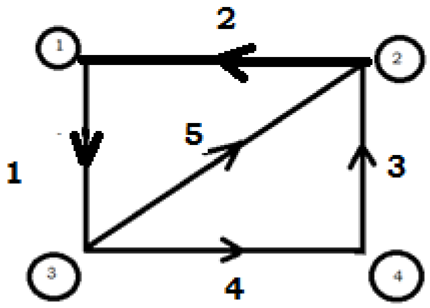
Using the equation 1,2,3&4Form the matrix

$$\begin{bmatrix} (Y_{12}+Y_{13}) & -Y_{12} & -Y_{13} & 0 \\ -Y_{12} & (Y_{12}+Y_{23}+Y_{24}) & -Y_{23} & -Y_{24} \\ -Y_{13} & -Y_{23} & (Y_{13}+Y_{32}+Y_{34}) & -Y_{34} \\ 0 & -Y_{24} & -Y_{34} & (Y_{24}+Y_{34}) \end{bmatrix}$$

Now substitute given values.

$$= \begin{bmatrix} 3-j9 & -2+j6 & -1+j3 & 0 \\ -2+j6 & 3.666-j11 & 0.666+j2 & -1+j3 \\ -1+j3 & -0.666+j2 & 3.666-j11 & -2+j6 \\ 0 & -1+j3 & -2+j6 & 3-j9 \end{bmatrix}$$

<u>2.singular transformation method.</u>



$$\begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{array} \begin{bmatrix} 1 & 2 & 3 & 4 \\ 1 & 0 & -1 & 0 \\ -1 & 1 & 0 & 0 \\ 0 & -1 & 0 & 1 \\ 0 & 0 & -1 & 1 \\ 0 & 0 & -1 & 1 \end{bmatrix} = [A]$$

$$[A][Y] = \begin{bmatrix} Y_{13} & 0 & -Y_{13} & 0 \\ -Y_{12} & Y_{12} & 0 & 0 \\ 0 & -Y_{24} & 0 & Y_{24} \\ 0 & 0 & Y_{34} & -Y_{34} \\ 0 & Y_{23} & -Y_{23} & 0 \end{bmatrix}$$

$$[A][Y]A^{-1} = \begin{bmatrix} Y_{13} & 0 & -Y_{13} & 0 \\ -Y_{12} & Y_{12} & 0 & 0 \\ 0 & -Y_{24} & 0 & Y_{24} \\ 0 & 0 & Y_{34} & -Y_{34} \\ 0 & Y_{23} & -Y_{23} & 0 \end{bmatrix} \begin{bmatrix} 1 & -1 & 0 & 0 & 0 \\ 0 & 1 & -1 & 0 & -1 \\ -1 & 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 & 0 \end{bmatrix}$$

$$Y_{Bus} = [A][Y]A^{-1} = \begin{bmatrix} (Y_{12}+Y_{13}) & -Y_{12} & -Y_{13} & 0 \\ -{}_{12} & ({}_{12}+{}_{23}+{}_{24}) & -{}_{23} & -{}_{24} \\ -{}_{13} & -{}_{23} & ({}_{13}+{}_{32}+{}_{34}) & -{}_{34} \\ 0 & -{}_{24} & -{}_{34} & ({}_{24}+{}_{34}) \end{bmatrix}$$

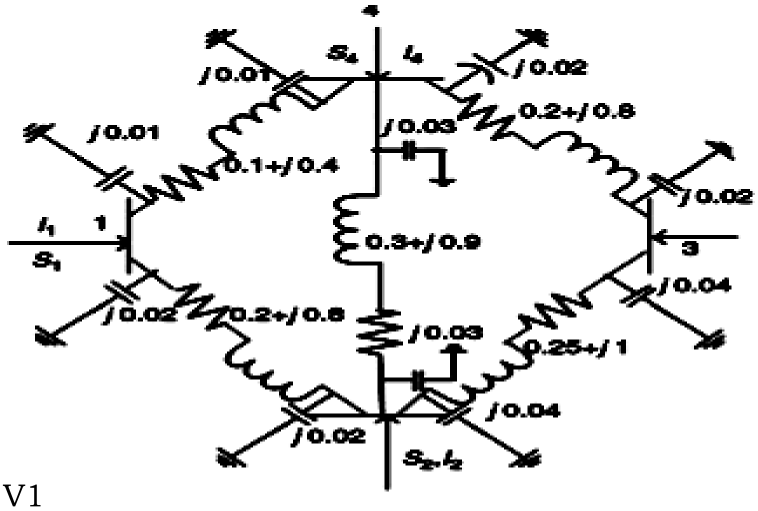
Now substitute given values.

$$= \begin{bmatrix} 3-9 & -2+6 & -1+3 & 0 \\ -2+6 & 3.666-11 & 0.666+2 & -1+3 \\ -1+3 & -0.666+2 & 3.666-11 & -2+6 \\ 0 & -1+3 & -2+6 & 3-9 \end{bmatrix}$$

31. The parameters of four bus system are:

Bus code	Line Impedance(p.u)	Charging admittance(p.u)
1-2	0.2+j0.8	j0.02
2-3	0.3+j0.9	j0.03
2-4	0.25+j1	j0.04
3-4	0.2+j0.8	j0.02
1-3	0.1+j0.4	j0.1

Draw the network find the bus admittance matrix.(May/june-2016)
(Nov/Dec 2016)



.Apply KCL At node V1

$$0 = (V_1 - V_2)Y_{12} + (V_1 - V_3)Y_{13}$$
$$= Y_{12}V_1 - Y_{12}V_2 + Y_{13}V_1 - Y_{13}V_3$$
$$= (Y_{12} + Y_{13})V_1 - Y_{12}V_2 - Y_{13}V_3 \ldots\ldots\ldots (1)$$

.Apply KCL At node V2

$$= (V_2 - V_1)Y_{12} + (V_2 - V_3)Y_{23} + (V_2 - V_4)Y_{24}$$
$$= Y_{12}V_2 - Y_{12}V_1 + Y_{23}V_2 - Y_{23}V_3 + Y_{24}V_2 - Y_{24}V_4$$
$$= -Y_{12}V_1 + (Y_{12} + Y_{23} + Y_{24})V_2 - Y_{23}V_3 - Y_{24}V_4 \ldots\ldots\ldots (2)$$

Apply KCL At node V3

$$= (V_3 - V_1)Y_{13} + (V_3 - V_4)Y_{34} + (V_3 - V_2)Y_{32}$$
$$= Y_{13}V_3 - Y_{13}V_1 + Y_{34}V_3 - Y_{34}V_4 + Y_{32}V_3 - Y_{32}V_2$$
$$= -Y_{13}V_1 - Y_{32}V_2 + (Y_{13} + Y_{32} + Y_{34})V_3 - Y_{34}V_4 \ldots\ldots\ldots (3)$$

Apply KCL At node V4

$$= (V_4 - V_2)Y_{24} + (V_4 - V_3)Y_{34}$$
$$= Y_{24}V_4 - Y_{24}V_2 + Y_{34}V_4 - Y_{34}V_3$$
$$= -Y_{24}V_2 - Y_{34}V_3 + (Y_{24} + Y_{34})V_4 \ldots\ldots\ldots (4)$$

Using the equation 1,2,3&4Form the matrix

$$Y_{\text{Bus}} = \begin{bmatrix} (Y_{12} + Y_{13} + Y_{10}) & -Y_{12} & -Y_{13} & 0 \\ -Y_{12} & (Y_{12} + Y_{23} + Y_{24} + Y_{20}) & -Y_{23} & -Y_{24} \\ -Y_{13} & -Y_{23} & (Y_{13} + Y_{32} + Y_{34} + Y_{30}) & -Y_{34} \\ 0 & -Y_{24} & -Y_{34} & (Y_{24} + Y_{34} + Y_{40}) \end{bmatrix}$$

Series admittance at different buses are:

$$Y_{12} = \frac{1}{Z_{12}} = \frac{1}{0.2 + j0.8} = 0.294 - j1.176\text{p.u}$$

$$Y_{13} = \frac{1}{Z_{13}} = \frac{1}{0.1 + j0.4} = 0.588 - j2.352\text{p.u}$$

$$Y_{23} = \frac{1}{Z_{23}} = \frac{1}{0.3 + j0.9} = 0.333 - j1\text{p.u}$$

$$Y_{24} = \frac{1}{Z_{24}} = \frac{1}{0.25 + j1} = 0.235 - j0.9\text{p.u}$$

$$Y_{34} = \frac{1}{Z_{34}} = \frac{1}{0.25 + j0.8} = 0.294 - j1.176\text{p.u}$$

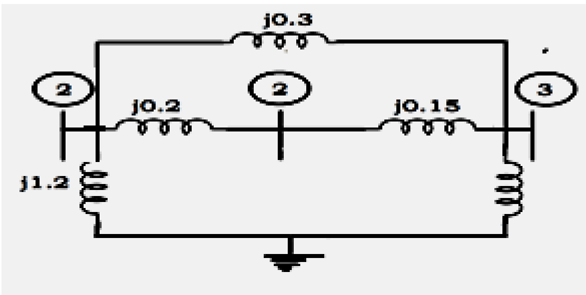
Shunt admittance at different buses are:

$$Y_{10} = j0.03\text{p.u}$$
$$Y_{20} = j0.09\text{p.u}$$
$$Y_{30} = j0.06\text{p.u}$$
$$Y_{40} = j0.06\text{p.u}$$

Now Y_{Bus}matrix is;

$$Y_{Bus} = \begin{bmatrix} 0.822 - j3.498 & -0.294 + j1.176 & -0.588 + j2.352 & 0 \\ -0.294 + j1.176 & 0.862 - j3.026 & -0.333 - j4.468 & -0.235 + j0.94 \\ -0.588 + j2.352 & -0.333 + j1 & 1.215 - j4.468 & -0.294 + j1.176 \\ 0 & -0.235 + j0.94 & -0.294 + j1.176 & 0.529 - j2.056 \end{bmatrix}$$

32. Determine the Z bus for the network shown in fig where all impedance are in p.u



Solution

Step1: Bus 1(New)to the ref bus (type 1 modification)

$$Z_{Bus} = [j1.2]$$

Step2:Connecting an impedance $Z_{21} = j0.2$ from new bus 2 to old bus 1(type 2 modification) j=1

$$Z_{Bus}(New) = \begin{bmatrix} Z_{Bus}(old) & Z_{1j} \\ Z_{j1} & Z_{jj} + Z_b \end{bmatrix}$$
$$= \begin{bmatrix} j1.2 & j1.2 \\ j1.2 & j1.4 \end{bmatrix}$$

Step3: Connecting an impedance $Z_{31} = j0.3$ from new bus 3(new) to old bus 1(type 2 modification)

$$= \begin{bmatrix} Z_{Bus}(old) & \ldots & Z_{1j} \\ \vdots & \vdots & Z_{2j} \\ Z_{j1} & Z_{j2} & Z_{jj} + Z_b \end{bmatrix}$$

$$Z_{Bus}(New) = \begin{bmatrix} j1.2 & j1.2 & j1.2 \\ j1.2 & j1.4 & j1.2 \\ j1.2 & j1.2 & j1.5 \end{bmatrix}$$

Step 4: Connecting $Z_{3r} = j1.5$ from new bus 3 (old) to ref bus

$$Z_{Bus}(New) = Z_{Bus}(old) - \frac{1}{Z_{jj} + Z_b}\begin{bmatrix} Z_{1j} \\ Z_{2j} \\ Z_{3j} \end{bmatrix}[Z_{j1} \quad Z_{j2} \quad Z_{j3}]$$

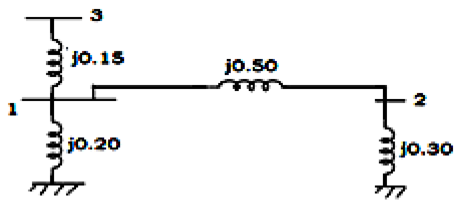
$$Z_{Bus}(New) = \begin{bmatrix} j0.72 & j0.72 & j0.6 \\ j0.72 & j0.92 & j0.6 \\ j0.6 & j0.6 & j0.75 \end{bmatrix}$$

Step 5: Adding impedance $Z_b = j0.15$ between old buses (2) and (3) i=2, j=3

$$Z_{Bus}(New) = Z_{Bus}(old) - \frac{1}{Z_{22} + Z_{33} + Z_b - 2Z_{23}}\begin{bmatrix} Z_{12} - Z_{13} \\ Z_{22} - Z_{23} \\ Z_{32} - Z_{33} \end{bmatrix}[(Z_{21} - Z_{31}) \quad (Z_{22} - Z_{32}) \quad (Z_{23} - Z_{33})]$$

$$Z_{Bus}(New) = \begin{bmatrix} j0.6968 & j0.6581 & j0.6290 \\ j0.6581 & j0.7548 & j0.6674 \\ j0.6290 & j0.6258 & j0.7157 \end{bmatrix}$$

33.b)using method of building algorithm find the bus impedance matrix for the network shown in fig.(Apr/May-2015)



Step1: Add $Z_{10} = j0.2$ between node 1 and reference node 0. **Type 1 modification**

$$Z_{bus} = [j0.2]$$

Step2: add branch 2, $Z_{20} = j0.3$ between node 2 and reference node 0 **Type 2 modification**.

$$Z_{bus} = \begin{bmatrix} Z_{11} & 0 \\ 0 & Z_{22} \end{bmatrix} = \begin{bmatrix} j0.2 & 0 \\ 0 & j0.3 \end{bmatrix}$$

Step3: Add , $Z_{13} = j0.15$ between new node 3 and existing node 1

$$Z_{bus} = \begin{bmatrix} Z_{11} & Z_{12} & Z_{11} \\ Z_{12} & Z_{22} & Z_{21} \\ Z_{11} & Z_{12} & Z_{11} + Z_{13} \end{bmatrix} = \begin{bmatrix} j0.2 & 0 & j0.2 \\ 0 & j0.3 & 0 \\ j0.2 & 0 & j0.35 \end{bmatrix}.$$

Step4: Add link , $Z_{12} = j0.5$between node2 and node 1

$$Z_{bus} = \begin{bmatrix} Z_{11} & Z_{12} & Z_{13} & Z_{12} - Z_{11} \\ Z_{21} & Z_{22} & Z_{23} & Z_{22} - Z_{21} \\ Z_{31} & Z_{32} & Z_{33} & Z_{32} - Z_{31} \\ Z_{21} - Z_{11} & Z_{22} - Z_{12} & Z_{23} - Z_{13} & Z_{44} \end{bmatrix}$$

$$= \begin{bmatrix} j0.2 & 0 & j0.2 & -j0.2 \\ 0 & j0.3 & 0 & j0.3 \\ j0.2 & 0 & j0.35 & -j0.2 \\ -j0.2 & j0.3 & -j0.2 & Z_{44} \end{bmatrix}$$

$$Z_{44} = Z_{12} + Z_{11} + Z_{21} - 2Z_{12} = j\big(0.5 + 0.2 + 0.3 - 2(0)\big) = j1.0$$

$$\frac{\Delta Z \Delta Z^T}{Z_{44}} = \frac{1}{j1.0}\begin{bmatrix} -j0.2 \\ +j0.3 \\ -j0.2 \end{bmatrix}[-j0.2 \quad +j0.3 \quad -j0.2]$$

$$= \begin{bmatrix} \text{j}0.04 & -\text{j}0.06 & \text{j}0.04 \\ -\text{j}0.06 & \text{j}0.09 & -\text{j}0.06 \\ \text{j}0.04 & -\text{j}0.06 & \text{j}0.04 \end{bmatrix}$$

$$= \begin{bmatrix} \text{j}0.2 & 0 & \text{j}0.2 \\ 0 & \text{j}0.3 & 0 \\ \text{j}0.2 & 0 & \text{j}0.35 \end{bmatrix} - \begin{bmatrix} \text{j}0.04 & -\text{j}0.06 & \text{j}0.04 \\ -\text{j}0.06 & \text{j}0.09 & -\text{j}0.06 \\ \text{j}0.04 & -\text{j}0.06 & \text{j}0.04 \end{bmatrix}$$

$$Z_{bus} = \begin{bmatrix} \text{j}0.16 & \text{j}0.06 & \text{j}0.16 \\ \text{j}0.06 & \text{j}0.21 & \text{j}0.06 \\ \text{j}0.16 & \text{j}0.06 & \text{j}0.31 \end{bmatrix}$$

UNIT-II

PART-A

1. What is the need for slack bus (or Swing bus)in a power system?(or)What is the role of swing bus in the load flow study? (Nov/dec-2007,2008) (May/June-2013&May/Jun 2014,2018) (Nov/Dec 2016)

One of the generator buses is assumed as slack bus to generate the power for line losses which are estimated through the solution of load flow equations.

(Sum of complex power of generators)= (sum of complex power of loads) + (Total power loss in transmission lines)

Transmission line losses can be estimated only if the real and reactive powers of all buses are known. The powers in the buses will be known only after solving the load flow equations. For these reasons, the real and reactive power of one of the generator bus is not specified and this bus is called slack bus. it is assumed that the slack bus, the magnitude and phase of bus voltage are specified and real and reactive powers are obtained through the load flow solution.

2. What is a slack bus? Or What is swing bus?(May/Jun 2006,Apr/may-2008,2011)

This bus is called as swing bus. But if the magnitude and phase angle of the bus voltage are specified for the bus. The slack bus is the reference bus for the load flow solution and usually one of the generator bus is selected as the slack bus. This bus makes up the difference between the scheduled loads and generated power that are caused by the losses in the network.

3. What is meant by acceleration factor in gauss seidel load flow solution and its best value? (Apr/Jun 2008,May/June-2013,2018)

$\alpha \rightarrow$ known as acceleration factor and is a real number a suitable value of α for a particular system can be obtained by running trial load flows. $\alpha = 1.6$ is a general recommended value for most of the systems. However it may be noted that a wrong relation of α may result in slower convergence and sometimes even result in divergence from the solution. Acceleration factor can be used to improve the rate of convergence.

4. What is load flow analysis? Give the significance in power system analysis? (May/June-2009)

Load flow analysis is determination of the voltage, current, real power and reactive power at various points in electrical networks.

It is the backbone of power system analysis and design. They are necessary for planning, operation, economic scheduling and exchange of power between utilities. It also gives the alternative plans for system expansion to meet increased load demand.

5. Why is one of the buses taken as slack bus in power system? (May/June-2009)

The need to designate one of the buses as swing or slack buses is evident from the fact that the system power losses are not known initially. Therefore the net power into the system cannot be fixed in advance. It is a generator bus and it will supply the difference between the specified real power injected into the system at other buses and the total system output pulse losses.

6. State at best four applications of power flow studies in the planning and operations of electric power systems? (Nov/dec-2007)

* Economic scheduling.
* Exchange of power between utilizes
* Transient stability
* Contingency studies.

7. Compare Gauss seidel and N-R method?(or) Distinguish between the Newton Raphson and Gauss-Seidel methods of load flow analysis? (Apr/may-2010 & Apr/May 2015) (Apr/May 2017)

S.No	Gauss seidel	N-R
i	Computation time per iteration is less	Computation time per iteration is more
ii	The number of iteration required for convergence increase with size of the system	The number of iteration are independent of the size of the system
iii	It has linear convergence characteristics	It has linear quadratic characteristics

8. How the buses are classified in a power system? (or) What are the types of buses?(Nov/Dec-2010 & Nov/Dec 2011, 2017,MAY-2016)

Bus type	Qualities specified	Qualities to be obtained
Load bus (or) PQ bus	P, Q	$\|V\|,\delta$
Generator bus(or)PV bus	P, $\|V\|$	Q, δ
Slack bus (or)Swing bus	$\|V\|,\delta$	P, Q

9. What is Jacobian matrix? (NOV/DEC-2010, Nov/Dec 2016)**)**

Jacobian matrix is the matrix formed from the first derivations of load flow equations is called Jacobian Matrix and it is denoted by J.

In each iteration the elements of the Jacobian matrix are obtained by partially differentiating the load flow equations with respect to an unknown variable and then evaluating the first derivatives using the solution of previous iteration.

10. How the disadvantages of -NR method are overcome? (Nov/Dec-2010)

The solution involves the inversion of J_A & J_D matrices whose dimensions are approximately one fourth the full size Jacobian matrixes which saves 35-50% of storage when compared to original Newton method. It reduces the computation time for each iteration that is 10%-20% less than original Newton method.

11. Define Generator bus?(or) What is voltage controlled bus or PV bus?(Nov/Dec 2014)

A bus is called generator bus if the magnitude of voltage and real power (P) are specified for it. The load flow equation can be solved to find the reactive power and phase of bus voltage. In a voltage controlled bus the magnitude of the voltage is not allowed to change. The other names for generator bus are voltage controlled bus and PV bus.

12. What do you meant by a flat voltage start?

In iteration method of load flow solution the initial voltage of all buses except slack bus are assumed as 1+j0 p.u. This is referred to as flat voltage start.

13. What is PQ bus (or) Load bus?(Apr/May 2005)

A bus is called load bus or PQ bus when real and reactive components of power are specified for the bus. The load flow equations can be solved to find the magnitude and phase of bus voltage In a load bus the voltage is allowed to vary within permitted limits for example $\pm$5 %.

14. What is the iterative method mainly used for the solution of load low problems?

1. Gauss seidel (G.S) method.
2. Newton Rephson (N-R) method.
3. Fast Decoupled Power Flow method

15. When the generator bus is treated as load bus?(or)At what condition generator bus is treated as load bus (May/Jun 2014,Nov/Dec-2015)

If the iterated value of reactive power of a generator bus violates the specified reactive power limits then the generator bus is treated as load buses.

16. What is infinite bus?

A bus is called infinite bus if its voltage remains constant and does not altered by any changes in generator excitation.

17. What are the advantages and disadvantage of Gauss Seidal(GS) method?

Advantages

1. Calculations are simple and so the programming take is lesser.
2. The memory requirement is less.
3. Useful for small systems.

Disadvantage

1. Requires large number of iteration to reach convergence.
2. Not suitable for large systems.
3. Convergence time increases with size of the systems.

18. How a load flow study is performed?(Nov/Dec 2004)

1. Representation of the system by single line diagram.
2. Formulation of network equations.
3. Solution of network equations.

19. What are the advantages and disadvantages of NR method?

Advantages

1. The N-R method is faster more reliable and the results are accurate.
2. Requires less numbers of iterations for convergence.
3. Suitable for large size systems.

Disadvantages

1. The programming is more complex.
2. The memory requirement is more.

3. Computational time per iteration is higher due to large number of calculations per iteration.

20. Mention three advantages of NR method over G.S?(May/Jun 2012)

1. The N-R method has quadratic convergence characteristic and so converges faster than G-S method.
2. The number of iteration for convergence is independent of the size of the system in N-R method.
3. In N-R method the convergence is not affected by the choice of slack bus.

21. How the convergence of N-R method is speeded up?

The convergence can be speeded up in NR method by using fast Decoupled load flow (FDLF) algorithm. In FDLF method the weak coupling between P-δ and Q-V are decoupled and then the equations are further simplified equations are further simplified using the knowledge of practical operating conditions a power system.

22. What are the information that are obtained from a load flow study?

The information obtained from a load flow study are magnitude and phase of bus voltage, real and reactive power flowing in each line and the line losses. The load flow solution also gives the initial condition of the system when the transient behavior of the system is to be obtained.

23. What is the need for load flow study (Nov/Dec-2015,2017,May -2016)

The load flow study of a power system is essential to decide the best operation of existing system and for planning the future expansion of the system. It is also essential for designing a new power system.

24. What are the quantities that are associated with each bus in a system? (Apr/May 2017)

Each bus in power system is associated with four quantities and they are real power, reactive power, magnitude of voltage and phase angle of voltage.

25. What are the operating constraints imposed in the load flow studies?

The operating constraints imposed in the load flow studies are reactive power limits for generator buses and allowable change in magnitude of voltage for load buses.

26. Why do we go for iterative method to solve load flow problems?

The load flow equations are non-linear algebraic equation and so explicit solution is not possible. The solution of nonlinear equation can be obtained only by iterative numerical techniques.

27. What approximation is performed in Newton-Raphson method?

In Newton Raphson method, the set of non linear simultaneous (load flow) equation are approximated to a set of linear simultaneous equation using Taylor's series expansion and the terms are limited to first order approximation.

28. What is the need for voltage control in a power system?

The various components of a power system are designed to work satisfactorily at rated voltage. If the equipment are not operated at rated voltage then the performances of the equipment will be poor and the life of the equipment will reduces. Hence the voltage at various points in a power system should be maintained at rated value.

39. What is synchronous capacitor?

The synchronous capacitor is over excited synchronous motor running on load and connected to a power system for the purpose of supplying reactive power.

31. What is off-nominal transformer ratio? Draw the equivalent circuit transformer with off-nominal transformer ratio connected to a transmission line?

When the voltage or turns ratio of a transformer is not used to decide the ratio of base KV then its voltage or turns ratio is called off nominal turn's ratio.

32. Write the load flow equation of Gauss-seidel method?

The load flow equation of Gauss-Seidel Method:

$$V_P^{K+1} = \frac{1}{Y_{pp}}\left[\frac{P_p - jQ_p}{(V_P^K)^*} - \sum_{q=1}^{p-1} y_{pq}.V_q^{k+1} - \sum_{q=p+1}^{n} y_{pq}.V_q^k\right]$$

33. Write the load flow equation of Newton Raphson method?

$$\boldsymbol{P_p = \sum_{q=1}^{n} e_p(e_q G_{pq} + f_q B_{pq}) + f_p(f_q G_{pq} - e_q B_{pq})}$$

$$\boldsymbol{Q_p = \sum_{q=1}^{n} f_p(e_q G_{pq} + f_q B_{pq}) - e_p(f_q G_{pq} - e_q B_{pq})}$$

34. Mention the various method of voltage control employed in power system?

- Voltage control by adjusting the excitation of generators
- Voltage control using shunt capacitors
- Voltage control using series capacitors
- Voltage control by synchronous capacitors
- Voltage control by tap-changing transformer
- Voltage control by regulating and booster transformer

35. What is the drawback in series connected capacitor?

- High voltage produced under short circuit condition
- High voltage produce damage the capacitor
- Capacitor will protected using a spark gap with a high speed contactor.

36. What are the two types of tap changing transformer? What is the difference between them?

- Off-load tap changing transformer
- On-load tap changing transformer

Off-load tap changing transformer the load is disconnected before changing the tap settings whereas in on load tap changing transformer special circuits are provided to change the tap settings without interrupting the load currents.

37. Write the static load flow equation (SLFE)

The equations for real and reactive power injected to the bus are called Static Load Flow Equations (SLFE)

$$\text{Real power injected to bus} - \text{p} ; P_p = Re\left\{\sum_{q=1}^{n} Y_{pq}V_q\right\}$$

$$\text{Reactive power injected to bus} - \text{p} ; Q_p = Im\left\{V_p^*\sum_{q=1}^{n} Y_{pq}V_q\right\}$$

Where ”Re” and ”Im” stands for “Real” and “imaginary part”

38. What is power flow study or load flow study?(Nov/Dec 2014)

The study of various methods of solution to power system network is referred to as load flow study. The solution provides the voltage at various buses, power flowing in various lines and line losses

39. **Briefly explain the importance of power flow analysis. (Nov/Dec-2011)**

Power flow studies are conducted to investigate the following features of a power system network.

*Bus voltage profile to acceptable value and also system voltage profile.

*The effect of temporary loss of transmission capacity mainly for security studies.

*System loss minimization and improvement of voltage regulation.

*The effect of change in configuration & incorporating of new circuit of system loading.

*Economic system operation.

*Transient or dynamic stability analysis.

40. How the disadvantages of N-R method are overcome?

The disadvantages of large memory requirement can be overcome by decoupling the weak coupling between P-δ,Q-V,(Using decoupled load floe algorithm).

The disadvantage of large computational time per iteration can be reduced by simplifying the decoupled load flow equation. The simplifications are made based on the practical operating conditions of a power system.

PART-B

1. Explain the importance of power flow analysis in planning and operation of power system.

Importance of power flow analysisin planning & operation of power system:

Power flow studies help the planning and operation to meet contingency situations such as loss of large generating unit or a major line outage due to thermal overloading of line.

Power flow studies help to determine the best size and most favorable location for power capacitors for improving power factor as well as voltage profile of a system.

Online power flow studies are periodically executed for monitoring and controlling a power system.

Power flow computation used to determine reactive power compensation needed to establish bus voltages.

Used to establish the incremental transmission line loss associated with changing the output of generator that is useful in deciding optimal generation allocation to the generating stations so that cost of generation is minimal.

A power system study is a steady-state analysis of an interconnected power system during normal operating conditions (the power system operating under balanced conditions).

Generation and load demand at the buses has non linear.

Power demand at the bus is closely modelled by constant real and reactive power, so that terminal voltage increase, but current demand decreases this type of load is suitable for fixed power demand at a bus.

The generating plants normally operate at a regulated voltage level and fixed real power injection.

The voltage phase angle between generator of the system are not known, if a generator's reactive power output is within acceptable limits, it is predetermined to vary so as to match system demand.

Mathematical formulation of power flow problem known as load flow problem.

Power flow problem (Important aspects of power flow analysis):

Sum of real power injected at generating bus must equal at each instant of time, the sum of total system load demand plus system losses to achieve optimum economic operation, total generated power must be scheduled between the generators outputs must be closely maintained at the predetermined set points. As load demand slowly changes throughout the day. Therefore these set point change slowly with time. Load flow changes hour by hour per day.

Power transfer capability of a transmission line is limited to the thermal loading limit and stability limit. Transmission lines do not operate too close to their stability or thermal limits.

IT is necessary to keep the voltage level of certain buses within close tolerances. This can be achieved by proper scheduling of reactive power.

Power system must fulfill contractual scheduled interchange of power to neighboring system.

Power flow analyses are very important in the planning stages of new networks or additions to existing ones.

Power flow or load flow problem to split into following sub problems:

The formulation of a mathematical model that describe the relationships between voltages and powers in the interconnected system.

Specifications of power and voltage constrains that must apply to the various bus of the network.

Computation of voltage magnitude and phase angle of each node or bus in a power system under balanced three-phase, steady-state conditions. As an offshoot of this calculation, the real and reactive power flow in transmission line, transformer as well as equipment and system losses can be computed.

load flow studies will give:

- Magnitude & phase angle of voltage at each bus,

- P,Q flowing at each line,
- Initial conditions & transient behavior of system.

Load flow essential:

- To decide the best operation of existing system,
- Planning future expansion of system,
- Designing a new power system.

Load flow under balanced conditions:

- Single phase equivalent circuit of power system such as impedance diagram.

Requirement of load flow study:

- Representation of the system by single line diagram.
- Draw the impedance diagram using single line diagram.
- Formation of network equations
- Solution of network equations.

Steady state condition:

Network equation will be simple algebraic equation (generator & load continuously charging) but while calculating assume load &generator are fixed at particular value for a suitable period of time Eg:15 (or) 30 minutes.

Bus: Meeting points of various components.

Generator: Feed energy to bus.

Load: Draw energy from bus.

Power system network bus = node (so voltage can be specified for each bus).

Quantities of bus: P, Q, $|V|$, δ-Load flow problem, 2 quantities are specified for each bus and remaining two quantities obtained by solving load flow equations.

Types of bus:

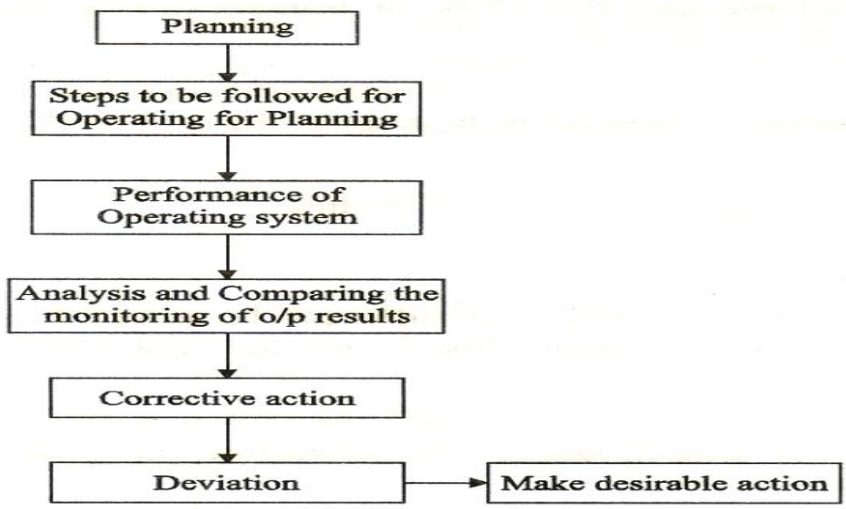
Load flow: P, Q (specified) --> $|V|$, δ--> voltage vary= $\pm$5%.

Generator bus, $|V|$ (specified) -->Q, δ --> Reactive power limit specified.

Slack bus: $|V|$, δ (specified) -->P, Q --> One of the generator bus selected as slack or reference bus.

Need for slack bus: Real &reactive power required for transmission

Block diagram of planning & operation of power systems:



2. Give the classification of various types of buses in a power system for load flow studies.

Buses in a system can be classified as: load bus or PQ bus, generator bus or PV bus and slack bus or swing bus.

Bus type	**Qualities specified**	**Qualities to be obtained**
Load bus (or) PQ bus	P, Q	$\lvert V\rvert,\delta$
Generator bus(or)PV bus	P, $\lvert V\rvert$	Q, δ
Slack bus (or)Swing bus	$\lvert V\rvert,\delta$	P, Q

Define Generator bus?(or) What is voltage controlled bus or PV bus?

A bus is called generator bus if the magnitude of voltage and real power (P) are specified for it. The load flow equation can be solved to find the reactive power and phase of bus voltage. In a voltage controlled bus the magnitude of the voltage is not allowed to change. The other names for generator bus are voltage controlled bus and PV bus.

What is PQ bus (or) Load bus?

A bus is called load bus or PQ bus when real and reactive components of power are specified for the bus. The load flow equations can be solved to find the magnitude and phase of bus voltage In a load bus the voltage is allowed to vary within permitted limits for example $\pm$5 %.

Slack bus or swing bus.

The need to designate one of the buses as swing or slack bus is evident from the fact that the system power loss are not known initially. Therefore, the net power flow into the system cannot be fixed in advance. The swing bus is a generator bus and generator at this bus supply the difference between the specified real powers injected in to the system at other buses and total system output plus losses. since voltage thought the system must be closed to 1pu, we generally specify the voltage at the swing bus equal to 1pu.from elementary AC theory we know that any one phasor can be selected as reference and voltage of swing bus as reference making its angle δ_I zero, the bus of largest generating station is selected as swing bus numbered as bus1

3. Load flow problem: Static load flow equation (SLFE)

Complex power injected by source in to i^{th} bus of a power system is

$$S_i = P_i + Q_i = V_i I_i^* : i = 1, 2 \dots\dots n$$

Take complex conjugate of above equation,

$$P_i - Q_i = V_I^* I_i ; i = 1,2, \dots\dots n$$

$$\text{Now } I_i = \frac{V_k}{Z_{ik}} = \sum_{k=1}^{n} Y_{ik} V_k$$

$$P_i - Q_i = V_I^* \left[\sum_{k=1}^{n} (Y_{ik} V_k) \right] ; i = 1,2 \dots . n$$

Equating real and imaginary parts

$$P_{i(\text{Real power})} = \text{Real}\left[V_I^*\left[\sum_{k=1}^{n}(Y_{ik}V_k)\right]\right]$$

$$Q_{i(\text{Reactive power})} = -\text{IM}\left[V_I^*\left[\sum_{k=1}^{n}(Y_{ik}V_k)\right]\right]$$

Now

$$V_i = |V_i|e^{j\delta i}$$

$$V_k = |V_k|e^{j\delta k}$$

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

$$P_{i(Real\,power)} = |V_i|\sum_{k=1}^{n}|V_K||Y_{IK}|\cos(\theta_{ik}+\delta_k-\delta_i)$$

$$P_{i(Reactive\ power)} = -|V_i|\sum_{k=1}^{n}|V_K||Y_{IK}|\,\text{Sin}(\theta_{ik}+\delta_k-\delta_i)\,;i=1,2\,\ldots n$$

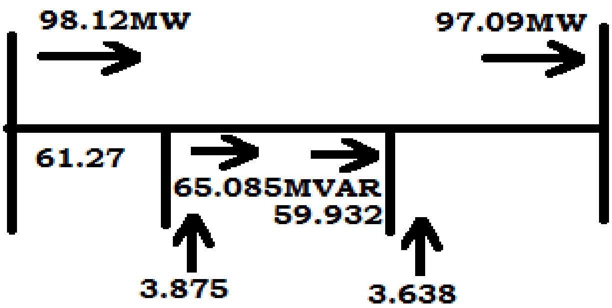
This is called power flow equation (or) static load flow equation [SLFE]

OPERATING CONSTRAINTS:

1. Voltage Magnitude$|V_i|$ Must Satisfy the Inequality$|V_i|_{min} \le |V_i| \le |V_i|_{max}$ power system equipment is designed to operate at fixed voltage with allowable variations of $\pm(5-10)\%$ of rated values.
2. Certain value of the$\delta_i(State\ variable)must satisfy\ |\delta_i-\delta_k| \le |\delta_i-\delta_k|$ $For\ stability\ of\ operation.$
3. $P_{Gi,min} \le P_{Gi} \le P_{Gi,max}$
   $Q_{Gi,min} \le Q_{Gi} \le Q_{Gi,max}$
   $\sum P_{Gi} = \sum P_{Di} + P_{Loss}$
   $\sum Q_{Gi} = \sum Q_{Di} + Q_{Loss}$

4.From the line flows shown in fig. calculate the current flowing in the equivalent circuit of line from bus 1 to bus 3.in 230KV system using calculated current and line parameters are R=0.00744, X=0.03720. calculate the line loss (I^2R) and compare this values with difference between the power in the line from bus 1.and power at bus 3.find I^2X in the line and compare with the values which could be found from the data given in fig. Assume base value 100MVA, 230KV.

Given Data:



$R = 0.0074, X = 0.03720$, Base Value $MVA_{Base} = 100, KV_{Base} = 230$

To Find:

1. I^2R Loss
2. I^2X Loss
3. Real power & *Reactive power at bus* 1 *and* 3

Formula used:

$$S = P + jQ$$

$$I = \frac{S}{\sqrt{3} \times KV}$$

Solution:

Total Megavolt ampere flow through R& X of all 3 phase is.

$$S = P + jQ \text{ at Bus 1}$$

$$= 98.12 + j65.085$$

$$= 117.74\angle 33.55 \text{ MVA}$$

$$S = P + jQ \text{ at Bus 3}$$

$$= 97.09 + j59.932$$

$$= 114.09\angle 31.69$$

NOW:

$$I = \frac{S}{\sqrt{3} \times KV}$$

$$I = \frac{117.74 \times 1000}{\sqrt{3} \times 230 \times 1.0} = 295.55A$$

$$I = \frac{114.09}{\sqrt{3} \times 230 \times 0.969} = 295.55A$$

The magnitude of current I in series $(R + jX)$ of line (1) and(3)

$$\text{Base impedance } Z_B = \frac{(KV)^2}{MVA}$$

$$= \frac{(230)^2}{100} = 529\Omega$$

Loss:

$$3I^2R = 3 \times (295.55)^2 \times 0.00744 \times 529$$

$$= 1.03MW$$

$$3I^2X = 3 \times (295.55)^2 \times 0.0372 \times 529$$

$$= 5.156MVAR.$$

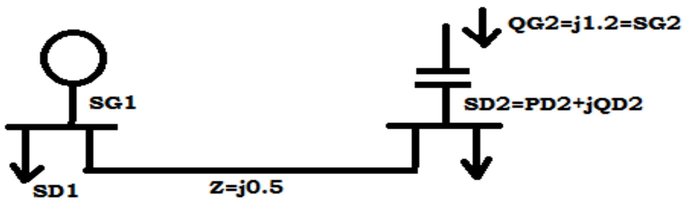
Conclusion: From diagram

Real power $P = 98.12 - 97.09 = 1.03MW$

Reactive power $Q = 65.085 - 59.932$ MVAR

5. In a given fig below bus 1 is reference bus with $V_1 = 1\angle 0$ and bus 2 is PQ bus (Load bus).Find complex power at bus 1 (S_1) voltage at Bus 2. (V_2)

Given Data:



complex power at bus 1 (S_1)
voltage at Bus 2. (V_2)

Formula used:

$$S = P + jQ$$

Solution:

Complex power injected at bus 2.

$$S_2 = S_{G2} - S_{D2}$$
$$= P_{G2} + jQ_{G2} - (P_{D2} - jQ_{D2})$$
$$= -P_{D2} + j0.2$$
$$P_S = \frac{|V|^2}{Z}\cos\theta - \frac{|V_S||V_R|}{Z}\cos(\theta + \delta)$$
$$Q_S = \frac{|V|^2}{Z}\sin\theta - \frac{|V_S||V_R|}{Z}\sin(\theta + \delta)$$
$$S_2 = S_{21} = \frac{|V|^2}{Z}\angle\theta - \frac{|V_2||V_1|}{Z}(\theta + \delta_2 - \delta_1)$$
$$Z = |Z|\angle\theta = 0.5\angle 90°$$

Now

$$-P_{D2} + j0.2 = j\frac{|V_2|^2}{Z} - \frac{|V_2|}{Z}\cos(\theta + \delta_2) - j\frac{|V_2|}{Z}\sin(\theta + \delta_2)$$

Equating real and imaginary parts:

REAL PART:

$$P_{D2} = \frac{V_2}{0.5}\cos(\theta + \delta_2)$$
$$= 2V_2\cos(\theta + \delta_2)$$
$$\cos(\theta + \delta_2) = \frac{P_{D2}}{2V_2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

IMAGENARY PART

$$0.2 = \frac{|V_2|^2}{Z} - \frac{|V_2|}{Z}\sin(\theta + \delta_2)$$
$$0.2 = 2V_2^2 - 2|V_2|\sin(\theta + \delta_2)$$
$$\frac{0.2 - 2V_2^2}{2|V_2|} = -\sin(\theta + \delta_2)$$
$$\sin(\theta + \delta_2) = \frac{V_2^2 - 0.1}{|V_2|} \ldots\ldots\ldots\ldots (2)$$

Squaring and adding equation (1)and(2)

$$\cos^2(\theta + \delta_2) + \sin^2(\theta + \delta_2) = \frac{P_{D2}^2}{4|V_2^2|} + \frac{(V_2^2 - 0.1)^2}{|V_2|^2}$$
$$1 = \frac{P_{D2}^2}{4|V_2^2|} + \frac{|V_2|^4 + 0.01 - 0.2V_2^2}{V_2^2}$$

$$1 = \frac{|V_2^2|P_{D2}^2 + 4|V_2|^6 + 0.04|V_2|^2 - 0.8|V_2|^4}{4|V_2|^4}$$

$$4|V_2|^4 = |V_2^2|P_{D2}^2 + 4|V_2|^6 + 0.04|V_2|^2 - 0.8|V_2|^4$$

$$4|V_2|^2 = P_{D2}^2 + 4|V_2|^4 + 0.04 - 0.8|V_2|^2$$

$$4|V_2|^2 + 0.8|V_2|^2 = P_{D2}^2 + 4|V_2|^4 + 0.04$$

$$4.8|V_2|^2 = P_{D2}^2 + 4|V_2|^4 + 0.04$$

$$4|V_2|^4 - 4.8|V_2|^2 + P_{D2}^2 + 0.04 = 0$$

$$|V_2|^2 = \frac{-b \mp \sqrt{b^2 - 4ac}}{2a}$$

$$|V_2|^2 = \frac{4.8 \mp \sqrt{(4.8)^2 - 4 \times 4(P_{D2}^2 + 0.04)}}{2 \times 4}$$

$$= \frac{4.8 \mp \sqrt{(4.8)^2 - 16(P_{D2}^2 + 0.04)}}{8}$$

$$i.e\ 16(P_{D2}^2 + 0.04) > (4.8)^2$$

$$16P_{D2}^2 + 16 \times 0.04 > (4.8)^2$$

$$16P_{D2}^2 + 0.64 > (4.8)^2$$

$$16P_{D2}^2 > (4.8)^2 - 0.64$$

$$P_{D2}^2 > 1.4$$

$$P_{D2}^2 \approx 1.183$$

$$|V_2|^2 = \frac{4.8 \mp \sqrt{(4.8)^2 - 4 \times 4((1.183)^2 + 0.04)}}{8}$$

$$|V_2|^2 = 0.6125$$

$$V_2 = 0.788\text{PU}$$

$$P_{D2} < 1.183, \textit{two solution not unique},$$

$$P_{D2} = 0.5, \text{than } |V_2| = 0.253 \text{and } 1.066\text{PU}$$

Angle δ_2

$$\cos(\theta + \delta_2)$$

$$\cos(90 + \delta_2) = -\sin\delta_2 = \frac{P_{D2}}{2|V_2|}$$

$$\sin\delta_2 = -\frac{P_{D2}}{2|V_2|} = \frac{0.5}{2 \times 1.066} = -0.2345$$

$$\delta_2 = \sin^{-1}(-0.2345)$$

$$\delta_2 = -13.56$$

$$S_1 = -S_2$$

$$= P_{D2} - j0.2$$

$$= 0.5 - j0.2 = 0.53\angle -21.8$$

6. Discuss in detail about gauss-seidal load flow analysis algorithm and give steps for its implementation when PV and PQ buses also present along with slack bus in the system.(Nov/Dec-2015,May/June-2016,Nov/Dec 2017)

Step by step procedure for G.S method

Step 1: assume a flat voltage profile 1+ j0 for all the bus except slack bus.

Step 2: assume a suitable value of convergence criterion.

Step 3: set iteration count K = 0, and assumed voltage profile of buses are $V_1^0, V_2^0, V_3^0, \ldots\ldots V_n^0$except slack bus.

Step 4: set bus count P =1.

Step 5: check for slack bus. If slack bus then goes to step .12 otherwise go to Next step.

Step 6: check for generator bus. If it is generator bus go to next otherwise go to Step 9.

Step 7: calculate reactive power of generator bus using

$Q^{K+1} = -I_m\{(V_P^K)\}\left[\sum_{Q=1}^{P-1} Y_{Pq}\, V_q^{k+1} + \sum_{q=p}^{n} \frac{1}{Pq} V_q^K\right]$

Calculated reactive power is specified limits then consider as Generator bus, then go to step 8.Calculated power is violate (not Specified limits) then treat the bus is load bus go to step 9.

$$\text{If } Q_{p.cal}^{k+1} < Q_P, min$$

$$Q_{p.cal}^{k+1} > Q_P, max$$

Step 8: generator bus the magnitude of voltage does not change bus voltage Can be calculated as

$V_p^{k+1} = \frac{1}{Y_{PP}}\left[\frac{P_P - jQ_P}{(V_P^K)} - \sum_{Q=1}^{P-1} Y_{Pq}\, V_q^{k+1} - \sum_{q=p+1}^{n} Y_{Pq}\, V_q^K\right]$

CalculatingV_p^{k+1}, for generator by go to step 11.

Step 9: for load bus. Calculate value of load bus voltage V_p^{k+1}

$V_p^{k+1} = \frac{1}{Y_{PP}}\left[\frac{P_P - jQ_P}{(V_P^K)} - \sum_{Q=1}^{P-1} Y_{Pq}\, V_q^{k+1} - \sum_{q=p+1}^{n} Y_{Pq}\, V_q^K\right]$

Step 10: an acceleration factor α can be used for faster convergence.

$$V_P^{k+1} = V_P^K + \alpha\left(V_P^{k+1} - V_P^K\right)$$

Step 11: calculate change in bus voltage using $\Delta V_P^{k+1} = V_P^{k+1} - V_P^K$

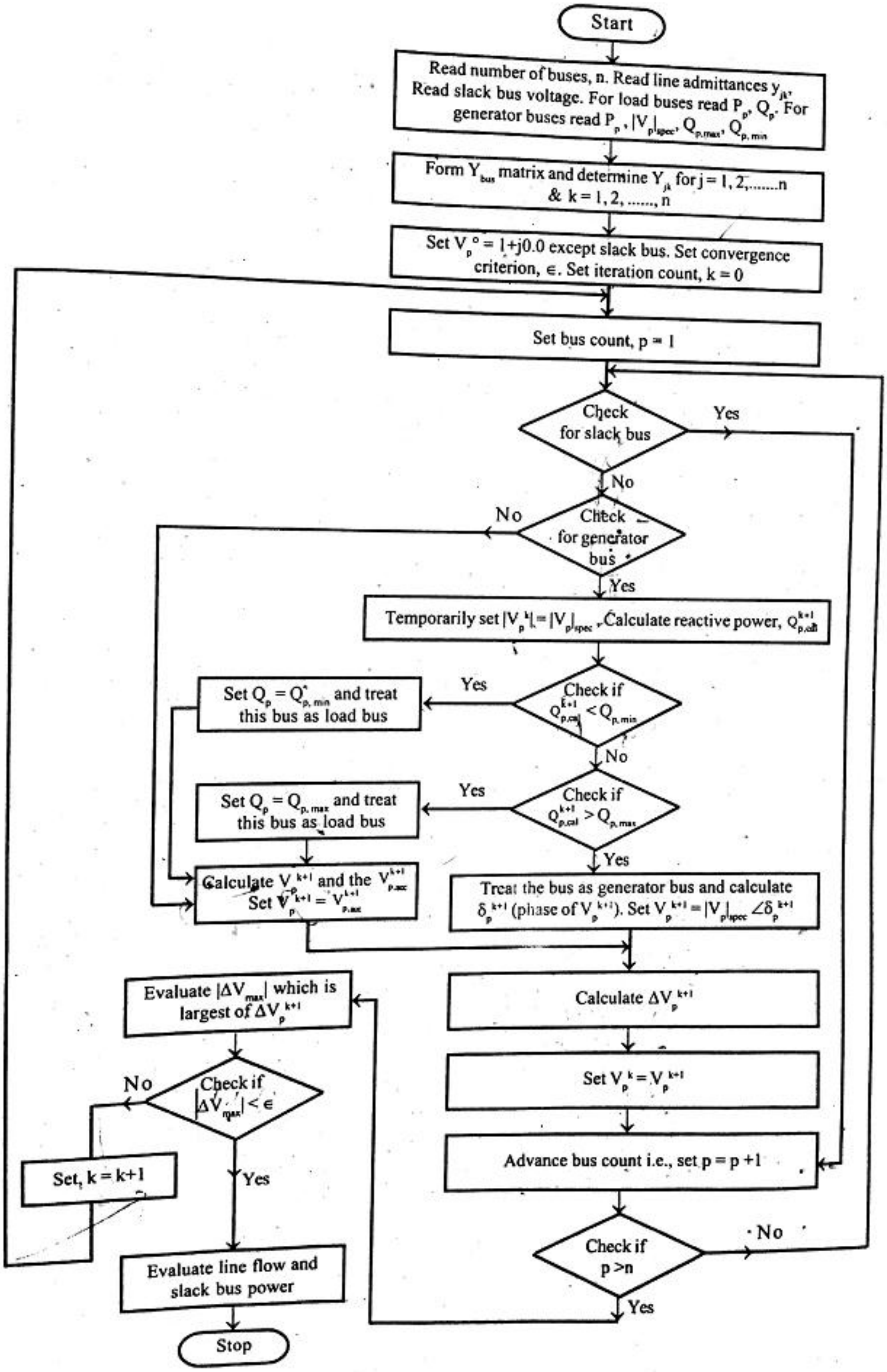
Step 12: repeat steps 5 to 11 until all bus voltage have been calculated. For Increment the bus counts by 1 and go to step 5. Until bus count n.

Step 13: find out largest value of change in voltage.

$|\Delta V_{max}|$ Is less than specified value move to next step. Otherwise

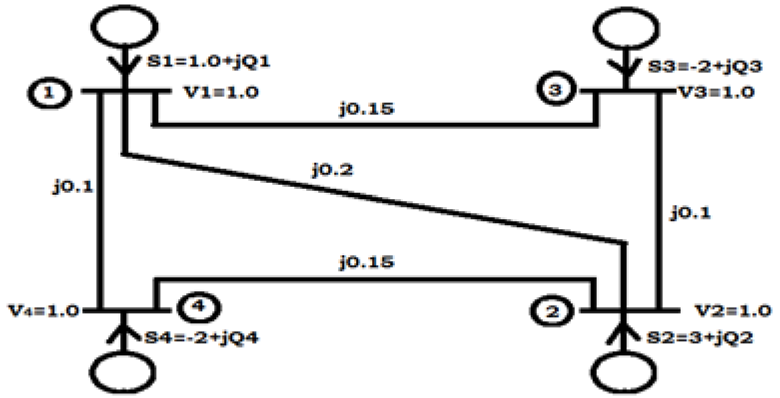
Increment the iteration count and go to step 4.

Step 14: calculate the line flows and slack bus power using bus (node) voltage.



Start
Read number of buses, n. Read line admittances y_jk, Read slack bus voltage. For load buses read P_p, Q_p. For generator buses read P_p, |V_p|_spec, Q_p,max, Q_p,min
Form Y_bus matrix and determine Y_jk for j = 1, 2,.......n & k = 1, 2, ..., n
Set V_p° = 1+j0.0 except slack bus. Set convergence criterion, ∈. Set iteration count, k = 0
Set bus count, p = 1
Check for slack bus
Yes
No
Check for generator bus
No
Yes
Temporarily set |V_p^k| = |V_p|_spec. Calculate reactive power, Q_p,cal^k+1
Check if Q_p,cal^k+1 < Q_p,min
Yes
Set Q_p = Q_p,min and treat this bus as load bus
No
Check if Q_p,cal^k+1 > Q_p,max
Yes
Set Q_p = Q_p,max and treat this bus as load bus
Yes
Calculate V_p^k+1 and the V_p,acc^k+1 Set V_p^k+1 = V_p,acc^k+1
Treat the bus as generator bus and calculate δ_p^k+1 (phase of V_p^k+1). Set V_p^k+1 = |V_p|_spec ∠δ_p^k+1
Calculate ΔV_p^k+1
Set V_p^k = V_p^k+1
Advance bus count i.e., set p = p +1
Check if p >n
No
Yes
Evaluate |ΔV_max| which is largest of ΔV_p^k+1
Check if |ΔV_max| < ∈
No
Set, k = k+1
Yes
Evaluate line flow and slack bus power
Stop

7.Consider the four – bus system, where line reactances are indicated in PU. Line resistances are negligible. The magnitudes of all bus voltages are specified to be 1.0 PU. The bus power specified below table. Calculate the real and reactive power flow on each line.



Bus	"P" Demand	"Q" Demand	P_{Gen}	Q_{Gen}
1	$P_{D1} = 1.0$	$Q_{D1} = 0.5$	$P_{G1} =?$	Q_{G1} $(unspecified)$
2	$P_{D2} = 1.0$	$Q_{D2} = 0.4$	$P_{G2} = 4.0$	Q_{G2} $(unspecified$
3	$P_{D3} = 2.0$	$Q_{D3} = 1.0$	$P_{G3} = 0.0$	Q_{G3} $(unspecified$
4	$P_{D4} = 2.0$	$Q_{D4} = 1.0$	$P_{G4} = 0.0$	Q_{G4} $(unspecified$

Solution:

Bus 3 and bus 4 have only Q sources.

System assumed loss less

Real power generation at bus 1 is $P_{G1} = P_{D1} + P_{D2} + P_{D3} + P_{D4} - P_{G2}$

$$P_{G1} = 1.0 + 1.0 + 2.0 + 2.0 - 4.0 = 2.0\ PU$$

To find: $\delta_2, \delta_2, \delta_3, Q_{G1}, Q_{G2}, Q_{G3}$ and Q_{G4}, $Real\ and\ Reactive\ Power$

CALCULATE Y BUS MATRIX:

$$Y_{BUS} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} Y_{14} \\ Y_{21} & Y_{22} & Y_{23} Y_{24} \\ Y_{31} & Y_{32} & Y_{33} Y_{34} \\ Y_{41} & Y_{42} & Y_{43} Y_{44} \end{bmatrix} = \begin{bmatrix} -21.667 & j5.000 & j6.667 & j10.000 \\ j5.000 & -j21.667 & j10.000 & j6.667 \\ j6.667 & j10.000 & j16.667 & j0.000 \\ j10.000 & j6.667 & j0.000 & -j16.667 \end{bmatrix}$$

Using Y_{BUS} Matrix Load Flow is expressed is

$$P_i = |V_i| \sum_{k=1}^{n} |V_K||Y_{ik}|(\delta_i - \delta_K), i = 2,3 \ldots..n\ [all\ the\ voltage\ magnitude\ 1\ PU]$$

$$P_2 = 3 = 5(\delta_2 - \delta_1) + 10(\delta_2 - \delta_3) + 6.667(\delta_2 - \delta_4)[Bus\ 1\ as\ reference\ \therefore\ \delta_1 = 0]$$

$$3 = 21.667\delta_2 - 10\delta_3 - 6.667\delta_4 -----(i)$$

$$P_3 = -2 = 6.667(\delta_3 - \delta_1) + 10(\delta_3 - \delta_2)$$

$$-2 = -10\delta_2 + 16.667\delta_3 -----(ii)$$

$$P_4 = -2 = 10(\delta_4 - \delta_1) + 6.667(\delta_4 - \delta_2)$$

$$-2 = -6.667\delta_2 + 16.667\delta_4 -----(iii)$$

$solving\ equation\ (i), (ii), (iii)$

$$\delta_2 = -0.077$$

$$\delta_3 = -0.074$$

$$\delta_4 = -0.089$$

Substituting values in the equation.

$$Q_i = -|V_i| \sum_{k=1}^{n} |V_K||Y_{ik}| cos\ (\delta_i - \delta_K) + |V_i|^2 |Y_{il}|, i = 1,2,3 \ldots..n$$

$Q_1 = -1.5\ COS\ (\delta_2 - \delta_1) - 6.667\ COS\ (\delta_3 - \delta_1) - 10\ COS(\delta_4 - \delta_1) + 21.667$
$\quad = -5\ COS\ (0.077 - 0) - 6.667\ COS(0.074 - 0) - 10\ COS(0.089 - 0) + 21.667$
$\quad = 0.07\ PU$
$Q_2 = -5\ COS\ (\delta_2 - \delta_1) - 10\ COS\ (\delta_2 - \delta_3) - 6.667\ COS\ (\delta_2 - \delta_4)$
$\quad = -5\ COS\ (0.077 + 0) - 10\ COS(0.077 + 0.074) - 6.667 COS(0.077 + 0.089) + 21.667$
$\quad = 0.22 PU$
$Q_3 = -6.667\ COS\ (\delta_3 - \delta_1) - 10\ COS\ (\delta_3 - \delta_2) + 16.667$
$\quad = -6.667\ COS\ (0.074 + 0 - 10)\ COS\ (0.074 + 0.077) + 16.667$
$\quad = 0.132\ PU$
$Q_4 = -10\ COS\ (\delta_4 - \delta_1) - 6.667\ COS\ (\delta_4 - \delta_2) + 16.667$
$\quad = -10\ COS\ (0.089) - 6.667\ COS\ (0.089 + 0.077) + 16.667$
$\quad = 0.132\ PU$

Reactive power generation at the four buses is:

$$Q_{G1} = Q_1 + Q_{D1} = 0.07 + 0.5 = 0.57\ PU$$
$$Q_{G2} = Q_2 + Q_{D2} = 0.22 + 0.4 = 0.62\ PU$$
$$Q_{G3} = Q_3 + Q_{D3} = 0.132 + 1.0 = 1.132\ PU$$
$$Q_{G4} = Q_4 + Q_{D4} = 0.07 + 0.5 = 1.132\ PU$$

Reactive line losses are:

$$Q_1 = \sum_{i=1}^{n} Q_{Gi} - \sum_{i=1}^{n} Q_{Di}$$

$sub\ n = 4, [Four\ Bus\ System]$

$$Q_L = \sum_{i=1}^{4} Q_{Gi} - \sum_{i=1}^{4} Q_{Di} \rightarrow 3.454 - 2.9 = 0.554\ PU$$

Power Flow (Line Flow):

$$P_S = \frac{|V_s|^2}{|Z|}\ COS\varphi - \frac{|V_S||V_R|}{|Z|}\ COS(\varphi + \delta)$$
$$P_R = \frac{|V_S||V_R|}{X} \sin\delta$$

$P_{CK}\ is\ real\ power\ flow\ from\ bus\ i\ to\ bus\ k$

$$P_{13} = -P_{31} = \frac{|V_1||V_3|}{0.15} \sin(\delta_1 - \delta_3) = 6.6667 \sin(0 + 0.074) = 0.492\ PU$$
$$P_{12} = -P_{21} = \frac{|V_1||V_2|}{X_{12}} \sin(\delta_1 - \delta_2) \rightarrow \frac{1}{0.2} \sin(0 - 0.077) = -0.385\ PU$$
$$P_{14} = -P_{41} = \frac{|V_1||V_4|}{X_{14}} \sin(\delta_1 - \delta_4) \rightarrow \frac{1}{0.1} \sin(0 + 0.089) = 0.888\ PU$$
$$P_{42} = -P_{24} = \frac{|V_4||V_2|}{X_{42}} \sin(\delta_4 - \delta_2) \rightarrow \frac{1}{0.15} \sin(0.089 + 0.077) = 1.10\ PU$$
$$P_{23} = -P_{32} = \frac{|V_2||V_3|}{X_{23}} \sin(\delta_2 - \delta_3) \rightarrow \frac{1}{0.1} \sin(0.077 + 0.074) = 1.50\ PU$$

REACTIVE POWER FLOW IN THE LINE IS:

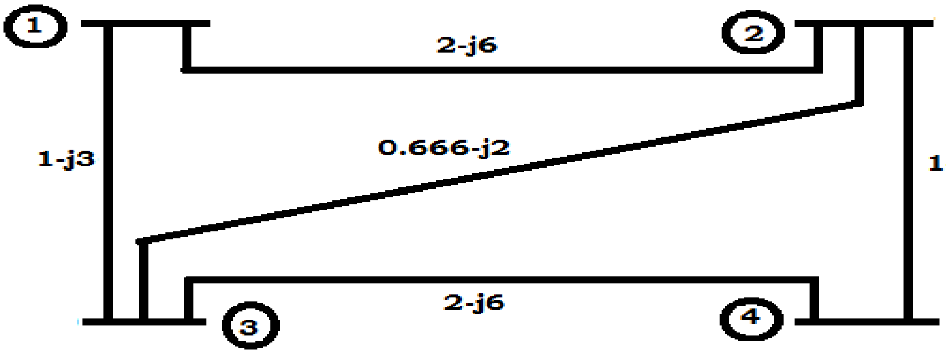
$$Q_S = \frac{|V_s|^2}{Z} \sin\varphi - \frac{|V_S||V_R|}{|Z|} \sin(\varphi + \delta);\ Q_{iK} = \frac{|V_i|^2}{X_{iK}} - \frac{|V_i||V_k|}{X_{iK}} \cos(\delta_i - \delta_K)$$
$$Q_R = \frac{|V_R|^2}{X} - \frac{|V_S||V_R|}{X} \cos\delta$$

$Q_{iK}\ is\ reactive\ power\ flow\ from\ bus\ i\ to\ bus\ K$

$$Q_{12}=Q_{21}=\frac{|V_1|^2}{X_{12}}-\frac{|V_1||V_2|}{X_{12}}\cos(\delta_1-\delta_2)\rightarrow\frac{1}{0.2}-\frac{1}{0.2}\cos(0+0.077)=0.015\ PU$$
$$Q_{13}=Q_{31}=\frac{|V_1|^2}{X_{13}}-\frac{|V_1||V_3|}{X_{13}}\cos(\delta_1-\delta_3)\rightarrow\frac{1}{0.15}-\frac{1}{0.15}\cos(0+0.074)=0.018\ PU$$
$$Q_{14}=Q_{41}=\frac{|V_1|^2}{X_{14}}-\frac{|V_1||V_4|}{X_{14}}\cos(\delta_1-\delta_4)\rightarrow\frac{1}{0.1}-\frac{1}{0.1}\cos(0+0.089)=0.04\ PU$$
$$Q_{42}=Q_{24}=\frac{|V_4|^2}{X_{42}}-\frac{|V_4||V_2|}{X_{42}}\cos(\delta_4-\delta_2)\rightarrow\frac{1}{0.15}-\frac{1}{0.15}\cos(0.089+0.077)=0.092\ PU$$
$$Q_{23}=Q_{32}=\frac{|V_2|^2}{X_{23}}-\frac{|V_2||V_3|}{X_{23}}\cos(\delta_2-\delta_3)\rightarrow\frac{1}{0.1}-\frac{1}{0.1}\cos(0.077+0.074)=0.1132\ PU$$

8.For the given system, the generators are connected at all the four buses, while loads are at bus 2 and 3. Values of real and reactive powers are given; all the buses other than slack bus are PQ type. Assume a flat voltage start; find the voltage and bus angle at the three buses at the end of first GS iteration.

Given data:



Bus	"P" PU	"Q" PU	"V" PU	REMARKS
1	–	–	1.04	Slack bus
2	0.5	−0.2	–	PQ Bus
3	−1.0	0.5	–	PQ Bus
4	0.3	−0.1	–	PQ Bus

To find:

Voltage and bus angle at all buses

Formula used:

$$V_2^1=\frac{1}{Y_{22}}\left[\frac{P_2-jQ_2}{(V_2^{\circ})}-Y_{21}V_1-Y_{23}V_3^{\circ}-Y_{24}V_4^{\circ}\right]$$
$$V_3^1=\frac{1}{Y_{33}}\left[\frac{P_3-jQ_3}{(V_3^{\circ})}-Y_{31}V_1-Y_{32}V_2^{'}-Y_{34}V_4^{\circ}\right]$$
$$V_4^1=\frac{1}{Y_{44}}\left[\frac{P_4-jQ_4}{(V_4^{\circ})}-Y_{41}V_1-Y_{42}V_2^{'}-Y_{43}V_3^{'}\right]$$

SOLUTION:

Calculate Y_{Bus} matrix of given system:

$$Y_{BUS} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} Y_{14} \\ Y_{21} & Y_{22} & Y_{23} Y_{24} \\ Y_{31} & Y_{32} & Y_{33} Y_{34} \\ Y_{41} & Y_{42} & Y_{43} Y_{44} \end{bmatrix} = \begin{bmatrix} 3-j9 & -2+j6 & 1-j3 & 0 \\ -2+j6 & 3.666-j11 & -0.666+j2 & -1+j3 \\ -1+j3 & -0.666+j2 & 3.666-j11 & -2+j6 \\ 0 & -1+j3 & -2+j6 & 3-j9 \end{bmatrix}$$

Bus voltages at the end of first iteration are:

$$V_2^1 = \frac{1}{Y_{22}}\left[\frac{P_2 - jQ_2}{(V_2^{\circ})} - Y_{21}V_1 - Y_{23}V_3^{\circ} - Y_{24}V_4^{\circ}\right]$$

$$= \frac{1}{Y_{22}}\left[\frac{0.5+j0.2}{1-j0} — 2 + j6\right)(1.04) — 0.666 + j2 — (-1+j3)\angle(1.019 + j0.046)$$

$$= \frac{4.246 - j11.04}{3.666 - j11} = 1.019 + j0.046 = V_2^1; 1.020\angle 0.045\ Rad$$

$$V_3^1 = \frac{1}{Y_{33}}\left[\frac{P_3 - jQ_3}{(V_3^{\circ})} - Y_{31}V_1 - Y_{32}V_2' - Y_{34}V_4^{\circ}\right]$$

$$= \frac{1}{Y_{33}}\left[\frac{-1.0+j0.5}{1-j0} - (-1+j3)(1.04) - (—0.666 + j2)(1.019 + j0.046) — (2+j6)\right)$$

$$= \frac{2.81 - j11.627}{3.666 - j11} = 1.028 - j0.087$$

$$= V_3^1;\ (1.028 - j0.087) = -0.084\ ; 1.031\angle -0.084\ Rad$$

$$V_4^1 = \frac{1}{Y_{44}}\left[\frac{P_4 - jQ_4}{(V_4^{\circ})} - Y_{41}V_1 - Y_{42}V_2' - Y_{43}V_3'\right]$$

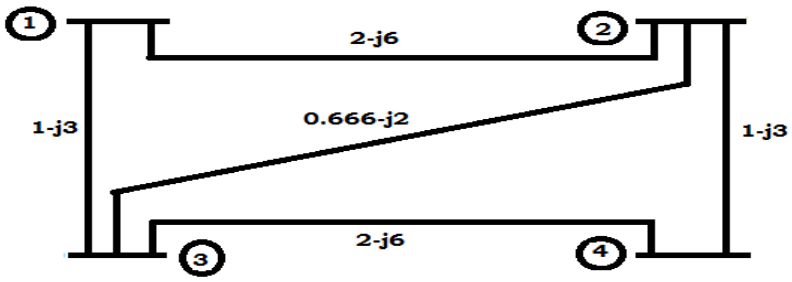
$$= \frac{1}{Y_{44}}\left[\frac{0.3+j0.1}{1-j0} - 0 - (-1+j3)(1.019 + j0.046) — 2 + j6\right)(1.028 - j0.087)$$

$$= \frac{2.991 - j9.253}{3\ - j9} = 1.025 - j0.0093 = 1.025\angle -0.0091\ Rad = V_4^1$$

Result:

$$V_2^1 = 1.019 + j0.046: 0.045\ Rad$$
$$V_3^1 = 1.028 - j0.087: -0.084\ Rad$$
$$V_4^1 = 1.025 - j0.0093: -0.0091\ Rad$$

9 . Given system shown in figure. Let bus 2 be a PV bus now with $|V_2| = 1.04\ PU$. Again a flat voltage start, find Q_2, δ_2, V_3, V_4 at the end of first GS iteration.(Nov/Dec 2017)



Given data:

Bus	"P" PU	"Q" PU	"V" PU	REMARKS
1	–	–	1.04	Slack bus
2	0.5	−0.2	–	PQ Bus
3	−1.0	0.5	–	PQ Bus
4	0.3	−0.1	–	PQ Bus

To find: Q_2, δ_2, V_3, V_4 *at the end of first iteration.*
Formula used:

$$Q_i^{(r+1)} = -lm\left\{V_i^{(r)} * \sum_{K=1}^{i-1} Y_{ik}V_K^{(r+1)} + V_i^{(r)} * \sum_{K=1}^{n} Y_{ik}V_K^{(r)}\right\} i = m+1, \dots n$$

$$\delta_i^{(r+1)} = \angle V_i^{(r+1)} = Angle\left[\frac{A_i^{(r+1)}}{\left(V_i^{(r)}\right)^*} - \sum_{K=1}^{i-1} B_{iK}V_K^{(r+1)} - \sum_{K=i+1}^{n} B_{iK}V_K^{(r)}\right]$$

$$Q_2^1 = -I_m\left[\left(V_2^{\circ}\right)Y_{21}V_1 + V_2^{\circ} * Y_{21}V_2^{\circ} + Y_{23}V_3^{\circ} + Y_{24}V_4^{\circ}\right]$$

$$\delta_2^1 = \angle\frac{1}{Y_{22}}\left[\frac{P_2 - jQ_2^1}{\left(V_2^{\circ}\right)} - Y_{21}V_1 - Y_{23}V_3^{\circ} - Y_{24}V_4^{\circ}\right]$$

Solution:

Note $\delta_2^{\circ} = 0$; $ie\ V_2^{\circ} = 1.04 + j0$; $V_3^{\circ} = 1$; $V_4^{\circ} = 1$

$$\delta_2^1 = -I_m[1.04(-2 + j6)1.04 + 1.04(3.66 - j11)1.04 + (-0.666 + j2) + (-1 + j3)]$$

$$= -I_m[0.0693 - j0.208] = j0.2097\ PU$$

$$\delta_2^1 = \angle\frac{1}{Y_{22}}\left[\frac{P_2 - jQ_2^1}{\left(V_2^{\circ}\right)} - Y_{21}V_1 - Y_{23}V_3^{\circ} - Y_{24}V_4^{\circ}\right]$$

$$= \angle\frac{1}{Y_{22}}\left[\frac{0.5 - j0.208}{1.04 - j0} - (2 + j6)\right)(1.04 + j0) - (-0.666 + j2)(1 + j0) - (-1 + j3)(1 + j0)$$

$$= \angle\frac{1}{Y_{22}}[4.2267 - j11.44]$$

$$= \angle\frac{4.2267 - j11.44}{3.666 - j11} = 1.0512 + j0.0339 = 0.032\ rad$$

$$V_2^1 = 1.04(\cos\delta_2^1 + j\sin\delta_2^1)$$

$$= 1.04(0.99948 + j0.0339)$$

$$V_2^1 = 1.03946 + j0.03327$$

$$Y_{BUS} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} & Y_{14} \\ Y_{21} & Y_{22} & Y_{23} & Y_{24} \\ Y_{31} & Y_{32} & Y_{33} & Y_{34} \\ Y_{41} & Y_{42} & Y_{43} & Y_{44} \end{bmatrix} = \begin{bmatrix} 3 - j9 & -2 + j6 & 1 - j3 & 0 \\ -2 + j6 & 3.666 - j11 & -0.666 + j2 & -1 + j3 \\ -1 + j3 & -0.666 + j2 & 3.666 - j11 & -2 + j6 \\ 0 & -1 + j3 & -2 + j6 & 3 - j9 \end{bmatrix}$$

$$Y_3^1 = \frac{1}{Y_{33}}\left[\frac{P_3 - jQ_3}{\left(V_3^{\circ}\right)} - Y_{31}V_1 - Y_{32}V_2^{\circ} - Y_{34}V_4^{\circ}\right]$$

$$= \frac{1}{Y_{33}}\left[\frac{-1 - j0.5}{1 - j0} - (-1 + j3)\right)1.04 - (-0.666 + j2)(1.0394 + j0.0332) - (-2 + j6)$$

$$= \frac{1}{Y_{33}}[2.7986 - j11.6766]$$

$$= \frac{2.7986 - j11.6766}{3.666 - j11} = 1.0317 - j0.08942 = V_3^1$$

$$Y_4^1 = \frac{1}{Y_{44}}\left[\frac{P_4 - jQ_4}{\left(V_4^{\circ}\right)} - Y_{41}V_1 - Y_{42}V_2^{\circ} - Y_{43}V_3^{\circ}\right]$$

$$= \frac{1}{Y_{44}}\left[\frac{0.3 + j0.1}{1 - j0} - 0 - (-1 + j3)\right)(1.0394 + j0.0332) - (-2 + j6)(1.0317 - j0.08942)$$

$$= \frac{1}{Y_{44}}[2.9658 - j9.3540] = \frac{2.9658 - j9.3540}{3 - j9}$$

$= 1.0342 - j0.01522 = V_4^1$

$Not\ Permissible\ limits\ on\ Q_2 (Reactive\ Power\ Injection)\ are\ revised.$

$0.25 \leq Q_2 \leq 1.0\ PU$

$Calculatd\ Value\ Q_2 = 0.208\ is\ less\ than\ Q_2 \min 0.2\ ;\ ie\ Q_2 = 0.25\ PU$

$\therefore\ Bus\ 2\ becomes\ PQ\ bus\ from\ PV\ bus.$

$|V_2| = 1.04\ ; \quad V_2^{\circ} = 1 + j0\ \ a\ flat\ start.$

$$V_2^1 = \frac{1}{Y_{22}}\left[\frac{P_2 - jQ_2}{(V_2^{\circ})^*} - Y_{21}V_1 - Y_{23}V_3^{\circ} - Y_{24}V_4^{\circ}\right]$$

$$= \frac{1}{Y_{22}}\left[\frac{0.5 - j0.25}{1 - j0} — (2 + j6)\right)(1.04) — (-0.666 + j2) — (-1 + j3)$$

$$= \frac{1}{Y_{22}}[4.246 - j11.49]$$

$$= \frac{4.246 - j11.49}{3.666 - j11}$$

$$= 1.0559 + j0.0341 = V_2^1$$

$$V_3^1 = \frac{1}{Y_{33}}\left[\frac{P_3 - jQ_3}{(V_3^{\circ})^*} - Y_{31}V_1 - Y_{32}V_2^{\circ} - Y_{34}V_4^{\circ}\right]$$

$$= \frac{1}{Y_{33}}\left[\frac{-1 - j0.5}{1 - j0} — (-1 + j3)\right)(1.04) — (-0.666 + j2)(1.0559 + j0.0341) — (2 + j6)$$

$$= \frac{1}{Y_{33}}[2.8114 - j11.709]$$

$$= \frac{2.8114 - j11.709}{3.666 - j11}$$

$$= 1.0347 - j0.08925 = V_3^1$$

$$V_4^1 = \frac{1}{Y_{44}}\left[\frac{P_4 - jQ_4}{(V_4^{\circ})^*} - Y_{41}V_1 - Y_{42}V_2^{\circ} - Y_{43}V_3^{\circ}\right]$$

$$= \frac{1}{Y_{44}}\left[\frac{0.3 + j0.1}{1 - j0} - 0 - (—1 + j3)\right)(1.0559 + j0.0341) — (-2 + j6)(1.0347 - j0.0893)$$

$$= \frac{1}{Y_{44}}[2.9868 - j9.405]$$

$$= \frac{2.9868 - j9.405}{3 - j9}$$

$$= 1.0401 - j0.0148 = V_4^1$$

Result:

$Q_2^1 = j\ 0.2097$

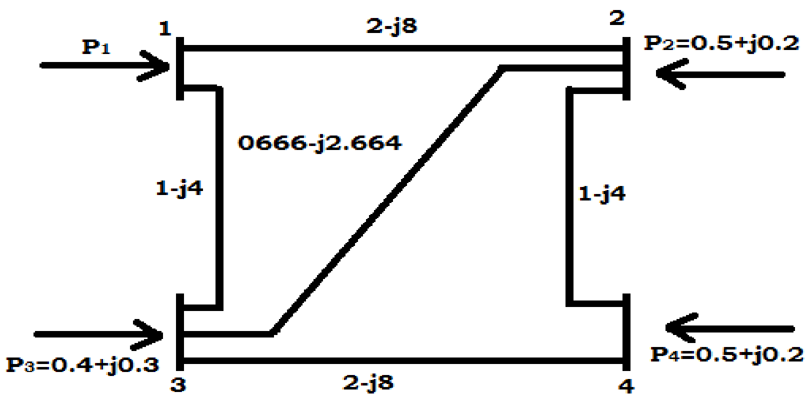
$\delta_2^1 = 0.032$

$V_2^1 = 1.0559 + j0.0341$

$V_3^1 = 1.0347 - j0.08925$

$V_4^1 = 1.0401 - j0.0148$

10. The system data for a load flow solution are given in tables2 and 3. Determine the voltages at the end of the first iteration using the Gauss-seidel method. Take $\alpha = 1.6$ (Nov/Dec-2015)



Line admittances

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

Real and reactive powers

Bus code	P in pu	Qin P.u	V in p.u	Remarks
1	-	-	1.06	slack
2	0.5	0.2	Not specified	PQ
3	0.4	0.3	Not specified	PQ
4	0.3	0.1	Not specified	PQ

Solution :

$\boldsymbol{Y_{11}} = \mathrm{Y}_{12} + \mathrm{Y}_{13} = (2 - \mathrm{j}8) + (1 - \mathrm{j}4) = 3 - \mathrm{j}12$

$\mathrm{Y}_{12} = \mathrm{Y}_{21} = -(2 - \mathrm{j}8) = -2 + \mathrm{j}8$

$\mathrm{Y}_{13} = \mathrm{Y}_{31} = -(1 - \mathrm{j}4) = -1 + \mathrm{j}4$

$\mathrm{Y}_{22} = \mathrm{Y}_{21} - \mathrm{Y}_{23} - \mathrm{Y}_{24} = (2 - \mathrm{j}8) - (0.666 - \mathrm{j}2.664) + (1 - \mathrm{j}4) = 3.666 - \mathrm{j}14.664$

$\mathrm{Y}_{23} = \mathrm{Y}_{32} = -\mathrm{Y}_{23} = -(0.666 - \mathrm{j}2.664) = -0.666 + \mathrm{j}2.664$

$\mathrm{Y}_{24} = \mathrm{Y}_{42} = -\mathrm{Y}_{24} == -(1 - \mathrm{j}4) = -1 + \mathrm{j}4$

$\mathrm{Y}_{33} = \mathrm{Y}_{31} = \mathrm{Y}_{32} = \mathrm{Y}_{34} = (1 - \mathrm{j}4) + (0.666 - \mathrm{j}2.664) + (2 - \mathrm{j}8) = 3.666 + \mathrm{j}14.664$

$\mathrm{Y}_{34} = \mathrm{Y}_{43} = -\mathrm{Y}_{34} = -(2 - \mathrm{j}8) = -2 + \mathrm{j}8$

$\mathrm{Y}_{44} = \mathrm{Y}_{42} + \mathrm{Y}_{43} = (1 - \mathrm{j}4) + (2 - \mathrm{j}8) = 3 - \mathrm{j}12$

$$Y_{BUS} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} Y_{14} \\ Y_{21} & Y_{22} & Y_{23} Y_{24} \\ Y_{31} & Y_{32} & Y_{33} Y_{34} \\ Y_{41} & Y_{42} & Y_{43} Y_{44} \end{bmatrix} = \begin{bmatrix} 3 - j12 & -2 + j8 & -1 + j4 & 0 \\ -2 + j8 & 3.666 - j14.664 & -0.666 + j2.664 & -1 + j4 \\ -1 + j4 & -0.666 + j2.664 & 3.666 - j14.664 & -2 + j8 \\ 0 & -1 + j4 & -2 + j8 & 3 - j12 \end{bmatrix}$$

At bus 2, $P_2 = P_{G2} - P_{D2} = 0 - 0.5 = -0.5 p.u$

$Q_2 = Q_{G2} - Q_{D2} = 0 - 0.2 = -0.2 p.u$

At bus 3, $P_3 = P_{G3} - P_{D3} = 0 - 0.4 = -0.4 p.u$

$Q_3 = Q_{G3} - Q_{D3} = 0 - 0.3 = -0.3 p.u$

At bus 4, $P_4 = P_{G4} - P_{D4} = 0 - 0.3 = -0.3 p.u$

$Q_4 = Q_{G4} - Q_{D4} = 0 - 0.1 = -0.1 p.u$

First iteration:

$$V_1^0 = V_1^1 = V_1^2 = V_1^3 = \cdots 1.06 - j0.0$$

Assume the flat start voltage for PQ buses

$$V_2^0 = 1\angle 0; V_3^0 = 1\angle 0; V_4^0 = 1\angle 0$$

The voltage at bus 2is

$$V_2^1 = \frac{1}{Y_{22}}\left[\frac{P_2 - jQ_2}{(V_2^0)} - Y_{21}V_1{}^1 - Y_{23}V_3^0 - Y_{24}V_4^0\right]$$

$$= \frac{1}{Y_{22}}\left[\frac{-0.5 + j0.2}{1 - j0} — 1.06(-2 + j8) — 1.0(-0.666 + j2.6664) — 1.0(-1 + j4)\right]$$

$$= \frac{1}{3.666 - j14.664}\left[\frac{-0.5 + j0.2}{1 - j0} — 1.06(-2 + j8) — 1.0(-0.666 + j2.6664) — 1.0(-1 + j4)\right]$$

$$V_2^1 = 1.01187 - j0.02888$$

$$\Delta V_2^1 = \quad V_2^1 - V_2^0 = 1.01187 - j0.02888 - (1 + j0) = 1.01187 - j0.02888$$

$$V_{2\,acc}^1 = V_2^0 + \alpha \quad \Delta V_2^1 = (1 + j0) + 1.6(0.01187 - j0.02888)$$

$$V_{2\,acc}^1 = 1.01896 - j0.04621$$

The voltage at bus 3is

$$V_3^1 = \frac{1}{Y_{33}}\left[\frac{P_3 - jQ_3}{(V_3^0)^*} - Y_{31}V_1^1 - Y_{32}V_2^1 - Y_{34}V_4^0\right]$$

$$= \frac{1}{3.666 - j14.664}\left[\frac{-0.4 - j0.3}{1 - j0} — (-1 + j4)\right)(1.06) — (-0.666 + j2.6664)(1.01187 - j0.0288) — (-2 + j8)(1)$$

$$V_3^1 \ = 0.9926 - j0.026$$

$$\Delta V_3^1 = \quad V_3^1 - V_3^0 = 0.9926 - j0.026 - (1 - j0) = -7.4 \times 10^{-3} - j0.026$$

$$V_{3\,acc}^1 = V_3^0 + \alpha \quad \Delta V_3^1 = (1 + j0) + 1.6 \times (-7.4 \times 10^{-3} - j0.026)$$

$$V_{3\,acc}^1 = 0.988 - j0.0416$$

The voltage at bus 4 is

$$V_4^1 = \frac{1}{Y_{44}}\left[\frac{P_4 - jQ_4}{(V_4^0)^*} - Y_{41}V_1^1 - Y_{42}V_2^1 - Y_{43}V_3^1\right]$$

$$= \frac{1}{3 - j12}\left[\frac{-0.3 + j0.1}{1 - j0} - 0(1.06)\right) - (-1 + j4)(1.01187 - j0.0288) — (-2 + j8)(0.988 - j0.0416)$$

$$= 0.9825 - j0.06$$

$$\Delta V_4^1 = \quad V_4^1 - V_4^0 = 0.9825 - j0.06 - (1 - j0) = -0.0175 - j0.06$$

$$V_{4\,acc}^1 = V_4^0 + \alpha \quad \Delta V_4^1 = (1 + j0) + 1.6 \times (-0.0175 - j0.06)$$

$$V_{4\,acc}^1 = 0.9721 - j0.096$$

Result:

The bus voltages at the end of first iteration are;

$$V_1^1 = 1.06 - j0.0$$

$$V_{2\,acc}^1 = 1.01896 - j0.04621$$

$$V_{3\,acc}^1 = 0.988 - j0.0416$$

$$V_{4\,acc}^1 = 0.9721 - j0.096$$

11. Develop an algorithm and draw the flow chart for solution of solution of load flow problem using N-R method.(Nov/Dec 2016,2017 ,Apr/May 2017)

Step 1: assume a flat voltage profile 1+ j0 for all buses (nodes).

Step 2: assume a suitable value of convergence criterion, the specified change in residue used to compare actual residue $(\Delta P, \Delta Q or \Delta V)$.

Step 3: set iteration count K = 0, assume voltage profile of buses are $V_1^0, V_2^0, V_3^0, \ldots\ldots V_n^0$except slack bus, real part e_P^0 , and Reactive part f_P^0

Step 4: set bus count p = 1

Step 5: check for slack bus. If slack bus then goes to step 13 otherwise go to next step.

Step6: calculate real and reactive power of bus, p

$$\boldsymbol{P_p = \sum_{q=1}^{n} e_p(e_q G_{pq} + f_q B_{pq}) + f_p(f_q G_{pq} - e_q B_{pq})} \quad \boldsymbol{Q_p = \sum_{q=1}^{n} f_p(e_q G_{pq} + f_q B_{pq}) - e_p(f_q G_{pq} - e_q B_{pq})}$$

Step7: calculate change in real power $\Delta_P^k = P_P - P_P^k$

Step8: check for generator bus. If generator bus go to step 9. If load bus go to step 12.

Step9: check reactive power limit of generator bus. If limit is violated go to step 11, otherwise go to next step.

Step 10: calculate reactive power is specified limit this bus generator bus. Now Calculate residue (change in voltage) $|DV_P^k|^2 = |V_P|^2 spec - |V_P^k|^2,$ Then go The step 13.

Step 11: if reactive power limit is violated, this bus load bus.

$Q_P^K < Q_P, min$ $\quad$ $Q_P^K > Q_P, max$

Step 12: change is reactive power for load bus. $\Delta Q_P^K = |Q_{Psec}|^{-Q_P^K}$

Step 13: repeat step 5 to 12 until all change in (P and Q (or) V) calculated for this increment the bus count by 1 and go to step 5.

Step 14: find largest of absolute value of residue $((\Delta P^k, SQ^k, \Delta P^k)^2$

Step15: compare $\Delta E, \Delta E < Convergeiterationgotostep$ 20.

$\Delta E > Convergeiterationgotonextstep.$

Step16: Determine element of Jacobian matrix$[J]$ by partially differentiating load flow equations.

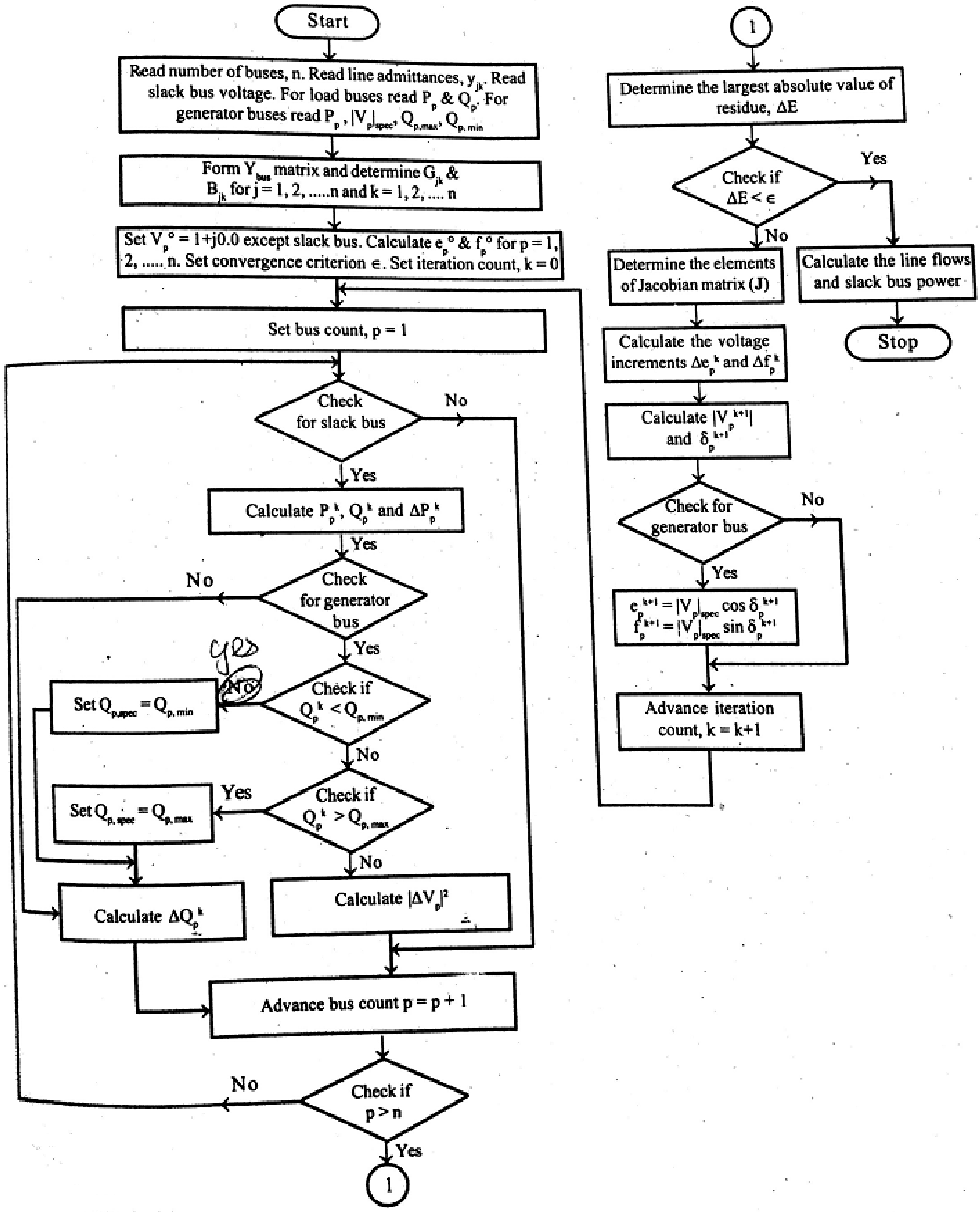
Step 17: calculate real and reactive part of voltage by solving matrix equation $[B] = [J][C]$.

step18: calculate new bus voltage$V^{(K+1)} = V^K + \Delta V^K$

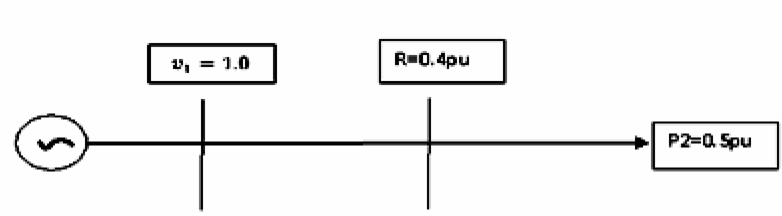
step19: Advance the iteration count i.e k=k+1 and go to step 14.

step20: Calculate line flow.

Flow chart



12.The resistance network shown, is supplying a load of 0.5 PU over a line with resistance 0.4 PU .if bus 1 is assumed to be a slack bus having a voltage of 1.0PU, using N.R iterative method, Determine,(Apr\May 2018)
(i)Voltage at load bus2,
(ii)current in line 1-2,
(iii)slack bus power,
(iv)power loss in the line.



Power at bus 2 in termes of voltage and resistance.

$$= \frac{V_2(V_1 - V_2)}{r}$$

$$= \frac{V_1V_2 - V_2^2}{0.4} = 0.5$$

$$V_1V_2 - V_2^2 = 0.2[single\ dimension\ non - linear\ function]$$

$$f(V) = V_2^2 - V_1V_2 + 0.2 = 0$$

$$f^{'}(V) = \frac{df(V)}{dV_2} = 2V_2 - V_1$$

Iterative formula

$$\Delta V_2^k = -\frac{fV^k}{\frac{df(V^k)}{dV_2}} = \frac{f(V^k)}{f'(V)} = \frac{V_2^2 - V_1V_2 + 0.2}{2V_2 - V_1}$$

$$V_2^{k+1} = V_2^k + \Delta V_2^k$$

Taking $V_1 = 1.0$,iterative formulaV_2 is assumed to 0.9(KVL)

K	V_2^k	$f(V) = V_2^2 - V_1V_2 + 0.2$	$\frac{df(V)}{dV_2}$	ΔV_2^k	$V_2^{k+1} = V_2^k + \Delta V_2^k$
0	0.9	0.1100	0.8000	-0.1375	0.7625
1	0.7625	0.0189	0.5250	-0.0360	0.7265
2	0.7265	0.0013	0.4530	-0.0029	0.7236
3	0.7236	-3.04×10^{-6}	0.4472	-6.7978×10^{-6}	0.7236

(i)Line current $= \frac{(V_1 - V_2)}{r} = \frac{(1.0 - 0.7236)}{0.4} = 0.691$ PU

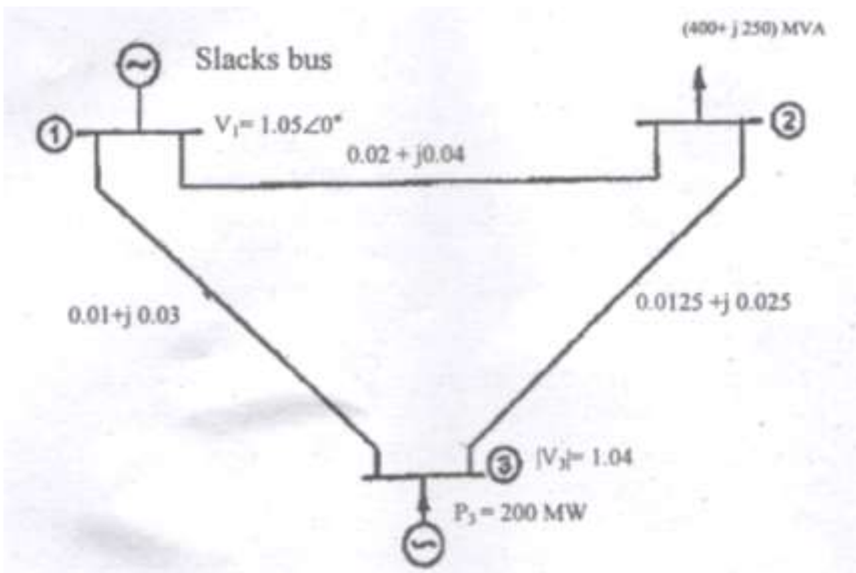
(ii)Slack bus power $= V_1 \times$ line current $= 0.691 \times 1 = 0.691$PU

(iii) power loss in the line = power at bus1 − power at bus2

$$= 0.691 - 0.5 = 0.191\text{PU}$$

13. Single line diagram of a simple power system, with generators at buses 1 and 3 is shown in Fig. The magnitude of voltage at bus 1 is 1.05 p.u. Voltage magnitude at bus 3 is fixed at 1.04p.u. with active power generation of 200MW. A load consisting of 400MW and 250 MVAR is taken from bus 2. Line impedances are marked in p.u. on a 100 MVA base and the line charging susceptances are neglected. Determine the voltage at buses 2 and 3 using Gauss-Seidal method at the end of first iteratin. Also calculate Slack bus power?(Apr/May 2017)

Solution:



The line admittances are

$$Y_{12} = \frac{1}{Z_{12}} = 10 - j20$$

$$y_{13} = 10 - j30 \; and y_{23} = 16 - j32$$

$$y_{Bus} = \begin{bmatrix} 20 - j50 & -10 + j20 & -10 + j30 \\ -10 + j20 & 36 - j52 & -16 + j32 \\ -10 + j30 & -16 + j32 & 26 - j62 \end{bmatrix}$$

$$S_2 = P_2 - jQ_2 = \frac{-(400 + j250)}{100} = -4 - j2.5 \, p.u.(\sin \; celoadbus \;)$$

$$P_3 \, 2.0 \, p.u.$$

Bus 1 is taken as a slack bus. Starting from an initial voltage of

$$V_2^0 = 1 + j \quad V_3^0 = 1.04 + j0$$

$$V_p^{k+1} = \frac{1}{Y_{pp}}\left[\frac{P_p - jQ_p}{\left(V_p^k\right)^*} - \sum_{q=1}^{p-1} Y_{pq}V_q^{k+1} - \sum_{q=p+1}^{n} Y_{pq}V_q^k\right]$$

$$V_2^1 = \frac{1}{Y_{22}}\left[\frac{P_2 - jQ_2}{\left(V_2^0\right)^*} - Y_{21}V_1^1 - Y_{23} - V_3^0\right]$$

$$= \frac{1}{32 - j52}\left[\frac{-4 - j2.5}{1 + j0} - (-10 + j20) \times 1.05 - (-16 + j32) \times 1.04\right]$$

$$= 0.97462 - j0.042307$$

Bus 3 is regulated bus where voltage magnitude and active power are specified. For a voltage control bus, first reactive power is

$$Q_3^1 = -\operatorname{Im}\left[\left(V_3^0\right)^*\left(Y_3V_1^1 + Y_{32}V_1^1 + Y_{33}V_3^0\right)\right]$$

$$= -\operatorname{Im}\left[\{1.04\,(-10 + j30) \times 1.05 + (-16 + j32) \times (0.97462 - j0.042307) + (26 - j62) \times 1.04\}\right]$$

$$= 1.16\ p.u$$

The value of Q_3^1 is used for the computation of voltage at bus 3.

$$V_3^1 = \frac{1}{Y_{33}}\left[\frac{P_3 - jQ_3}{\left(V_3^0\right)^*} - Y_{31}V_1^1 - Y_{32} - V_2^0\right]$$

$$= \frac{1}{26 - j62}\left[\frac{0.2 - j1.16}{1.04} - (-10 + j30) \times 1.05 - (-16 + j32)(0.97462 - j0.042307)\right]$$

$$= 1.03783 - j0.00517 = 1.03783 < -0.2854\ p.u$$

Since $\left|V_3\right|_{spec}$ is held constant at 1.04p.u. and δ_3 can obtain only

$$V_3^1 = 1.04 < -0.2854\ p.u$$

$$= 1.039987 - j0.00517\ p.u.$$

Slack bus power

$$S_p = P_p - jQ_p = V_p^0 \sum_{q=1}^{n} Y_{pq} V_q$$

$$S_1 = P_1 - jQ_1 = V_1^0 \left[Y_{11} V_1 + Y_{12} V_2 + Y_{13} V_3 \right]$$

$$= 1.05 \left[(20 - j50) \times 1.05 + (-10 + j20) \times \left[(0.97462 - j0.042307) + (-10 + j30)(1.030087 - j0.00517) \right] \right]$$

$$= 2.1842 + j1.4085 \ p.u$$

The complex power can be calculated as

$$S_{pq} = P_{pq} + jQ_{pq} = V_p I_{pq}^* = V_p (V_p^* - V_q^*) y_{pq}^*$$

$$S_{12} = V_1 (V_1^* - V_2^*) y_{12}^* = (167.97 + j113.88)\,MVA$$

$$S_{21} = V_2 (V_2^* - V_1^*) y_{21}^* = (-160.51 - j98.94)\,MVA$$

$$S_{13} = (26.8 + j26.11)\,MVA \qquad S_{31} = (-26.67 - j25.73)\,MVA$$

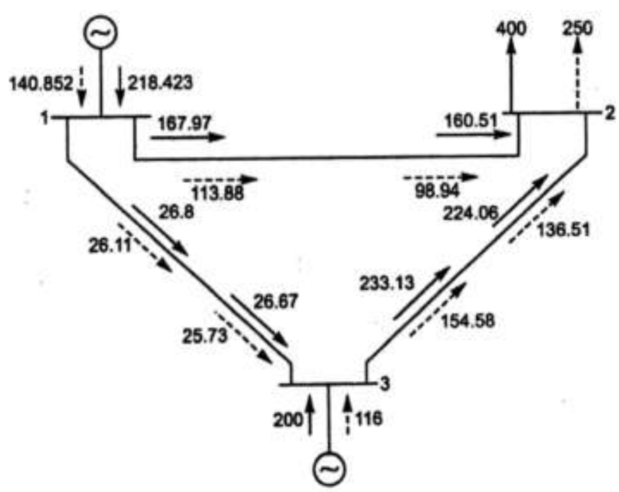
$$S_{23} = (-224.06 - j136.51)\,MVA \qquad S_{32} = (233.13 + j154.58)\,MVA$$

The line losses are

$$S_{losspq} = P_{losspq} + jQ_{losspq} = S_{pq} + Sqp$$

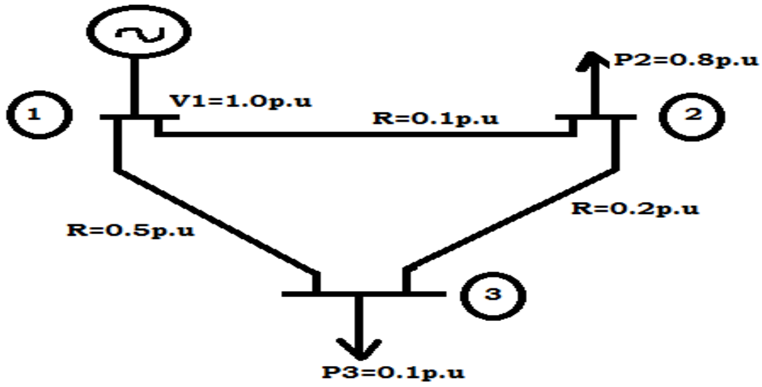
$$S_{loss\,12} = S_{12} + S_{21} = (7.47 + j14.94)\,MVA$$

$$S_{loss\,13} = (0.13 + j0.38)\,MVA \qquad S_{loss\,23} = (9.06 + j18.08)\,MVA$$



14.The three-bus power system network shown by using the G.S method (iterative) to compute (i) Bus voltage,(ii) Line currents,(iii)slack bus power (iv) total loss in the system. Assume bus 1 as slack bus with a voltage of 1.0PU.the parameters of the system in PU. (Apr/May 2017,2018)

Given Data:



To find:

$$V_2 = ?, V_3 = ?, slack\ power, Total\ loss$$

Formula used:

Form Jacobian matrix$V^{K+1} = V^K - [J^K]^{-1}[\Delta P_K]$

Solution:

$$Z_{Bus} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & Y_{23} \\ Y_{31} & Y_{32} & Y_{33} \end{bmatrix} = \begin{bmatrix} \frac{1}{0.5}+\frac{1}{0.1} & -\frac{1}{0.1} & -\frac{1}{0.5} \\ -\frac{1}{0.1} & \frac{1}{0.1}+\frac{1}{0.2} & -\frac{1}{0.2} \\ -\frac{1}{0.5} & -\frac{1}{0.2} & \frac{1}{0.2}+\frac{1}{0.5} \end{bmatrix} = \begin{bmatrix} 12 & -10 & -2 \\ -10 & 15 & -5 \\ -2 & -5 & 7 \end{bmatrix}$$

The power at bus 2 and bus 3 is

$$\begin{aligned} P_2 &= -10V_2V_1 + 15V_2V_2 - 5V_2V_3 \\ &= -10V_2V_1 + 15V_2^2 - 5V_2V_3 \\ P_3 &= -2V_1V_3 - 5V_2V_3 + 7V_3V_3 \\ &= -2V_1V_3 - 5V_2V_3 + 7V_3^2 \end{aligned}$$

Jacobian matrix:

$$[J^K] = \begin{bmatrix} \left(\frac{\partial P_2}{\partial V_2}\right)^K & \left(\frac{\partial P_2}{\partial V_3}\right)^K \\ \left(\frac{\partial P_3}{\partial V_2}\right)^K & \left(\frac{\partial P_3}{\partial V_3}\right)^K \end{bmatrix}$$

Assume $V_1 = V_2^0 = V_3^0 = 1.0PU$	K=0	K=1	K=2
$\frac{\partial P_2}{\partial V_2} = -10V_1 + 30V_2^K - 5V_3^K$	15	14.4450	14.429
$\frac{\partial P_2}{\partial V_3} = -5V_2^K$	-5	-4.8815	-4.878
$\frac{\partial P_3}{\partial V_2} = -5V_3^K$	-5	-4.8440	-4.839
$\frac{\partial P_3}{\partial V_3} = -2V_1 - 5V_2^K + 14V_3^K$	7	6.6817	6.6712
$\Delta P_2^K = P_2 = -10V_1V_2^K + 15[V_2^K]^2 - 5V_2^KV_3^K$	0.2	0.0052	0.0000
$\Delta P_3^K = P_3 = -2V_1V_3^K - 5V_2^KV_3^K + 7[V_3^K]^2$	0.1	0.0032	0.0000

Jacobian matrix:

$$V^{K+1} = V^K - [J^K]^T[\Delta P_K]$$

K = 0

$$J^0 = \begin{bmatrix} 15 & 5 \\ -5 & 7 \end{bmatrix}$$

$$[J^0]^T = \frac{1}{80}\begin{bmatrix} 7 & 5 \\ 5 & 15 \end{bmatrix} = \begin{bmatrix} 0.0875 & 0.0625 \\ 0.0625 & 01875 \end{bmatrix}$$

$$[J^0]^T[\Delta P_K] = \begin{bmatrix} 0.0875 & 0.0625 \\ 0.0625 & 0.1875 \end{bmatrix}\begin{bmatrix} 0.2 \\ 0.1 \end{bmatrix} = \begin{bmatrix} 0.02375 \\ 0.03125 \end{bmatrix}$$

$$V^0 - [J^0]^T[\Delta P_0] = \begin{bmatrix} 1.0 \\ 1.0 \end{bmatrix} - \begin{bmatrix} 0.02375 \\ 0.03125 \end{bmatrix}; \qquad \begin{bmatrix} V_2^1 \\ V_3^1 \end{bmatrix} = \begin{bmatrix} 0.9763 \\ 0.9688 \end{bmatrix}$$

K = 1

$$J^1 = \begin{bmatrix} 14.4450 & -4.8815 \\ -4.8440 & 6.6817 \end{bmatrix}$$

$$[J^1]^T = \frac{1}{72.87}\begin{bmatrix} 6.6817 & 4.8815 \\ 4.8440 & 14.4450 \end{bmatrix} = \begin{bmatrix} 0.09169 & 0.06699 \\ 0.06647 & 0.19823 \end{bmatrix}$$

$$[J^1]^T[\Delta P_1] = \begin{bmatrix} 0.09169 & 0.06699 \\ 0.06647 & 0.19823 \end{bmatrix}\begin{bmatrix} 0.0052 \\ 0.0032 \end{bmatrix} = \begin{bmatrix} 0.0007 \\ 0.0010 \end{bmatrix}$$

$$\begin{bmatrix} V_2^2 \\ V_3^2 \end{bmatrix} = V_2^1 - [J^1]^T[\Delta P_1]$$

$$\begin{bmatrix} V_2^2 \\ V_3^2 \end{bmatrix} = \begin{bmatrix} 0.9763 \\ 0.9688 \end{bmatrix} - \begin{bmatrix} 0.0007 \\ 0.0010 \end{bmatrix} = \begin{bmatrix} 0.9756 \\ 0.9678 \end{bmatrix}$$

K = 2

$$J^2 = \begin{bmatrix} 14.429 & -4.878 \\ -4.839 & 6.6712 \end{bmatrix}$$

$$[J^2]^T = \frac{1}{72.65}\begin{bmatrix} 6.6712 & 4.878 \\ 4.839 & 14.429 \end{bmatrix} = \begin{bmatrix} 0.09183 & 0.0671 \\ 0.0666 & 0.1986 \end{bmatrix}$$

$$[J^2]^T[\Delta P_2] = \begin{bmatrix} 0.09183 & 0.0671 \\ 0.0666 & 0.1986 \end{bmatrix}\begin{bmatrix} 0.0000 \\ 0.0000 \end{bmatrix} = \begin{bmatrix} 0.0000 \\ 0.0000 \end{bmatrix}$$

$$\begin{bmatrix} V_2^3 \\ V_3^3 \end{bmatrix} = V_2^2 - [J^2]^T[\Delta P_2]$$

$$= \begin{bmatrix} 0.9756 \\ 0.9678 \end{bmatrix} - \begin{bmatrix} 0.0000 \\ 0.0000 \end{bmatrix}$$

$$\begin{bmatrix} V_2^3 \\ V_3^3 \end{bmatrix} = \begin{bmatrix} 0.9756 \\ 0.9678 \end{bmatrix}$$

Line current (Line 1 − 2) $= \dfrac{V_1 - V_2}{r} = \dfrac{1.0 - 0.9756}{0.1} = 0.2440\ pu$

(Line 1 − 3) $= \dfrac{V_1 - V_3}{r} = \dfrac{1.0 - 0.9678}{0.5} = 0.0644\ pu$

(Line 2 − 3) $= \dfrac{V_2 - V_3}{r} = \dfrac{0.9756 - 0.9678}{0.2} = 0.039\ pu$

Slack bus power $= V_1 \times (Line\ current\ of\ line\ 1-2 + line 1-3)$

$$= 1 \times (0.2440 + 0.0644) = 0.3084$$

$Loss\ in\ the\ system = (slack\ bus\ power - system\ load)$

$$= 0.3084 - (0.2 + 0.1) = 0.0084 pu$$

UNIT-III

PART-A

1. **What is meant by a symmetrical fault ? (May/June-2016)(Nov/Dec 2017)**
   - A fault in a circuit is any failure which interferes with the normal flow of current. The faults are associated with abnormal change in current, voltage and frequency of the power system.
   - The faults may cause damage to the equipments if it is allowed to persist for a long time.
   - Hence every part of a system has been protected by means of relays and circuit breakers to sense the faults and to isolate the faulty part from the healthy part in the event of fault.
   - Fault involving all three phase.

2. Why faults occur in a power system? (Nov/Dec-2007,Nov/Dec-2015)

The fault occur in a power system due to:

- Insulation failure of the system.
- Flashover of lines initiated by a lightning stroke
- Permanent damage to conductors and towers.
- Accidental faulty operations
- Falling of free along a line.

3. How the circuit breaker can be selected? (Nov/Dec-2007)

The circuit breaker for a particular application in selected based on the follow ing ratings:

- Speed of circuit breaker.
- Normal working voltage.
- Momentary current rating.
- Normal working power level specified as rated interrupting current or rated interrupting kVA.

4. Define short circuit MVA? (Or) What is short circuit capacity (SCC)(or) What for short circuit capacity (SCC) should be known at any bus.Write down the expression for SCC. (Apr/May 2015) (Nov/Dec 2016)

- The short circuit capacity at a bus is a common measure of the strengt h of a bus.
- The short circuit capacity at bus k is defined at the product of the mag nitude of the sated bus
  Voltage and the fault current.
- The short circuit MVA is used for determining the dimension of a bus b ar and the interrupting capacity of a circuit breaker.

$$Short\ crcuit\ capacity\ given\ by\ SCC = |V| \times |I| \times MVA_B = \sqrt{3}|V||I|$$
$$= V_{prefault} \times I_{shortcircuit}$$

$V_{prefault}$ = Pre fault voltage.

$|I|_{SC}$ = Short circuit current.

MVA_b = Base MVA

5.Drew the zero sequence network of a star connection alternator with zero sequence impedance when the neutral is grounded though impedance Zn. (N ov/Dec-2007)

Zero sequence networks current causes zero sequence voltage drop only.
The grounding impedance is reflected to the zero sequence networks as **3Zn**.

6.What is advantages of building algorithm over other method of forming Z bus?

Any modification of the network does not require complete rebuilding of Z bus

- Easily computerized.
- Simplicity of the technique.
- Less computational time per iteration.

7. Explain the following terms:

i) momentary current. ii) Interruption current? (Nov/Dec-2009)

Momentary current:

The maximum current that may flow through a circuit breaker for a short durationits is the current that may flow during subtrascent period of fault condition.

Interruption current:

It's the current in the transient that flows at the time of circuit interrup tion. It's result in large value flowing during a fault and must be interrupted before the steady state condition are established.

8. The Zbus method is very suitable for fault studies on large system.why? (or) Why is bus impedance matrix preferred for fault analysis? (Nov/Dec-2009 & Apr/May 2015)

In Z bus method with the knowledge of the bus impedance matrix the fault cu rrent & bus voltage

during the fault are reading obtained for any faulted bus network.

- This method is very simple & practical.
- Thus all fault calculation is formulated in bus frame of reference using bus impedance matrix Z bus.

9. What are model used to represent generator in short circuit analysis? (Ap ril/May-2010)

- Zero sequence.
- Negative sequence.
- Positive sequence.

10. What is need for fault analysis in power system? (Nov/Dec-2010)

- To obtain the rating of the productive switches.
- To determine bus voltage and line current during various types of fault.
- To obtain proper relay setting & coordinators.
- The three phase balanced fault in formulae is used to select & set phas e relays.

11. List the symmetrical & unsymmetrical fault that occurs in a power syst em? (May/June-2012,Apr/May-2011)

Shunt fault:

- Three phase fault (LLLG fault)
- Line to ground fault (LG fault)
- Line to line fault (LL fault)
- Double line to ground fault (LLG fault)
- Shunt fault are characterized by increase in current & fall in voltage & f requency.

Series fault:

- Open circuit fault.
- Two open conductor fault.

12. Write symmetrical component of 3 phase system and advantages of symmetrical components?

Zero sequence components–It consists of three components is equal magnitude zero displacement each other by.
Negative sequence components.–It consists of three components is equal magnitude displacement each other by.
Positive sequence components.–It consists of three components is equal magnitude displacement each other by.

Advantages

- The unbalanced system of n related vector can be resolved into n system of balance vector.
- The positive sequence component consists three vectors in equal to magnitude displaced from
  Each other by 120° in phase as the original vector.
- Unsymmetrical fault analysis can be by using symmetrical components.

13.Name the two method of reducing short circuit current?(May/June-2012)

- By providing neutral reactance.
- By introducing a large value of shunt reactance between buses.

14. Write the relative frequency occurrence of various types of fault? (May/June-2014)

Type of faults	Relative frequency occurrence
3 phase fault	5%
Double line to ground fault	10%
Line to line fault	15%
Single line to ground fault	70%

15. What is meant by fault calculation?(Apr/May 2018)

The fault condition are power system can be divided into subtraction ,transient and steady state
period.

- The current in the various parts of the system & in the fault are deferent in three in three period.
- The estimation of these current for various types of fault at various location in the system are commonly referred to as fault calculation.

16. Define DC off set current?

The unidirectional transient of short circuit is called DC off set current.

17. What is meant by doubling effect?

In a symmetrical fault occurs when the voltage wave going though zero then the max momentary of short circuit current will be double the value of minimum symmetrical short circuit current. This effect is called doubling effect.

18.Difference between transient & sub transient reactance of a synchronous machine?

- The transient reactance is the ratio of induced emf and transient current.
- Sub transient reactance is the ratio of induced emf and sub transient current.

19. Why the circuit breaker interrupting current is asymmetrical?

- The interrupting current of circuit breaker is the sum of symmetrical short circuit current & dc off set current.
- The presence of DC offset current makes the intercepting current symmetric.

20.Determine the interrupting of 3 cycle circuit breaker employed in a gene rator rated at 20 MVA 33kV take. Take X'_d=25% , E_g=1 p.u

Solution

$$\text{Transient symmetrical rms current, } I' = \frac{Eg}{Xd'} = \frac{1}{jo.25} = -j4\text{p.u} = 4\angle -90° \text{ p.u}$$

$$interrupting\ current\ in\ p.u = 1.2 \times |I'| = 1.2 \times 4 = 4.8\ p.u$$

(i.e, for 3-cycles breaker the multiplication factor is 1.2)

$$\text{Base current, } I_B = \frac{\text{kVAb}}{\sqrt{3}\ KVb} = \frac{20\times10^3}{\sqrt{3}\times33} = 350$$

$$\text{Interrupting current in KA} = (4.8 \times 350)/1000 = 1.68 \text{ KA}$$

21. Distinguish symmetrical and unsymmetrical faults? (May/June-2013)

Symmetrical Fault:

- The phase current and phase voltage are equal.(i.e.) equal magnitude & equal phase shift (120°).
- 5% of the fault in any 1Φ or 3Φ.

Unsymmetrical faults:

- The phase current and phase voltage are unequal.
- 70% to 80% of the fault in 3Φ causes imbalances between the phases.

22. What are the characteristic of shunt and series fault?(Nov/Dec-2013)

- Shunt fault will decrease the voltage and frequency but increase the cu rrent flow
- Series fault will increase the voltage and frequency but decrease the cur rent flow.

23. Define bolted fault or solid fault. (May/June 2014 ,may 2016)(Nov/Dec 2017)

A fault represents a structural network change equivalent with that caused by the addition of impedance at the place of fault. If the fault impedance is zero, then the fault is referred as bolted or solid fault.

24. What is synchronous reactance?

The synchronous reactance is the ratio of induced emf and the steady state rms current (i.e it is the reactance of a synchronous machine under steady state condition). It is the sum of leakage reactance and the reactance representing armature reaction.

25. Write the equation to find the subtransient current?

$$|I''| = \frac{|Eg|}{Xd''}$$

| I” | = Subtransient symmetrical fault current.

| E_g | = RMS voltage from one terminal to neutral at no load.

X_d'' = Direct axis subtransient reactance.

26. Given one application of subtransient reactance?

Subtransient reactance of generators and motors are used to determine the initial current flowing on the occurrence of the short circuits.

27. Write the equation to determine subtransient internal voltage of the generator?

$$Eg'' = Vt + jI_L X_d''$$

E_g'' = Subtransient internal voltage.

I_L = Load current.

V_t = Terminal voltage.

X_d'' = Direct axis subtransient reactance.

28. Write the equation to determine transient internal voltage of the generator?

$$Eg' = Vt + jI_L X_d''$$

Eg' = Transient internal voltage.
I_L = Load current.
V_t = Terminal voltage.
X_d' = Direct axis transient reactance.

29. Write the equation for subtransient internal voltage and transient internal voltage of the motor.

$$Em'' = Vt - jI_L X_d''$$
$$Em' = Vt - jI_L X_d'$$

E_g'' = Subtransient internal voltage.
I_L = Load current.
V_t = Terminal voltage.
X_d'' = Direct axis subtransient reactance.
Eg' = Transient internal voltage.
X_d' = Direct axis transient reactance .

30. A motor is drawing 10,000 kw at 0.85 pf leading and a terminal voltage of 12 kv. Determine the load current.

Load current, $I_L = \frac{10,000}{\sqrt{3} \times 0.85 \times 12} \angle \cos^{-1} 0.85 = 566\angle 31.8^\circ$ amps

31. The thevenin's impedance and voltage at a fault is 0.576∠ 84° pu and 1∠ 0° pu respectively. Determine the short circuit MVA for a base of 30 MVA, 11 Kv.

Solution

Fault current in pu, If $= \frac{Vth}{Zth} = \frac{1\angle 0^\circ}{0.576\angle 84^\circ} = 1.736\angle -84^\circ$ pu.

Base current, Ib $= \frac{KVAb}{\sqrt{3}\, kVb} = \frac{30 \times 1000}{\sqrt{3} \times 11} = 1574.6$ A

Line value of the magnitude of fault current in amperes

$= |\ I_{FL}\ | = |\ I_{FL}$ in p.u. $| \times I_b = 1.736 \times 1574.6 = 2733.5$A= 2.7335 kA.

Short circuit MVA $= \sqrt{3} \times |\ VpfL\ | \times |\ IfL\ | = \sqrt{3} \times 11 \times 2.7335 = 52.08$ MVA.

32. The generator emf is 1p.u. and the subtransient reactance is 20% . Find the subtransient current.

Solution

Given that

$E_g = 1$ p.u
$X_d'' = j0.2$

Subtransient current I'' $= \frac{Eg}{Xd''} = \frac{1}{j0.2} = -j5 p.u = 5\angle -90^\circ p.u.$

33. Generator emf is 1 p.u and the transient reactance is 25%. Find the transient current.

SolutionGiven that

$E_g = 1$ p.u
$X_d' = j0.25$

Transient current I' $= \frac{E_g}{X'_d} = \frac{1}{j0.25} = -j4$ p.u. $= 4\angle -90^\circ$ p.u.

34. E_g = 1 p.u and X_d = 40%. Find the short circuit current.

Solution Short circuit current I $= \frac{E_g}{X_d} = \frac{1}{j0.4} = -j2.5$ p.u. $= 2.5\angle -90^\circ p.u.$

35. Find the momentary current through the circuit breaker if the initial symmetrical short circuit current through it is 5270.9A

SolutionThe momentary current = 1.6 × Initial symmetrical short circuit current

= 1.6 × 5270.9 A = 8433.44 A

= 8.433 kA

36.What is the significance of sub transient reactance and transient reactance in short circuit studies?(Apr/May 2017)

The sub transient reactance can be used to estimate the initial value of fault current immediately on the occurrence of the fault. The maximum momentary short circuit current rating of the circuit breaker used for protection or fault clearing should be less than this initial fault current.

The transient reactance is used to estimate the transient state fault current. Most of the circuit breakers open their contacts only during this period. Therefore for a circuit breaker used for fault clearing, its interrupting short circuit current rating should be less than the transient fault current.

37.what is direct axis reactance?(Nov/Dec-2015)

Under steady state three phase short circuit conditions, the armature reaction of an alternator produces a demagnetizing flux. This effect is represented as a reactance called armature reaction X_a.the combined armature reaction X_a and leakage reactanceX_l is called synchronous reactance $X_s$in case salient pole alternator the synchronous reactance is called direct axis reactanceX_d.

38. What is the need for short circuit study?(Nov/Dec 2016)

The short circuit studies are essential in order to design or develop the protective schemes for various parts of the system. The protective schemes consists of current & voltage sensing devices, protective relays and circuit breakers. The selection of these devices mainly depends on various currents that may flow in the fault conditions.

39.How the shunt and series fault are classified?(Nov/Dec 2016)

In one method of classification, the faults are classified series and shunt faults. The shunt faults are due to short circuits in conductors and the series faults are due to open conductors.

In another method of classification the faults are classified into symmetrical and unsymmetrical faults. In symmetrical faults the fault currents are equal in all the phases and can be analysed on per phase basis. In unsymmetrical faults the fault currents are unbalanced and so they can be analysed only using symmetrical components.

40. For a fault at a given location, rank the various faults in the order of severity?

(Apr/May 2017)

In a power system relatively the most severe fault is three phase fault and less severe fault is open conductor fault.

- 3-phase fault
- Double line to ground fault
- Line to line fault
- Single line to ground fault
- Open conductor fault.

41. What are all the assumption to be made to simplify the short circuit study? (Apr/May 2018)

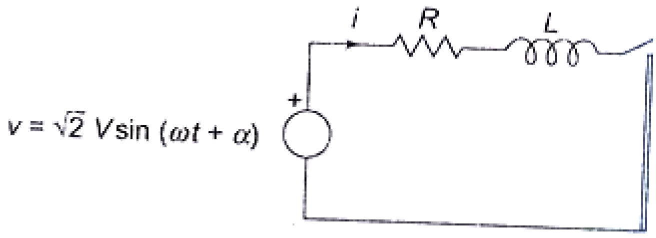
All line capacitances are ignored
All non-motor shunt impedances are ignored , motor loads are treated the same way as generators
The voltage magnitude and phase angle of generators and in feeds are all set to the same value.

PART-B

1. Explain the Transient analysis of a transmission line:

Assumptions made by transient on a transmission line:

- Line fed from a constant voltage source.
- Short circuit takes place when the line is unloaded.
- Line capacitance is negligible and line can be represented by a lumped RL Series circuit.



The short circuit takes place at t = 0,

$\alpha \rightarrow$ Control the instant on voltage wave when short circuit occurs.

$$Apply\ KVL: Ri + L\frac{di}{dt} = V$$

$$\frac{di}{dt} + \frac{R}{L}i = \frac{V}{L}$$

$$\left(\frac{d}{dt} + \frac{R}{L}\right)i = \frac{V}{L}$$

$\left(\frac{d}{dt}+\frac{R}{L}\right) i = \frac{V}{L}$ Is a non-homogeneous differential equation, forced response is obtained from its solution.

The solution is given by

$$i = i_s + i_t$$

$$i_s = steady\ state\ current$$

$$= \frac{\sqrt{2}V}{|Z|} sin(\omega t + \alpha - \theta)$$

$$Z = \sqrt{R^2 + \omega^2 L^2} < \theta = \tan^{-1}(\omega L/R)$$

$$i_t = \text{transient current}$$

$$i(0) = i_s(0) + i_t(0) = 0$$

Time constant of RL circuit is $(\frac{L}{R})$

$$i_t = -i_s(0)e^{-\left(\frac{R}{L}\right)t}$$

$$I_t = \frac{\sqrt{2}V}{|Z|}\sin(\theta - \alpha)\, e^{-\left(\frac{R}{L}\right)t}$$

Short circuit current is

$$I_t = \frac{\sqrt{2}V}{|Z|} sin(\omega t + \alpha - \theta) + \frac{\sqrt{2}V}{|Z|}\sin(\theta - \alpha)\, e^{-\left(\frac{R}{L}\right)t}$$

$$symmetrical\ short\ ckt\ current\ +\ \ DC\ off-set\ current$$

- Sinusoidal steady state current is called symmetrical short circuit current.
- Unidirectional transient component called DC off set current.
- Which causes the total short circuit current to be unsymmetrical till transient decays.
- Maximum momentary short circuit current

$$i_{mm}(short\ circuit\ time\ neglected)$$

$$i_{mm} = \frac{\sqrt{2}V}{|Z|} sin(\theta - \alpha) + \frac{\sqrt{2}V}{|Z|}$$

Since transmission line resistance is small, $\theta = 90^{\circ}$

$$i_{mm} = \frac{\sqrt{2}V}{|Z|}\cos\alpha + \frac{\sqrt{2}V}{|Z|}$$

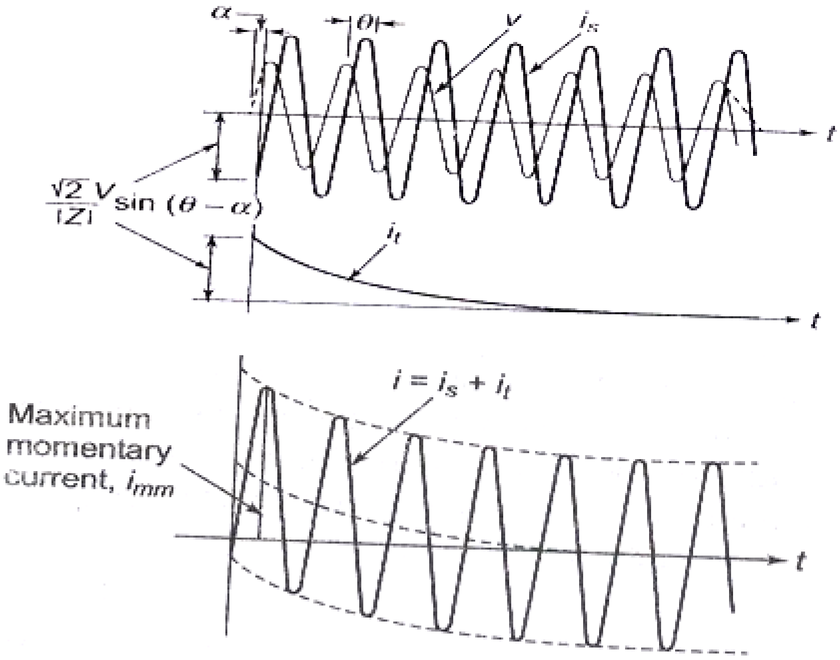
Maximum possible value for $\alpha = 0$,

Short circuit occurring when the voltage wave is going through zero.

$$i_{mm(\max possible)} = \frac{2\sqrt{2}V}{|Z|}$$

= twice the maximum of symmetrical short circuit current (doubling effect)

Selection of CB. Momentary short circuit current is taken corresponding maximum possible value.



What is the current to be interrupted in CB?

Symmetrical short circuit current is interrupted in CB.

2. SHORT CIRCUIT OF NO LOADED SYNCHRONOUS MACHINE.

No load short circuit conditions.

$$X_a = \text{Armature reactance}$$
$$X_L = \text{Leakage reactance}$$
$$X_d = \text{synchronous reactance(direct axis)}$$

SUDDEN SHORT CIRCUIT THREE PHASE

Synchronous generator initially operating under open circuit conditions, machine undergoes transient in all three phase DC off-set current appear in all three phase, each with different magnitude, short circuit occurs at difference phase.

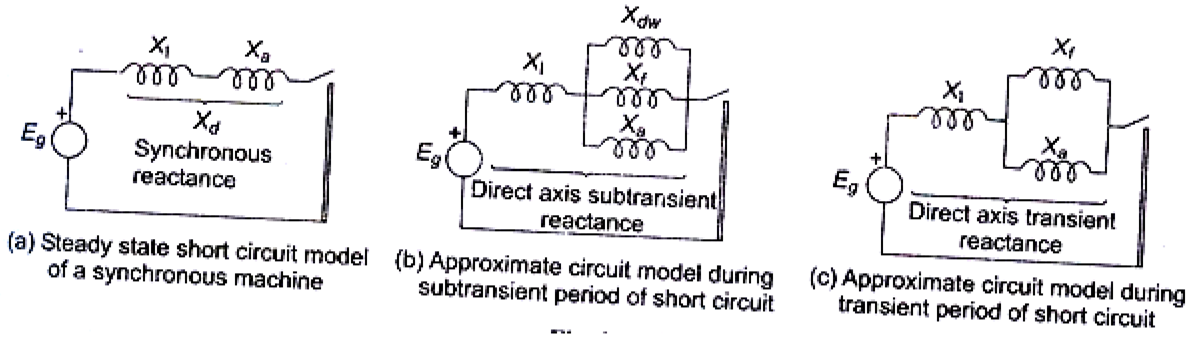
Short circuit studies need to concentrate symmetrical short circuit current symmetrical short circuit current is limited only by leakage reactance of machine (constant flux linkage)

$$X_f = \text{field winding}$$
$$X_{dw} = \text{damper winding}$$
$$X_1 = \frac{1}{\frac{1}{Xa}+\frac{1}{Xf}+\frac{1}{Xdw}} = \text{Xd"} = \text{sub} - \text{transient reactance.}$$
$$X_d^{''} = X_1\ parallel\ X_f = damper\ winding\ current\ died\ out$$

Short circuit current divided in to 3 periods

- ✓ Initial sub transient period---current is large machine offers sub transient reactance.
- ✓ Middle transient period ---machine offers transient reactance.

✓ Steady state period---machine offers synchronous reactance.



(a) Steady state short circuit model of a synchronous machine (b) Approximate circuit model during subtransient period of short circuit (c) Approximate circuit model during transient period of short circuit

<u>Relation between SC MVA and total fault impedance</u>

Let $V^0 = pre\ fault\ voltage\ in\ KV = Base\ voltage$

$Z = impedance\ from\ source\ to\ fault\ location$

$$fault\ current\ I_{f=}\frac{V_0}{\sqrt{3}Z}\ KA$$

$$Short\ circuit\ MVA = \sqrt{3}V_0 I_{f=}V_0 \times \frac{V_0}{\sqrt{3}Z}$$

$$Short\ circuit\ MVA = \frac{V_0^2}{Z}$$

$$\text{Now } Z_{pu} = z \times \frac{MVA_B}{KV_B^2} = Z \times \frac{MVA_B}{V_0^2}$$

$$Z = Z_{pu} \times \frac{V_0^2}{MVA_B}$$

$$short\ circuit\ MVA = \frac{V_0^2}{Z_{pu} \times \frac{V_0^2}{MVA_B}} = \frac{MVA_B}{Z_{pu}}$$

<u>Assumptions for S.C study.</u>

- Synchronous machine are represented by an EMF behind appropriate reactance$X_d^{''}, X_d^{'}, X_d$.
- Sub transient reactance (or) momentary S.C current –Use $X_d^{''}$ for synchronous machine.
- Transient current (after 3 cycle)-Used $X_d^{'}$ for synchronous machine.
- Steady state current- Used X_d for synchronous machine.
- Circuit breaker interruption capacity-Use of $X_d^{''}$ Use of synchronous generator. -X_d For synchronous motor.
- Transformer model – shunt element on account of magnetizing current and core loss are neglected.
- Transmission line model- shunt capacitance neglected.
- Prefault current is much smaller than the fault current.
- Normal or prefault operating conditions, bus voltage of lower system are usually close to the normal value.
- **All prefault voltage and prefault voltage at fault point can be taken as1∠0p.u called Flat voltage profile**.

3. SHORT CIRCUIT OF LOADED SYNCHRONOUS MACHINE.

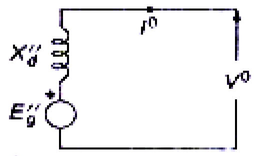
Circuit model of a synchronous generator operating under steady state conditions supplying a load current I^0 to the bus at a terminal of V^0.

E_g – Is induced EMF under loaded conduction,

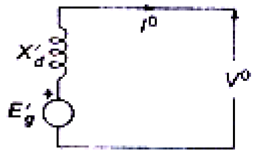
X_d – When short circuit occurs at the terminals of this machine

When short circuit occurs at the terminal of this machine.

Circuit model of a loaded machine



(a) Circuit model for computing subtransient current



(b) Circuit model for computing transient current

Induced EMF to be used in these models are:

$$E_g'' = V^0 + I^0 X_d''$$

$$E_g' = V^0 + I^0 X_d'\,'$$

E_g'' = voltage behind sub transient reactance.

E_g' = voltage behind transient reactance.

$I^0 = 0$(no load),

$E_g'' = E_g' = E_g$ = no load voltage

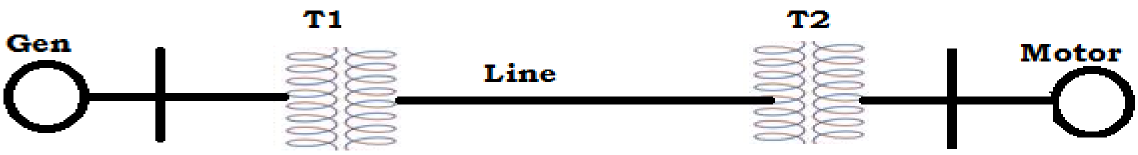
$E_m'' = V^0 - jI^0 X_d''$

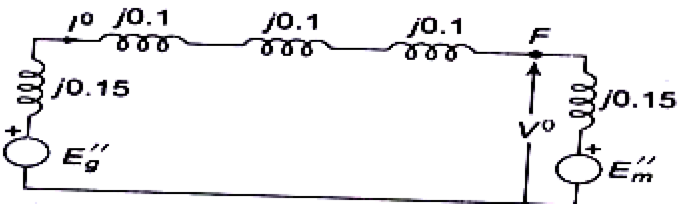
$E_m' = V^0 - j\, I^0 X_d'$

Synchronous machines (generator and motors)replaced by corresponding circuit model having voltage behind sub transient reactance in series with sub transient reactance. The rest of the net work being passive remains unchanged.

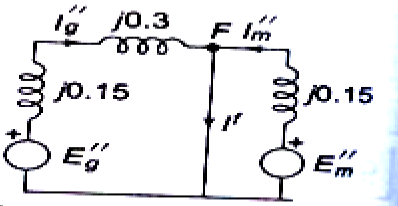
4. A synchronous generator and synchronous motor each rated 25 MVA, 11kV having 15% sub-transient reactance are connected through transformer and lines. Transformer rated 25 MVA, 11/66kV And 66/11KV with leakage reactance of 10% each. The line has a reactance of 10% on a base of25 MVA, 66kV. The motor drawing 15MW at 0.8 p.f leading and a terminal voltage of 10.6kV.when 3 phase symmetrical fault occurs at the motor terminal. Find sub-transient current in the generator, motor and fault.

<u>GIVEN DATA</u>:





(b) Prefault equivalent circuit



(c) Equivalent circuit during fault

Formula used

$$E_g^{''} = V^{\circ} + jI^{\circ}Xd^{''}$$

$$E_m^{''} = V^{\circ} - jI^{\circ}Xd^{''}$$

$$I_g^{''} = E_g^{''}/Xd^{''}$$

$$I_m^{''} = E_m^{''}/Xd^{''}$$

$$I_f = I_g^{''} + I_m^{''}$$

$$I_g^{''} = I_B \times I_g^{''}$$

$$I_m^{''} = I_B \times I_m^{''}$$

Solution:

All reactance on a base of $25MVA$.

$$\text{Pre} - \text{fault voltage } V^{\circ} = \frac{Terminal\ voltage}{Actual\ voltage} = \frac{10.6}{11} = 0.9636\angle 0$$

$$Load = 15MW, 0.8\ p.f\ leading$$

$$= \frac{15}{25} = \frac{load}{Act.MVA} = 0.6\ PU, 0.8\ p.f\ leading$$

$$\text{Pre} - \text{fault current } P = VI \times cos\varphi$$

$$I^{\circ} = \frac{Load(P)}{V \times pf}$$

$$= \frac{0.6}{0.9636 \times 0.8} = 0.7783\angle 36.9$$

$voltage\ behind\ subtransient\ reactance(generator)$ $E_g^{''} = V^{\circ} + jI^{\circ} \times d^{''}$

$$= 0.9630\angle 0 + j0.7788\angle 36.9 \times j0.45 + 0.35046\angle 36.9$$

$$E_g^{''} = 0.7532 + j0.28\ P.U$$

$voltage\ behind\ subtransient\ reactance(Motor)$ $E_m^{''} = V^{\circ} - jI^{\circ} \times d^{''}$

$$= 0.9636\angle 0 - j0.15 \times 0.7788\angle 36.9$$

$$= 1.0337 - j0.0934PU$$

Under fault condition

$$I_g^{''} = \frac{E_g^{''}}{d^{''}} = \frac{0.7532 + j0.28}{j\ 0.45} = 0.6226 - j1.6737PU$$

$$I_m^{''} = \frac{E_m^{''}}{d^{''}} = \frac{1.0337 - j0.0934}{j0.15} = -0.6226 - j6.8913PU$$

Fault current $I^f = I_g^{''} + I_m^{''} = 0.6226 - j1.6737 + (-0.6226 - j6.8913)$

$$I^f = -j8 \cdot 5644$$

$$Fault\ Current\ (generator) = \frac{25 \times 10^3}{\sqrt{3} \times 11} = 1312.2A$$

$$I_g^{''} = I_B \times I_g^{''} = 1312.2(0.6226 - j1.6737) = (816.9 - j2196.2)A$$

$$I_m^{''} = I_B \times I_m^{''} = 1312.2(-0.6226 - j6.8913) = (-816.9 - j9042.7)A$$

$$I_f = I_g^{''} + I_m^{''} = -j11239$$

5. A25 $MVA, 11KV$ generator with $\times d^{''} = 20\%$ is connected through a transformer, line and a transformer to a bus that supplies three identical motor as shown. Each motor has $\times d^{''} = 25\%$ and $\times d^{'} = 30\%$ on a base of $5MVA, 6.6kV,$ 3phase rating of the step up transformer is

$25MVA, 11/66kV$ with leakage reactance of 10% and that of step down transformer is $25MVA, 66/6.6kV$ with leakage reactance of 10%. The bus voltage at the motor is $6.6kV$ when a 3phase fault occurs at point F. for specified fault calculate:

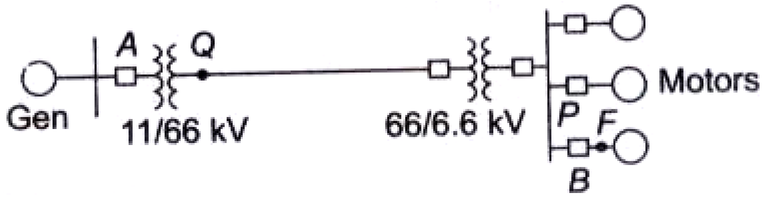
(a) Sub – transient current is the fault.

(b) Sub – transient current in the breaker B,

(c) Momentary current in breaker B,

(d) Current to be interrupted by breaker B in five cycles. (Apr/May 2017)

<u>Given Data:</u>



Gen: 25MVA, 11KV, $X_d^{''} = 20\%$

Transformer 1: 25MVA, 11/66 KV, $X_d^{''} = 10\%$

Transformer 2: 25MVA, 66/6.6 KV, $X_d^{''} = 10\%$

Motor: 5MVA, 6.6 KV, $X_d^{'} = 30, X_d^{''} = 25\%$

<u>To Find:</u>

$Xd^{''}m, I_{sc}$, Momentary current in breaker B, interrupted current.

<u>Formula used:</u>

$$Xd^{''}m = \frac{X_d^{''}}{X_{PU}}; \quad X_{PU} = \frac{Act.Value}{Base\ Value}$$

$$I = \frac{MVA}{\sqrt{3} \times KV}$$

$$Momentary\ current = 1.6 \times I_{sc}$$

<u>Solution:</u>

Choose a system base of $25MVA$

$$Generator\ voltage = 11kV$$

$$Transmission\ voltage = 66kV$$

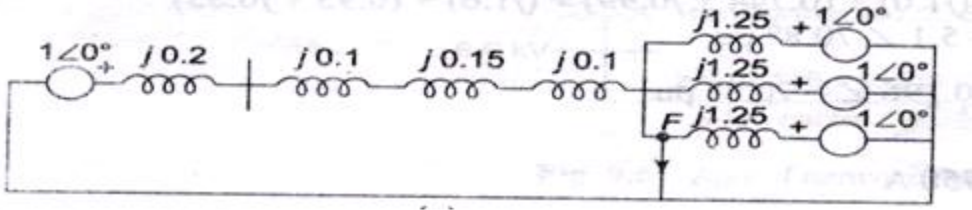
$$motor\ voltage = 6.6kV$$

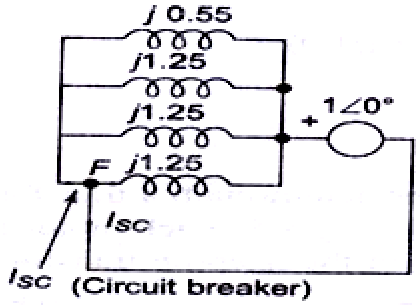
(a) For each motor,

$$X_{dm}^{''} = \frac{X_d^{''}}{X_{PU}}; \quad X_d^{''} \times \frac{MVA_B}{MVA_{ACT}}$$

$$X_{dm}^{''} = 0.25 \times \frac{25}{5} = j1.25PU$$

Line, Transformer, Generator, Reactance are 25MVA base.





$$I_{sc} = 3 \times \frac{1}{j1.25} + \frac{1}{j0.55}$$
$$I_{sc} = -j4.22PU$$

Base current in 6.6 KV circuit $I = \frac{MVA}{\sqrt{3} \times KV} = \frac{25 \times 1000}{\sqrt{3} \times 6.6} = 2187A$

$$I_{sc} = 4.22 \times 2187 = 9229A\ for\ 6.6KV\ line.$$

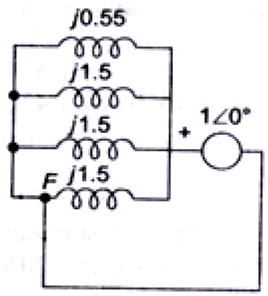
(b) Current through breaker B is

$$I_{sc}(B) = 2 \times \frac{1}{j1.25} + \frac{1}{j0.55} = -j3.42$$
$$= 3.42 \times 2187 = 7479.5A$$

(c) Momentary current through breaker B $= 1.6 \times I_{sc} = 1.6 \times 7479.5 = 11967A$

(d) Current to be interrupted by breaker, motor sub-transient reactance ($X_d^{''} = j0.25$) is now replaced by transient reactance ($X_d^{'} = j0.30$).

$$X_d^{'}(motor) = j0.3 \times \frac{25}{5} = j1.5PU$$



$$= 2 \times \frac{1}{j1.5} + \frac{1}{j0.55} = 3.1515PU$$

DC. off set value multiplying a factor of $= 1.1 \times 3.1515 \times 2187$

$$= 7581A$$

6. THEVENIN'S EQUALIENT CIRCUIT:

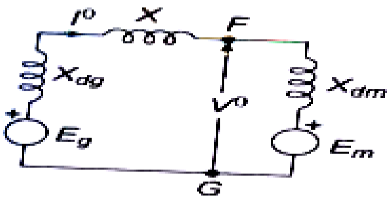
According to thevenin's theorem any linear network containing any number of voltage source and impedance can be replaced by a single EMF and an impedance .The EMF is the open circuit voltage as seen from these terminal and impedance is the network impedance as seen from these terminal .the circuit consisting of a single EMF and impedance is known as thenevnin's equivalent circuit.

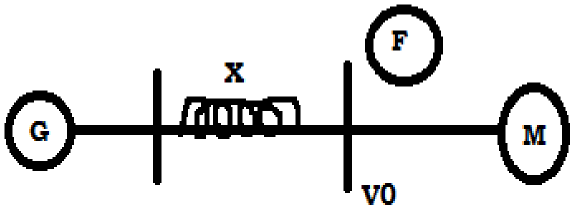
The calculation of the fault current can be very easily done by applying this theorem .it is only necessary to find the open circuit emf and network impedance as seen from the fault point .In the most of the calculation the open circuit emf can be assumed to be 1 pu.

S.C.CURRENT COMPUTATION BY THEVININ'S THEOREM:

This method is faster, easily adopted to systematic computation for large networks.

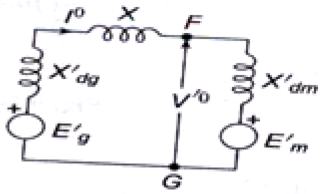
Consider a synchronous generator feeding a synchronous motor over a line.



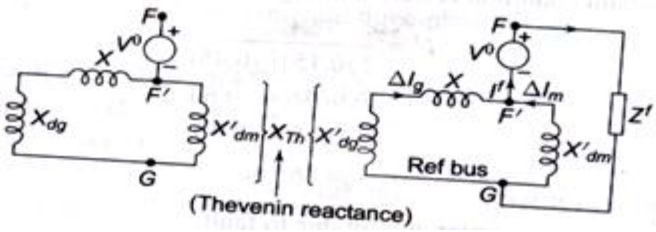


The circuit model of the system under conditions of steady load fault occur at the point "F" at the motor terminals.

Synchronous machine are represented by their transient reactance in series with voltage behind transient reactance. This change does not disturb the prefault current $I^0$and pre fault voltageV^0 (at 'F')



Thenevnin's equivalent circuit is



It comprises prefault voltage V^0 in series with thevin impedance network. Pre fault current I^0 does not appear thevinin impedance network.

Consider now a fault at F through an impedance Z^f.thevenin equivalent of the system feeding fault impedance.

$$I^f = \frac{V_0}{jX_{th} + Z^f}$$

Current Caused By Fault in Generator Circuit $\Delta I_g = \dfrac{X'_{dm}}{(X'_{dg} + X + X'_{dm})} \times I^f$

Current caused by fault in motor circuit $\Delta I_m = \dfrac{X'_{dg} + X}{(X'_{dm} + X + X'_{dg})} \times I^f$

Prefault current and voltage are obtained by superposition

$$I_g^f = I^0 + \Delta I_g$$

$$I_m^f = -I^0 + \Delta I_m$$

Post fault voltage $V^f = V^0 + (-jX_{th} I^f)$

$$V^f = V^0 + \Delta V$$

7. GENERAL PROCEDURE FOR CALCULATION OF SHORT CIRCUIT MVA &SHORT CIRCUIT CURRENT :

(i).Draw single line diagram of given Power system network, on this diagram indicate rating, voltage, impedance of generator, transformer, line& loads.

(ii).select common MVA_b & KV_b and convert all impedance to pu(per unit)on this base.

(iii).draw pu (per unit)impedance diagram on single phase basis.

(iv).calculate total pu (per unit)impedance from the source to fault point by circuit reduction. this may involve series parallel combinations conversions, etc.

<u>STEPS TO FOLLOW USING THEVENIN'S THEOREM:</u>

(i).obtain steady state solution of loaded system.

(ii).replace the reactance of synchronous machines by their subtransient/transient values. Short circuit all emf sources, this is passive thevenin's impedance network.

(iii).excite passive thevenin's impedance network at fault point by negative of prefault voltage in series with fault impedance, compute voltage & current at all points.

(iv).post fault voltage and current are obtained by adding the steps (i) & (iii).

<u>ASSUMPTION MADE IN FAULT CALCULATION</u>

1. The emf of all the generator are 1.0 per unit. This means that the system voltage is at it nominal value of the system is operating on no load at the time of fault. The effect of this is that all generated can be replaced by a single generated since all emf are equal and in phase when desirable the load current can be taken into the account ,at a later stage by superposition
2. Shunt elements in the transformer model that account for magnetizing current and core loss are neglected.
3. Shunt capacitance of the transmission line are neglected.
4. System resistance is neglected and only inductive reactance of the system is taken into account.

This assumption is generally made only for hand calculation and approximation is not necessary .The subtransient reactances of the generation are generally used in calculation. However, transient current is to be determined, and then transient reactance should be used.

8. GENERAL PROCEDURE FOR CALCULATION OF SHORT CIRCUIT MVA & SHORT CIRCUIT CURRENT :

(i).Draw single line diagram of given Power system network, on this diagram indicate rating, voltage, impedance of generator, transformer, line & loads.

(ii).select common MVA_b&KV_b and convert all impedance to pu (per unit) on this base.

(iii).draw pu (per unit) impedance diagram on single phase basis.

(iv).calculate total pu (per unit) impedance from the source to fault point by circuit reduction. This may involve series parallel combinations.

Step in the calculation are as under: USING THEVENIN'S THEOREM

1. Draw a single line diagram of the system.
2. Select a common base and find out per unit reactance's of all generator, transformer, lines, etc. as referred to common base.
3. From the single line diagram draw a single line reactance diagram showing one phase and neutral. Indicate all the reactance etc. On the reactance diagram
4. Reduce the reactance diagram keeping the identity of the fault point intact. Find the reactance of the system as seen from the fault point.
5. Find the fault current and fault MVA in per unit. convert these per unit values to actual values
6. Retrace the steps of calculation to find the current and voltage distribution throughout the network.

Assumption made in fault calculation:

1. EMF of all generator are 1<0
2. Shunt element in transformer model that account for magnetizing current.
3. Shunt capacitance of the line neglected
4. System resistance are neglected, inductive reactance of system taken in to account.

Assumption made only for calculation and educational purpose. computer solution this approximation not necessary, subtransient reactance used in calculation.

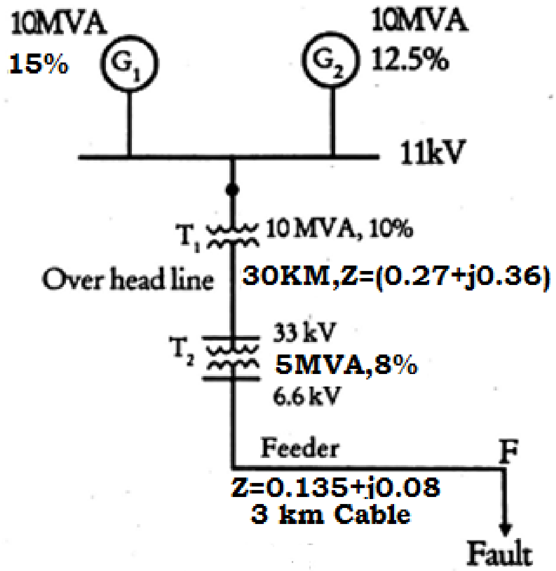
CONSIDERATION OF PRE FAULT LOAD CURRENT:

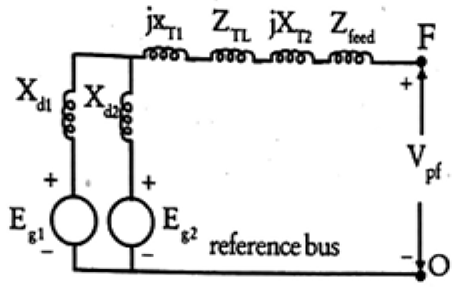
1. In general fault current much larger than load current, load current cab be neglected during fault.
2. Flow of current, voltage at different point in power network 1pu.it is necessary to calculate prefault voltage at the fault point fault current can be determined using prefault voltage.
3. Total current is phasor sum of load current and fault current.

MOTOR CURRENT UNDER FAULT:

Direction of motor current and fault current opposite to each other for motor because load current flow in to motor terminal. While fault current flow out of motor terminal.

9. For the radial network shown in fig, a 3-phase fault occurs at F, Determine the fault current and the line voltage at 11KV bus under fault conditions.(Nov/DEC-14) (Nov/Dec 2016)





To Find:

$$\text{Fault current} \ = I_f$$

$$\text{Line voltage} = V$$

Formula used:

$$Z_{pu} = Z \times \frac{MVA}{KV^2}$$

$$I_f = \frac{V}{Z_f}$$

Solution:

Select a system base of 100MVA,

Base voltage 11 kv in generator,33 KV for OHT line,6.6 KV for cable.

$$\text{Reactance of } G_1 = Z \times \frac{(MVA)_{Base}}{(MVA)_{Actual}}$$

$$G_1 = \frac{15}{100} \times 10 = j1.5 \text{ pu}$$

$$G_2 = \frac{12.5}{100} \times 10 = j1.25 \text{ pu}$$

$$T_1 = \frac{10}{100} \times 10 = j1.0 \text{ pu}$$

$$T_2 = \frac{0.08 \times 100}{5} = j1.6 \text{ pu}$$

$$\text{OHT Line impedance} = Z \times \frac{(MVA)_{Base}}{(KV_B)^2} \times \text{Length}$$

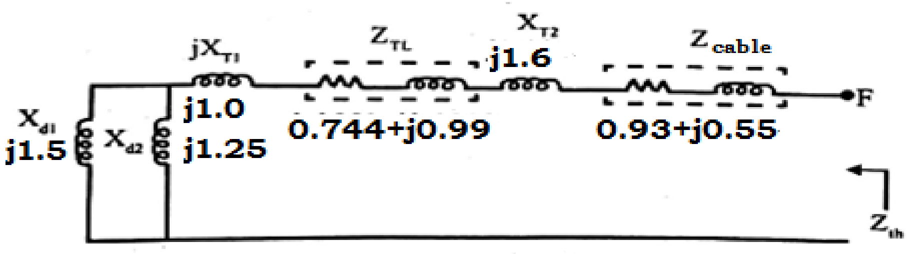
$$= (0.27 + j0.36) \times \frac{30 \times 100}{(33)^2}$$

$$= 0.744 + j0.992 \text{ pu}$$

$$\text{cable impedance} = Z \times \frac{(MVA)_{Base}}{(KV_B)^2} \times \text{Length}$$

$$= 3(0.135 + j0.08) \times \frac{100}{(6.6)^2}$$

$$= 0.93 + j0.55 \text{ pu}$$



Total impedance up to fault F,

$$Z_f = \frac{j1.5 \times j1.25}{j1.5 + j1.25} + j1.0 + (0.744 + j0.99) + j1.6 + (0.93 + j0.55)$$

$$= 1.674 + j4.82 = 5.104\angle 70.8$$

Short circuit current

$$I_f = \frac{V}{Z_f} = \frac{1.0\angle 0}{5.1\angle 70.8}$$

$$= 0.196\angle -70.8$$

$$I_{Base} = \frac{100 \times 10^3}{\sqrt{3} \times 6.6} = 8747.7A$$

$$I_{SC} = I_f \times I_{Base}$$

$$I_{SC} = 0.196 \times 8748 = 1715A$$

Total impedance between fault F and 11 KV bus.

$$Z_f = (0.93 + j0.55) + (j1.6) + (0.744 + j0.99) + j1.0$$

$$= 1.674 + j4.14$$

$$Z_f = 4.46\angle 67.9 \text{ pu}$$

Voltage at 11KV bus $V = Z_f \times I_f$

$$= 4.46\angle 67.9 \times 0.196\angle -70.8$$

$$= 0.88\angle -3 \text{ pu}$$

$$= 0.88 \times 11$$

$$= 9.68 \text{ KV}$$

Result:

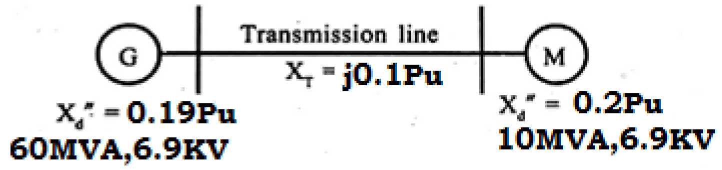
Fault occurs at = 6.6KV

Fault voltage = 9.68KV

short circuit current = 1715 A

10.A 3-phase generator is rated for 60MVA, 6.9KV and sub transient reactance of j0.19 p.u. the generator feeds a motor through a line with impedance of j0.1pu on generator rating., the motor is rated at 10MVA, 6.9 KV with $X_d'' = 0.2\text{pu}$**.voltage at motor terminal is 1.0p.u and take a load current of 1pu at unity power factor .A symmetrical fault occurs at the generator terminal. Determine the sub transient current in the fault in the generator and in the motor in KA.**

Given data:



To find:

Sub transient fault

Formula used:

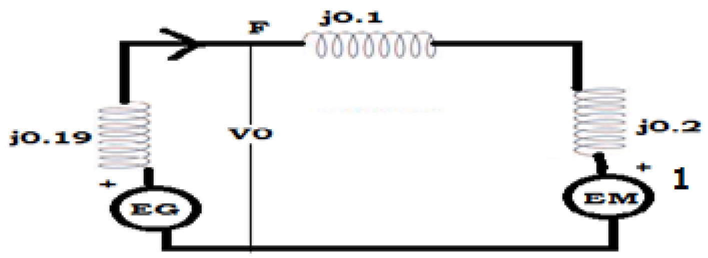
(pre fault condition)

$$(\text{MVA})_{\text{Base}} = 60, \text{KV}_b = 6.9$$

$$I_0 = \text{prefault current} = 1 \text{ pu}$$

$$V_{m0} = \text{prefault voltage at motor terminal} = 1\text{pu}$$

Reactance diagram:



Prefault voltage at fault point (generator terminal)

$$V_{g0} = V_{m0} + I_0 X_L$$

$$= 1 + j0.1 = 1.0049\angle 5.7105$$

Using Thevenin's theorem:

$$X_{th} = \frac{j0.19 \times j1.3}{j1.49} = j0.1657\text{pu}$$

$$I_f = \frac{V_{g0}}{X_{th}} = \frac{1.0049\angle 5.7105}{j0.1657}$$

$$= 6.0645\angle -84.3 \text{ pu}$$

$$\Delta I_g^{''} = I_f \times \frac{X_{dm}^{'} + X}{\left(X_{dg}^{'} + X + X_{dm}^{'}\right)}$$

$$= 6.0645\left(\frac{j1.2 + 0.1}{j1.2 + 0.1 + 0.19}\right)$$

$$= 5.2911\angle - 84.3 \text{ pu}$$

$$\Delta I_m^{''} = \frac{X_{dg}^{'}}{\left(X_{dg}^{'} + X + X_{dm}^{'}\right)} \times I^f$$

$$= 6.0645\angle - 84.3\left(\frac{0.19}{1.49}\right)$$

$$= 0.7733\angle - 84.3 \text{ pu}$$

$$\Delta I_g^{''} = \Delta I_g^{'} + I_0 = 5.2911\angle 84.3 + 1$$

$$= 5.48\angle - 73.84$$

$$\Delta I_m^{''} = \Delta I_m^{'} - I_0$$

$$= 0.7733\angle - 84.3 - 1$$

$$= 1.201\angle - 140.18$$

$$I_{Base}(\text{motor and generator}) = \frac{60 \times 10^6}{\sqrt{3} \times 6.9 \times 10^3} = 5020.43$$

$$I_g^{'} = I_{B\times}\Delta I_g^{''} = 5.4811 \times 5020.43 = 27.511\text{KA}$$

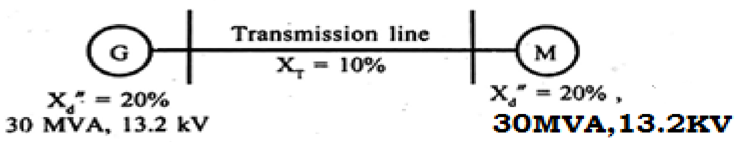
$$I_m^{'} = I_{B\times}\Delta I_m^{''} = 1.201 \times 5020.43 = 6.029\text{KA}$$

$$I_F = I_g^{'} + I_m^{'} = 27.511 + 6.029$$

$$I_F = 33.540 \text{ KA}$$

11.A generator is supplying a motor over a cable as shown. the motor is drawing 20MW at 0.8 pf leading at the terminal voltage of 12.8 KV, when symmetrical 3-phase fault occurs at the motor terminal. Find sub transient current in generator and motor terminals and fault.

Given data:



To find:

$I_g^{''}, \quad I_m^{''}$

Formula used:

$$I_g^{''} = \frac{E_g^{''}}{X_g^{''} + X_l} \qquad\qquad I_m^{''} = \frac{E_m^{''}}{X_m}$$

Solution:

Machine internal voltage method, machine model before fault and after fault

$$(\mathrm{MVA})_{\mathrm{Base}} = 30, \mathrm{KV_b} = 13.2\mathrm{KV}$$

$$\mathrm{V^0} = \text{prefault voltage at fault pint (motor terminal)}$$

$$\mathrm{V^0} = \frac{12.8}{13.2} = 0.97\ \mathrm{pu}$$

$$\text{Load} = 20\mathrm{MW}, 0.8\ \text{pf leading (power)}$$

$$\text{power} = \frac{20}{30} = 0.666\mathrm{pu}, 0.8\ \text{pf leadng}$$

prefault load current $\mathrm{P = VIcos\varphi}$

$$\mathrm{I} = \frac{\mathrm{P}}{\mathrm{Vcos\varphi}} = \frac{0.666}{0.97 \times 0.8} = 0.86\angle\ 36.87$$

$$\mathrm{I_g''} = \mathrm{V^0} + \mathrm{I^0}\left(\mathrm{jI_g''} + \mathrm{jX_l}\right)$$

$$= 0.97 + 086\angle\ 36.87(\mathrm{j}0.2 + \mathrm{j}0.1)$$

$$= (0.815 + \mathrm{j}0.206\ )\mathrm{pu}$$

$$\mathrm{I_m''} = \mathrm{V^0} - \mathrm{I^0}\left(\mathrm{I_m''}\right)$$

$$= 0.97 - 0.86\angle 36.87(\mathrm{j}0.2)$$

$$= (1.073 - \mathrm{j}0.1375)\ \mathrm{pu}$$

$$\mathrm{I_g''} = \frac{\mathrm{E_g''}}{\mathrm{X_g''} + \mathrm{X_l}} = \frac{(0.814 + \mathrm{j}0.207)}{\mathrm{j}0.2 + \mathrm{j}0.1} = 0.69 - \mathrm{j}2.71\ = 2.799\angle - 75$$

$$\mathrm{I_m''} = \frac{\mathrm{E_m''}}{\mathrm{X_m}} = \frac{1.073 + \mathrm{j}0.1375}{\mathrm{j}0.2} = 0.69 - \mathrm{j}5.365\ = 5.408\angle - 82.69$$

$$\mathrm{I_{base}}(\text{motor and generator}) = \frac{20 \times 10^6}{\sqrt{3} \times 13.2 \times 10^3} = 874.773\mathrm{A}$$

$$\text{Fault current}\quad \mathrm{I_F} = \mathrm{I_g''} + \quad \mathrm{I_m''}$$

$$= (0.69 - \mathrm{j}2.71) + (0.69 - \mathrm{j}5.365)$$

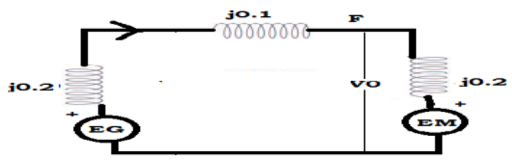
$$= 0.38 - \mathrm{j}5.636$$

$$= 8.192\angle - 80.30$$

$$\mathrm{I_B} \times \mathrm{I_F} = 874.773 \times 8.192$$

$$\mathrm{I_F} = \mathrm{I_B} \times \mathrm{I_F} = 7166.12\mathrm{A}$$

Using thevenin’s theorem:



$$Z_{th} = \frac{0.3 \times 0.2}{0.3 + 0.2} = j0.12 \text{ pu}$$

$$I_F = \frac{V^0}{Z_{th}} = \frac{0.97}{j0.12} = -j8.08 \text{ pu}$$

$$\Delta I_g^{''} = \frac{X_{dm}^{'}}{\left(X_{dg}^{'} + X + X_{dm}^{'}\right)} \times I^f = -j8.08 \times \left(\frac{j0.2}{j0.2 + j0.1 + j0.2}\right) = -j3.232 \text{ pu}$$

$$\Delta I_m^{''} = \frac{X_{dg}^{'} + X}{\left(X_{dm}^{'} + X + X_{dg}^{'}\right)} \times I^f = -j8.08 \times \left(\frac{j0.2 + j0.1}{j0.2 + j0.1 + j0.2}\right) = -j4.848 \text{ pu}$$

$$I_g^{''} = \Delta I_g^{''} + I^0 = -j3.232 + (0.687 + j0.516) = 0.687 - j2.716$$

$$= 2.8\angle - 75.8 \text{ pu}$$

$$I_m^{''} = \Delta I_g^{''} - I^0 = -j4.848 - (0.687 + j0.516) = -0.687 - j5.364$$

$$= 5.4\angle - 97.3 \text{ pu}$$

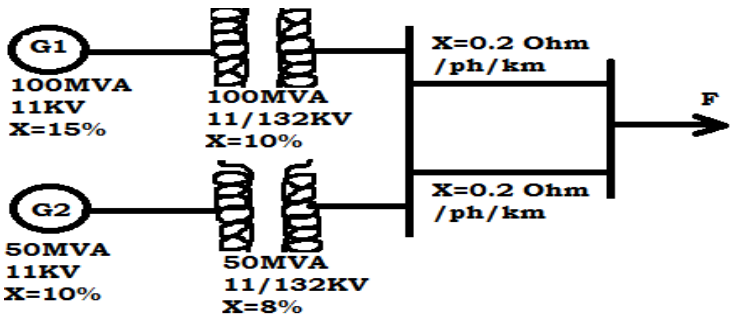
$$I_F = -j8.08 \times I_{base} = j8.08 \times 874.773 = 7068A$$

$$I_g^{''} = 2.8 \times 874.77 = 2449.36A$$

$$I_m^{''} = 5.4 \times 874.77 = 4723.75A$$

12.A generating station feeding a 132 KV system. Determine the total fault current. fault level and fault current supplied by each alternator for a 3- phase fault at he receiving end bus. The line is 200KM long. Take Base of 100MVA, 11KV for LV side and 132 KV for HV side (Nov/dec-13,May/June-2016)(Nov/Dec 2017)

Given Data:



Tofind:

(i) I_F, (ii) I_F suppiled by each alternator, (iii) Fault level.

Formula used:

$$Z_{pu} = Z \times \frac{(MVA)_{Base}}{(MVA)_{Actual}}, I_f = \frac{V}{Z_f}, I_1 = \frac{I \times Z_2}{Z_1 + Z_2}, I_2 = \frac{I \times Z_1}{Z_1 + Z_2}$$

Solution:

$$\text{P.U Reactance of } G_1 = j0.15 \times \frac{100}{100} = j0.15\Omega$$

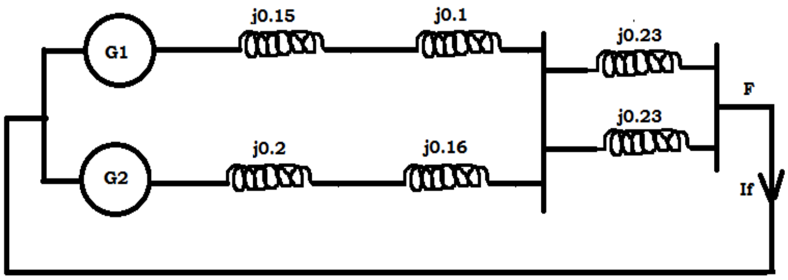
$$\text{P.U Reactance of } G_2 = j0.10 \times \frac{100}{50} = j0.2\Omega$$

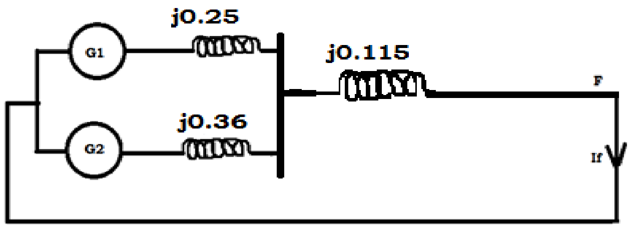
$$\text{P.U Reactance of } T_1 = j0.10 \times \frac{100}{50} = j1.0\Omega$$

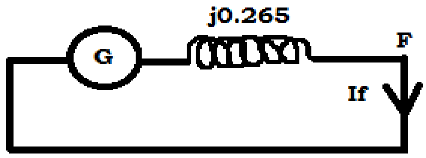
$$\text{P.U Reactance of } T_2 = j0.08 \times \frac{100}{50} = j0.16\Omega$$

$$\text{P.U Reactance of transmission line} = \frac{j0.2 \times 100}{(132)^2} \times 200 = j0.23\Omega$$

Reactance diagram:







$$\text{Fault current: } I_f = \frac{V}{Z_f} = \frac{1\angle 0}{j0.2625}$$

$$= -j3.8095 \text{ pu}$$

$$\text{baes current for 132 KV side } P = \sqrt{3} \times VI_B\cos\varphi$$

$$100 \times 10^6 = \sqrt{3} \times 132 \times 10^3 I_B$$

$$I_B = 437.4 \text{ A}$$

Now

(i) $\text{Short circuit current} I_{sc} = I_f \times I_B$

$$= 3.8095 \times 437.4\angle -90$$

$$= 1666.27\angle -90$$

(ii) $\text{Fault level } I_f \times 100 = 3.8095 \times 100$

$$= 380.95\text{MVA}$$

(iii) Base current for 11 KV side of transformer $I_B = \dfrac{100 \times 10^6}{\sqrt{3} \times 11 \times 10^3} = 5248.63$

$$\text{Total current supplied by generator} = -j3.8095 \times 5248.63$$

$$= 19995\angle -90$$

$$\text{Fault current supplied by } G_1 = \frac{(19995\angle-90)(j0.36)}{j0.25 + j0.36} = 11800.3\angle-90A$$

$$\text{Fault current supplied by } G_2 = (19995\angle-90) - (11800.3)$$

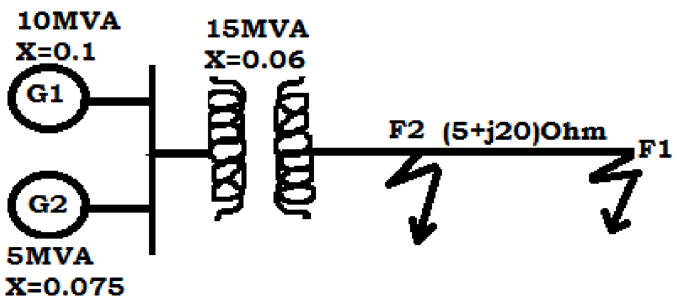
$$= 8194.7\angle-90A$$

13.A 3-phase transmission line operating at 33KV and having resistance and reactance 5Ω and 20Ω respectively is connected to a generator bus bar through a 15 MVA sep up transformer which has a reactance 0.06pu alternator having capacities of 10 MVA and 5 MVA with reactance's of 0.1pu and 0.075pu respectively are connected to generator bus. Calculate short circuit MVA for short circuit between the phases occurring at,

(i)HV terminal of transformer,

(ii) At load end of line Select Base MVA=10,BaseKV=33(Line); (APR/MAY-2015)

Given Data:



Transmission line operating at 33KV

To find:

(i) I_{F2} at HV terminal

(ii) I_{F1} at load end of transmission line

Formula used:

$$Z_{pu} = Z \times \frac{(MVA)_{Base}}{(MVA)_{Actual}}$$

$$\text{P.U Reactance of } G_1 = j0.1 \times \frac{10}{10} = j0.1\Omega$$

$$\text{P.U Reactance of } G_2 = j0.075 \times \frac{10}{5} = j0.15\Omega$$

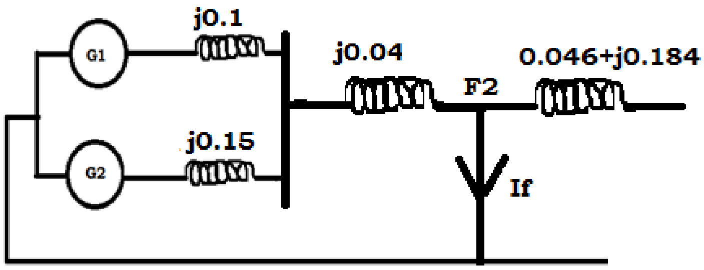
$$X_t = j0.06 \times \frac{10}{15} = j0.04\Omega$$

$$Z_L = Z \times \frac{MVA}{KV^2}$$

$$Z_L = (5 + j20) \times \frac{10}{(33)^2}$$

$$= (0.046 + j0.184)\ pu$$

(i)FAULT AT HIGH VOLTAGE TERMINAL OF TRANSFORMER .



$$X_{equ} = \left(\frac{j0.1 \times j0.15}{j0.1 + j0.15}\right) + j0.04$$

$$= 0 + 0.06j + j0.04$$

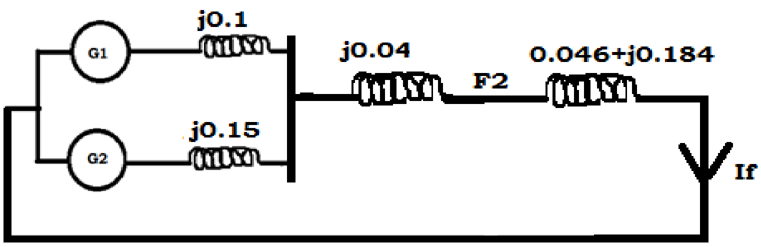
$$X_{equ} = j0.1$$

$$\text{Short circuit MVA} = MVA_B \times V \times I$$

$$I_{F2} = \frac{V}{X_{equ}} = \frac{1\angle 0}{j0.1} = -j10$$

$$\text{SHORT CIRCUIT MVA} = 10 \times 1 \times 10 = 100MVA$$

(ii)FAULT AT LOAD END.



$$X_{equ} = \left(\frac{j0.1 \times j0.15}{j0.1 + j0.15}\right) + j0.04 + 0.046 + j0.184$$

$$= 0.046 + j0.284$$

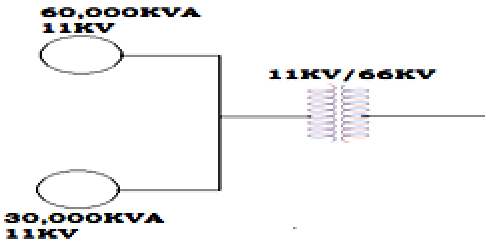
$$I_{F1} = \frac{V}{X_{equ}} = \frac{1\angle 0}{0.046 + j0.284} = 3.4758\angle -80.79$$

$$\text{Fault MVA} = MVA_{Base} \times V \times I_{F1}$$

$$= 10 \times 1 \times 3.4758$$

$$\text{Fault MVA} = 34.758MVA$$

14.Two generators are connected in parallel to the low voltage side of a 3 phase delta star transformer as shown in fig. generator 1 is rated 60,000KVA,11KV.Generator 2 is rated 30000 KVA,11KV.each generator has sub-transient reactance of $X_d^{"} = 25\%$.the transformer is rated 90,000 KVA at 11KV -$\Delta/66KV\ Y$ with a reactance of 10%.before a fault occurred, the voltage on the high tension side of the transformer is 63KV.the transformer is unloaded and there is no circulating current between the generators. Find the sub-transient current in each generator when a three phase fault occurs on the HT side of the transformer. (APR/MAY-2015)



Let $KVA_{Base} = 90{,}000KVA$

$KV_{Base} = 66KV$

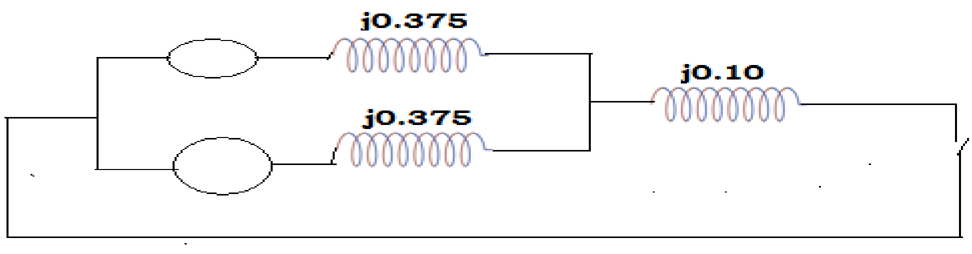
$$For\ Generator\ G_1 \ : X_d^{"} = 0.25 \times \frac{90MVA}{60MVA} = 0.375\ p.u$$

$$For\ Generator\ G_2 : X_d^{"} = 0.25 \times \frac{90MVA}{60MVA} = 0.375\ p.u$$

$$E_{g1} = \frac{0.63}{0.66} = 0.955\ p.u$$

$$E_{g2} = \frac{0.63}{0.66} = 0.955\ p.u$$

Reactance diagram:



$$Total\ reactance\ of\ parallel\ circuit = \frac{j0.375 \times j0.375}{j0.375 + j0.375} = j0.25p.u$$

$$\text{Sub transient current } I^{"} = \frac{0.955}{(j0.25 + j0.10)} = j2.7285\ p.u$$

Voltage at the delta side of the transformer is $= (-j2.7285\ )(j0.10) = 0.27205\ p.u$

$$Subtransient\ current\ flowing\ in\ to\ fault\ current\ from\ generator\ 1\ I_1^{"} = \frac{0.955 - 0.2785}{j0.375}$$

$$= -j1.819\ p.u$$

$$Subtransient\ current\ flowing\ in\ to\ fault\ current\ from\ generator\ 2\ I_2^{"} = \frac{0.955 - 0.2785}{j0.375}$$

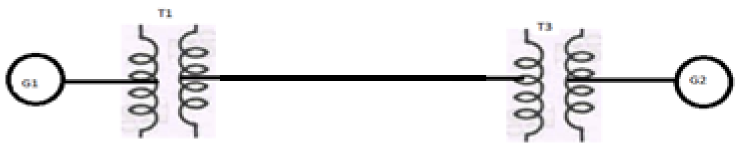
$$= -j1.819\ p.u$$

Actual fault current supplied in amperes

$$I_1^{"} = \frac{1.189 \times 90000}{\sqrt{3} \times 11} = 8592.78A$$

$$I_2^{"} = \frac{0.909 \times 90000}{\sqrt{3} \times 11} = 4294.37A$$

15. Generator G1 and G2 are identical and rated 11kv,20MVA and have a transient reactance of 0.25 p.u at own MVA base. The transformers T1 and T2 are also identical and are rated 11/66KV, 5MVA and have a reactance of 0.06 p.u to their own MVA base. A 50 KM long transmission line is connected between the two generators. Calculate three phase fault, when fault occurs at middle of the line as shown in Fig. (Nov/DEC-2015)



Solution:

$$Base\ MVA, MVA_{New} = 20MVA$$
$$Base\ KV, KV_{New} = 11KV$$

Reactance of generator G1

$$= 0.25 \times \left(\frac{20}{20}\right) \times \left(\frac{11}{11}\right)^2 = 0.25\ \text{p.u}$$

Reactance of transformer T1

$$\text{X}_{\text{New}} = \text{X}_{\text{old}} \times \left(\frac{\text{MVA}_{\text{New}}}{\text{MVA}_{\text{Given}}}\right) \times \left(\frac{\text{KV}_{\text{Given}}}{\text{KV}_{\text{New}}}\right)^2$$

$$= 0.06 \times \left(\frac{20}{25}\right) \times \left(\frac{11}{11}\right)^2 = 0.24\ \ \text{p.u}$$

Reactance of transmission line

Middle of the line (25km long),Actual reactance= $0.848 \times 25 = 21.2\Omega$

$$\text{Base KV on HT side of transformer } \text{T}_1 = \text{Base KV on LT side } \times \frac{\text{HT voltage rating}}{\text{LT voltage rating}}$$

$$\text{Base KV on HT side of transformer } \text{T}_1 = 11 \times \frac{66}{11} = 66\text{Kv}$$

$$Basd\ impedance = \frac{\text{KV}^2}{\text{MVA}_{\text{New}}} = \frac{66^2}{20} = 217.8\Omega$$

$$\text{per unit reactance of transmission line} = \frac{\text{Actual reactance } \Omega}{\text{Base reactance } \ \Omega} = \frac{21.2}{217.8} = \text{j}0.0973\ \text{p.u}$$

Reactance of transformer T2(primary side)

$$X_{New} = X_{old} \times \left(\frac{MVA_{New}}{MVA_{Given}}\right) \times \left(\frac{KV_{Given}}{KV_{New}}\right)^2$$

$$= 0.06 \times \left(\frac{20}{25}\right) \times \left(\frac{11}{11}\right)^2 = 0.24 \text{ p.u}$$

Reactance of generator G2

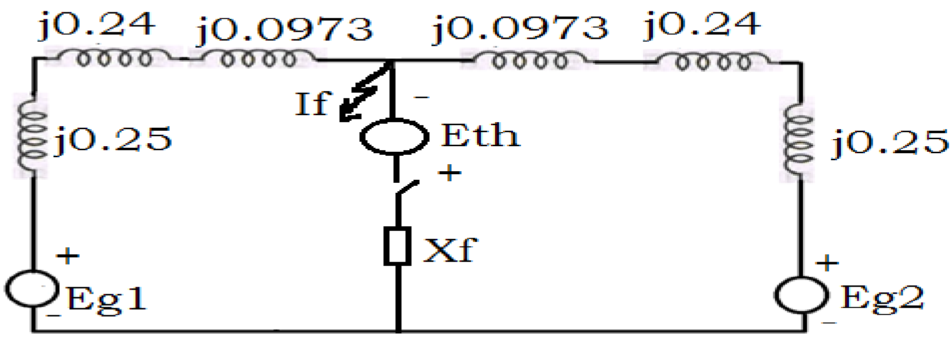
$$\text{Base KV on LT side of transformer } T_2 = \text{Base KV on HT side} \times \frac{\text{LT voltage rating}}{\text{HT voltage rating}}$$

$$\text{Base KV on LT side of transformer } T_2 = 66 \times \frac{11}{66} = 11 \text{ KV}$$

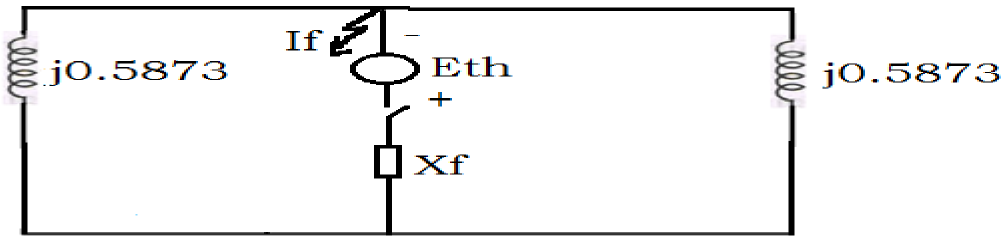
$$X_{New} = X_{old} \times \left(\frac{MVA_{New}}{MVA_{Given}}\right) \times \left(\frac{KV_{Given}}{KV_{New}}\right)^2$$

$$= 0.25 \times \left(\frac{20}{20}\right) \times \left(\frac{11}{11}\right)^2 = 0.25 \text{ p.u}$$

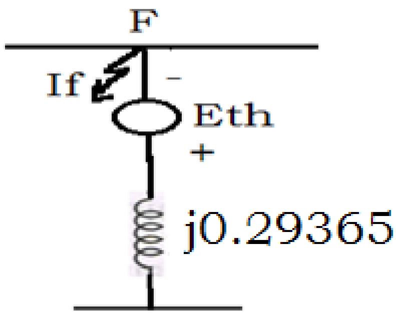
Pre fault reactance diagram



The above diagram is reduced to j0.25 + j0.24 + j0.0973 = j0.5873



Thevenin equalvant network



Thevenin equivalent impedance X_{th} *is* $j0.5873$ *parallel with* $j0.5873$

$$X_{th} = \frac{j0.5873 \times j0.5873}{j0.5873 + j0.5873} = j0.29365\, p.u$$

Per unit voltage $E_{th} = 1 \angle 0°$

Fault impedance or reactance $X_f = 0$

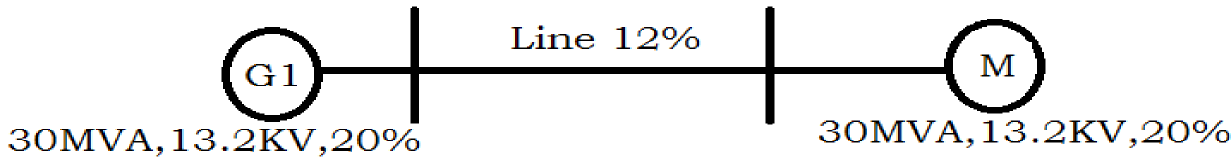
$$\text{Fault current } I_{th} = \frac{E_{th}}{j(X_{th} - X_f)} = \frac{1 \angle 0°}{j0.29365} = -j3.405 p.u$$

$$\text{Base current} = \frac{\text{MVA}_{\text{Base}}}{\sqrt{3}\text{KV}_{\text{Base}}} \times 10^3 = \frac{20}{\sqrt{3} \times 11} \times 10^3 = 174.95 \text{ A}$$

$$\text{Fault current in A} = \text{Fault current in p.u } I_f \times Base\ current$$

$$I_f = 3.405 \times 174.95 = 595.705A$$

16. A synchronous generator and synchronous motor each rated 30MVA,13.2KV and both have subtransient reactance of 20% and the line reactance of 12% on a base of machine ratings. The motor is drawing 25 MW at 0.85 p.f leading .the terminal voltage is 12KV when a three phase short circuit fault occurs at motor terminals. Find the subtransient current in generator, motor and at the fault point.(Nov/Dec-2015)



Solution

$$Base\ MVA, MVA_{New} = 30MVA$$

$$Base\ KV, KV_{New} = 13.2KV$$

<u>Reactance of generator G1</u>

$$X_{New} = X_{old} \times \left(\frac{\text{MVA}_{\text{New}}}{\text{MVA}_{\text{Given}}}\right) \times \left(\frac{\text{KV}_{\text{Given}}}{\text{KV}_{\text{New}}}\right)^2$$

$$= 0.2 \times \left(\frac{30}{30}\right) \times \left(\frac{13.2}{13.2}\right)^2 = 0.2 \text{ p.u}$$

Reactance of transmission line

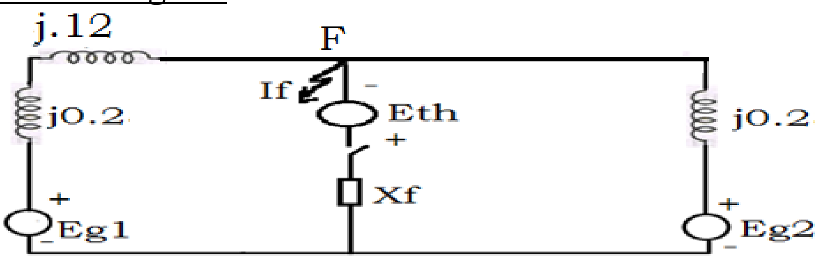
Actual reactance 12% = 0.12Ω

<u>Reactance of Motor M</u>

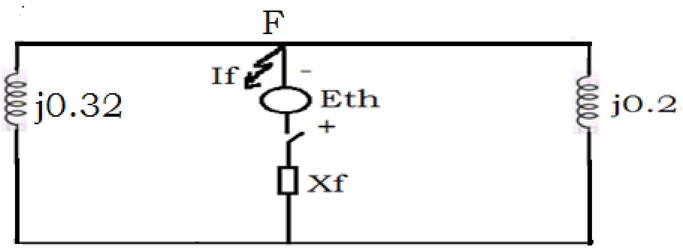
$$X_{New} = X_{old} \times \left(\frac{\text{MVA}_{\text{New}}}{\text{MVA}_{\text{Given}}}\right) \times \left(\frac{\text{KV}_{\text{Given}}}{\text{KV}_{\text{New}}}\right)^2$$

$$= 0.2 \times \left(\frac{30}{30}\right) \times \left(\frac{13.2}{13.2}\right)^2 = 0.2 \text{ p.u}$$

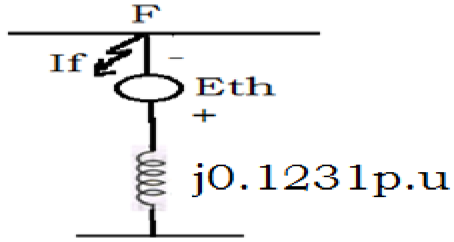
<u>Prefault reactance diagram</u>



The above diagram is reduced to j0.2 + j0.12 = j0.32



Thevenin equivalent network



Thevenin equivalent impedance X_{th} *is* 0.32 *parallel with* $j0.2$

$$X_{th} = \frac{j0.32 \times j0.2}{j0.32 + j0.2} = j0.1231\ p.u$$

Pre fault voltage at fault point=12V

Base KV, $KV_{new=}$13.4 KV

Pre fault voltage or Thevenin voltage $\mathrm{E_{th}} = \frac{12}{13.2} = 0.9091\angle 0°$

Fault impedance or reactance $X_f = 0$

(i) sub transient current:

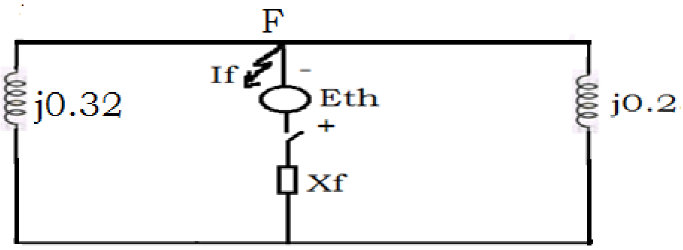
$$\boldsymbol{I_f} = \frac{E_{th}}{j(X_{th} - X_f)} = \frac{0.909\ \angle 0°}{j0.1231\angle 90°} = 7.385\angle -90° p.u$$

$$\text{Base current} = \frac{\mathrm{MVA_{Base}}}{\sqrt{3}\mathrm{KV_{Base}}} \times 10^3 = \frac{30}{\sqrt{3} \times 13.2} \times 10^3 = 1312.16\ \mathrm{A}$$

Fault current in A = Fault current in p.u $I_f \times Base\ current$

$$I_f = 7.385\angle -90 \times 1312.16 = 9.690\angle -90\ KA$$

(ii) Sub transient current controlled by generator and motor:



$$\mathrm{I_G} = \frac{\mathrm{jX_m}}{\mathrm{j(X_G + X + X_m)}}\mathrm{I_f} = \frac{\mathrm{j0.2}}{\mathrm{j0.52}} \times 7.385\angle -90° = 2.840\angle -90°$$

$$\mathrm{I_M} = \frac{\mathrm{jX_g + X}}{\mathrm{j(X_G + X + X_M)}}\mathrm{I_f} = \frac{\mathrm{j0.32}}{\mathrm{j0.52}} \times 7.385\angle -90° = 4.545\angle -90°$$

17. Z BUS ALGORITHAM FOR SHORT CIRCUIT STUDY. (Apr/May 2017)

Explain how the fault current can be determined using Zbus with neat flow chart. (Apr/May 2018)

It is step by step programmable technique which produces branch by branch. it has the advantage that any modification of the network does not require complete rebuilding of Z_{bus}

Adding a new branch:

1. Z_b Is added from a new bus to the reference bus (ie. new branch is added and the dimension of Z_{bus} goes up by one) - **Type 1 modification**.

$$Z_{BUS(NEW)} = \left[\begin{array}{ccc|c} & Z_{BUS(old)} & & \begin{matrix}0\\0\\0\end{matrix} \\ \hline 0 & 0 & 0 & Z_b \end{array}\right]$$

2. Z_b Is added from a new bus to an old bus (ie. a new branch is added and dimension of Z_{bus} goes up by one)-**Type 2 modification.**

$$Z_{BUS(NEW)} = \left[\begin{array}{ccc|c} & Z_{BUS(old)} & & \begin{matrix}Z_{1j}\\Z_{2j}\\Z_{nj}\end{matrix} \\ \hline Z_{j1} & Z_{j2} & Z_{jn} & Z_{jj}+Z_b \end{array}\right]$$

3. Z_b Is connected an old bus to ref bus (ie. a new loop is formed but the dimension of Z_{bus} does not change)-**Type 3 modification.**

$$Z_{BUS(NEW)} = \left[\begin{array}{ccc|c} & Z_{BUS(old)} & & \begin{matrix}Z_{1j}\\Z_{2j}\\Z_{nj}\end{matrix} \\ \hline Z_{j1} & Z_{j2} & Z_{jn} & Z_{jj}+Z_b \end{array}\right]$$

$$Z_{Bus(New)} = Z_{Bus(old)} - \frac{1}{Z_{jj}+Z_b}\begin{bmatrix}Z_{1j}\\ \vdots \\ Z_{nj}\end{bmatrix}\begin{bmatrix}Z_{j1} & \cdots & Z_{jn}\end{bmatrix}$$

4. Z_b Connected two old buses (ie, new loop is formed but the dimension of Z_{bus} does not change)-**Type 4 modification.**

$$Z_{BUS(NEW)} = \left[\begin{array}{cccc|c} & & Z_{BUS(old)} & & \begin{matrix}Z_{1i}-Z_{1j}\\Z_{2i}-Z_{2j}\\ \vdots \\Z_{ni}-Z_{nj}\end{matrix} \\ \hline Z_{i1}-Z_{j1} & Z_{i2}-Z_{j2} & \cdots & Z_{in}-Z_{jn} & Z_b+Z_{ii}+Z_{jj}-2Z_{ij} \end{array}\right]$$

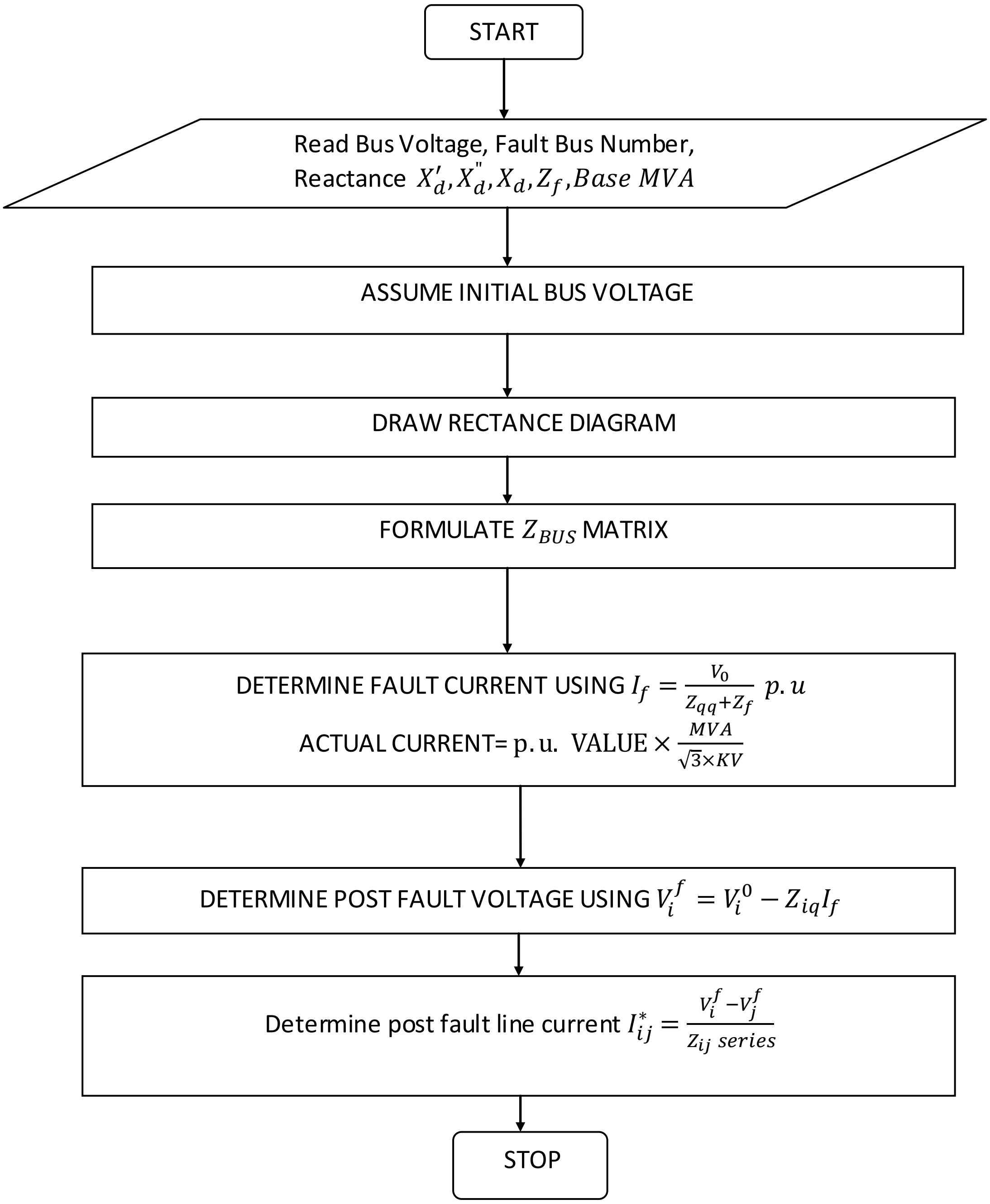
$$Z_{Bus(New)} = Z_{Bus(old)}$$

$$-\frac{1}{Z_b+Z_{jj}+Z_{ii}-2Z_{ij}}\begin{bmatrix}Z_{1i} & \cdots & Z_{1j}\\ \vdots & \vdots & \vdots \\ Z_{ni} & \cdots & Z_{nj}\end{bmatrix}\begin{bmatrix}Z_{i1} & \cdots & Z_{j1}\end{bmatrix}\ldots\begin{bmatrix}Z_{in}-Z_{jn}\end{bmatrix}$$

5. Z_b Connects two new bus (Z_{bus}remains unaffected in this case) this situation can be avoided by suitable numbering of buses and from onwards will be ignored.

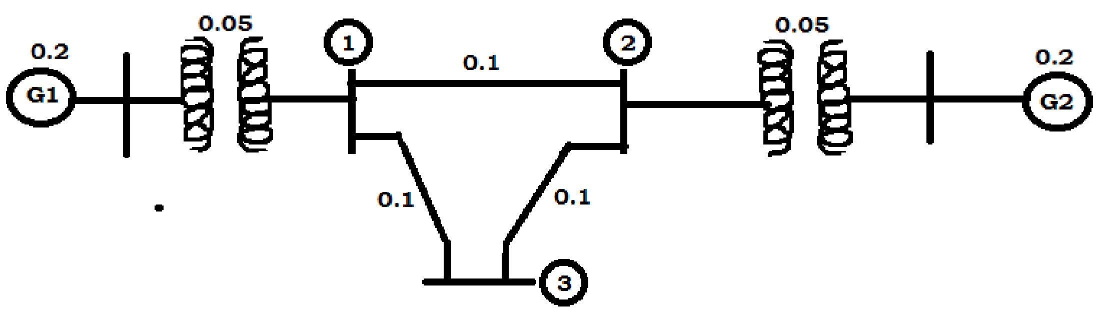
Notation: i, j-old buses; r-reference bus; k-new bus.

Flow chart:



18. Calculate Z_{Bus} For given power system shown diagram.

Given data:



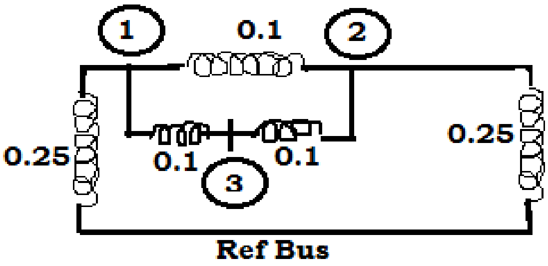
To find:

Calculate Z_{Bus} Algorithm

Formula used: Z_{Bus} building Algorithm

Solution:

Thevenin passive network for above system is



Step1: Add branch Z_{1r} = 0.25 [from bus1 to Ref bus]

$$Z_{Bus} = [0.25]$$

Step2: Add branch Z_{21} = 0.1 [from bus2 to bus1] Type 2 modification.

$$Z_{Bus} = \begin{bmatrix} 0.25 & 0.25 \\ 0.25 & 0.25 + 0.1 \end{bmatrix}$$

$$= \begin{bmatrix} 0.25 & 0.25 \\ 0.25 & 0.35 \end{bmatrix}$$

Step3: Add branch Z_{13} = 0.1 [from bus3 to bus1] Type 2 modification.

$$Z_{Bus} = \begin{bmatrix} 0.25 & 0.25 & 0.25 \\ 0.25 & 0.35 & 0.25 \\ 0.25 & 0.25 & 0.25 + 0.1 \end{bmatrix}$$

$$= \begin{bmatrix} 0.25 & 0.25 & 0.25 \\ 0.25 & 0.35 & 0.25 \\ 0.25 & 0.25 & 0.35 \end{bmatrix}$$

Step4: Add branch $Z_{2r} = 0.25$ [from bus 2 old to ref bus] Type 3 modification

$$Z_{Bus} = Z_{Bus(old)} - \frac{1}{Z_{33} + Z_b} \begin{bmatrix} Z_{21} \\ Z_{22} \\ Z_{23} \end{bmatrix} [Z_{21} \quad Z_{22} \quad Z_{23}]$$

$$Z_{Bus} = \begin{bmatrix} 0.25 & 0.25 & 0.25 \\ 0.25 & 0.35 & 0.25 \\ 0.25 & 0.25 & 0.35 \end{bmatrix} - \frac{1}{(0 \cdot 35 + 0 \cdot 25)} \begin{bmatrix} 0 \cdot 25 \\ 0 \cdot 35 \\ 0 \cdot 25 \end{bmatrix} [0.25 \quad 0.35 \quad 0.25]$$

$$Z_{Bus} = \begin{bmatrix} 0.1458 & 0.1042 & 0.1458 \\ 0.1042 & 0.1458 & 0.1042 \\ 0.1458 & 0.1042 & 0.2458 \end{bmatrix}$$

Step5: Add branch $Z_{23} = 0.1$ [from bus 2 old to bus 3 old] Type 4 modification

$$Z_{Bus} = Z_{Bus\,(old)} - \frac{1}{Z_b + Z_{ii} + Z_{jj} - 2Z_{ij}} \begin{bmatrix} Z_{1i} - Z_{1j} \\ Z_{2i} - Z_{2j} \\ \vdots \\ Z_{ni} - Z_{nj} \end{bmatrix} [Z_{i1} - Z_{j1} \quad \ldots \quad Z_{in} - Z_{jn}]$$

$$= \begin{bmatrix} 0.1458 & 0.1042 & 0.1458 \\ 0.1042 & 0.1458 & 0.1042 \\ 0.1458 & 0.1042 & 0.2458 \end{bmatrix} - \frac{1}{0 \cdot 1 + 0 \cdot 1458 + 0 \cdot 2458 - 0 \cdot 2 \times 0 \cdot 1042} \times \begin{bmatrix} -0.0416 \\ 0.0416 \\ -0.1416 \end{bmatrix} \times [-0.0416 \quad 0.416 \quad -0.1416]$$

$$Z_{Bus} = \begin{bmatrix} 0.1458 & 0.1042 & 0.1458 \\ 0.1042 & 0.1458 & 0.1042 \\ 0.1458 & 0.1042 & 0.2458 \end{bmatrix} - \frac{1}{0.2832} \times \begin{bmatrix} -0.0416 \\ 0.0416 \\ -0.1416 \end{bmatrix} \times [-0.0416 \quad 0.416 \quad -0.1416]$$

$$Z_{Bus} = \begin{bmatrix} 0.1458 & 0.1042 & 0.1458 \\ 0.1042 & 0.1458 & 0.1042 \\ 0.1458 & 0.1042 & 0.2458 \end{bmatrix} - \begin{bmatrix} 0.0061 & 0.0061 & 0.0208 \\ 0.0061 & 0.0061 & -0.0208 \\ 0.0208 & -0.0208 & 0.0708 \end{bmatrix}$$

$$Z_{Bus} = \begin{bmatrix} 0.1397 & 0.1103 & 0.1250 \\ 0.1103 & 0.1397 & 0.1250 \\ 0.1250 & 0.1250 & 0.1750 \end{bmatrix}$$

19. For the above problem a solid 3-phase fault on bus 3, calculate the following (a) Fault current (b) V_1^f *and* V_2^f (C) $I_{12}^f, I_{13}^f,$ *and* I_{23}^f (d) I_{G1}^f *and* I_{G2}^f.

(a) Fault current

$$I^f = \frac{V_r^0}{(Z^f + Z_{rr})};$$

$V_r^0 = 1$ *pre fault voltage*

Fault occurs at bus 3; $I^f = \dfrac{V_3^0}{(0 + Z_{33})} = \dfrac{1}{j0.175} = -j5.71$

(b) V_1^f *and* V_2^f Fault voltage at bus 1 and bus 2.

$$V_1^f = \left(1 - \frac{Z_{ir}}{(Z^f + Z_{rr})}\right) V_r^0$$

$$= \left(1 - \frac{Z_{13}}{(0 + Z_{33})}\right) V_3^0$$

$$= \left(1 - \frac{Z_{13}}{(0 + Z_{33})}\right) V_3^0$$

$$= \left(1 - \frac{0 \cdot 1250}{(0 + 0 \cdot 1750)}\right) \times 1$$

$$V_1^f = 0 \cdot 286$$

$$V_2^f = \left(1 - \frac{Z_{23}}{(0 + Z_{33})}\right) V_r^0 = \left(1 - \frac{0.1250}{(0 + 0.1750)}\right) \times 1$$

$$V_2^f = 0.286$$

Two Voltages are equal because of symmetry of given power network.

(C)post fault current [Fault current of line 1 and 2]

$$I_{ij}^f = Y_{ij}\left(V_i^f - V_j^f\right)$$

$$I_{12}^f = Y_{12}\left(V_1^f - V_2^f\right)$$

$$I_{12}^f = \frac{1}{j0.1103}(0.286 - 0.286) = 0$$

$$I_{13}^f = Y_{13}\left(V_1^f - V_3^f\right)$$

$$I_{13}^f = \frac{1}{j0.1250}(0.286 - 0) = -2.288i$$

$(d) I_{G1}^f$ *and* I_{G2}^f Fault current of generator 1 and 2.

$$I_{Gi}^f = \frac{E_{Gi}^f - V_i^f}{jX_{Gi}^f} = \frac{E_{G1}^f - V_1^f}{jX_{G1}^f + jX_{T1}}; E_{G1}^f = 1$$

$$= \frac{1 - 0.286}{j0.2 + j0.05}$$

$$I_{Gi}^f = -j2.86$$

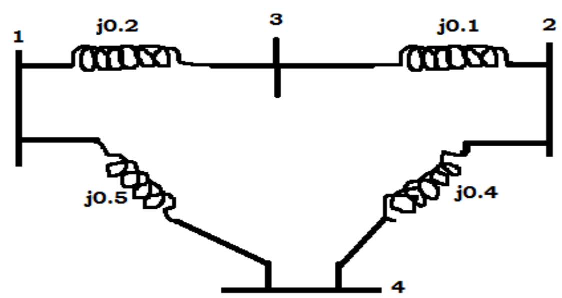
$$I_{G2}^f = \frac{E_{G2}^f - V_2^f}{jX_{G2}^f + jX_{T2}}; E_{G1}^f = 1$$

$$= \frac{1 - 0.286}{j0.2 + j0.05}$$

$$I_{G2}^f = -j2.86$$

20. Four bus system shown in fig calculate Z_{Bus} using bus building algorithm, take bus 4 as reference bus.

Given data:



To find:

Calculate Z_{Bus} Algorithm

Formula used: Z_{Bus} building Algorithm

Solution:

Step1: Add the element j0.5 between bus 1 and ref bus - **Type 1 modification**

$$Z_{Bus} = [j0.5]$$

Step2: Add the element j0.4 between bus 2 and bus 4 - **Type 1 modification**

$$Z_{Bus} = \begin{bmatrix} j0.5 & 0 \\ 0 & j0.4 \end{bmatrix}$$

Step3: Add the element j0.2 between old bus 1 and new bus 3

- **Type 2 modification**

$$Z_{Bus} = \begin{bmatrix} j0.5 & 0 & j0.5 \\ 0 & j0.4 & 0 \\ j0.5 & 0 & j0.7 \end{bmatrix}$$

Step4: Add the element j0.1 between old bus 2 and bus 3

- **Type 4 modification**

$$\mathrm{Z_{Bus}} = \begin{bmatrix} \mathrm{j}0.5 & 0 & \mathrm{j}0.5 \\ 0 & \mathrm{j}0.4 & 0 \\ \mathrm{j}0.5 & 0 & \mathrm{j}0.7 \end{bmatrix} - \frac{1}{\mathrm{j}0\cdot 1 + \mathrm{j}0\cdot 4 + \mathrm{j}0\cdot 7 - 0\cdot 2 \times 0} \times \begin{bmatrix} -\mathrm{j}0.5 \\ \mathrm{j}0.4 \\ -\mathrm{j}0.7 \end{bmatrix} \times [-\mathrm{j}0.5 \quad \mathrm{j}0.4 \quad -\mathrm{j}0.7]$$

$$= \begin{bmatrix} \mathrm{j}0.5 & 0 & \mathrm{j}0.5 \\ 0 & \mathrm{j}0.4 & 0 \\ \mathrm{j}0.5 & 0 & \mathrm{j}0.7 \end{bmatrix} - \frac{1}{\mathrm{j}1.2} \times \begin{bmatrix} -\mathrm{j}0.5 \\ \mathrm{j}0.4 \\ -\mathrm{j}0.7 \end{bmatrix} \times [-\mathrm{j}0.5 \quad \mathrm{j}0.4 \quad -\mathrm{j}0.7]$$

$$= \begin{bmatrix} \mathrm{j}0.5 & 0 & \mathrm{j}0.5 \\ 0 & \mathrm{j}0.4 & 0 \\ \mathrm{j}0.5 & 0 & \mathrm{j}0.7 \end{bmatrix} - \begin{bmatrix} -\mathrm{j}0.4166 \\ \mathrm{j}0.3333 \\ -\mathrm{j}0.5833 \end{bmatrix} \times [-\mathrm{j}0.5 \quad \mathrm{j}0.4 \quad -\mathrm{j}0.7]$$

$$= \begin{bmatrix} \mathrm{j}0.5 & 0 & \mathrm{j}0.5 \\ 0 & \mathrm{j}0.4 & 0 \\ \mathrm{j}0.5 & 0 & \mathrm{j}0.7 \end{bmatrix} - \begin{bmatrix} \mathrm{j}0.2083 & \mathrm{j}0.1666 & \mathrm{j}0.2916 \\ -\mathrm{j}0.1665 & \mathrm{j}0.1333 & -\mathrm{j}0.2333 \\ \mathrm{j}0.2916 & \mathrm{j}0.2333 & \mathrm{j}0.4083 \end{bmatrix}$$

$$\mathrm{Z_{Bus}} = \begin{bmatrix} \mathrm{j}0.2917 & \mathrm{j}0.1666 & \mathrm{j}0.2084 \\ \mathrm{j}0.1665 & \mathrm{j}0.2667 & \mathrm{j}0.2333 \\ \mathrm{j}0.2084 & \mathrm{j}0.2333 & \mathrm{j}0.2917 \end{bmatrix}$$

21. A 3 phase 5 MVA,6.6 KV alternator with reactance of 8% is connected to a feeder of series impedance of 0.12+j0.48 ohm/ph/Km. The transformer is rated at 3 MVA,6.6 KV/33KV and has a reactance of 5%.Determine the fault current supplied by the generator operating under no-load with a voltage of 6.9KV when a 3 phase symmetrical fault occurs at point 15 km along the feeder. (Apr/May-2008; May/Jun-2012) (Nov/Dec 2016)(Apr/May 2017)

Given data:

Base MVA = 5 MVA
Base kV = 6.6 KV

Solution:

The single line diagram of the power system and the prefault reactance diagram are shown in figure. Let the point F be the point where the fault occours.

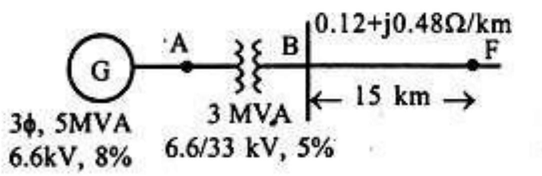


Fig .1 : Single line diagram

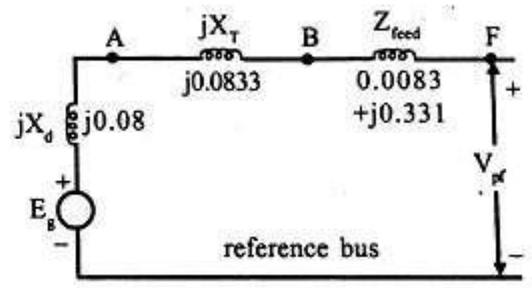


Fig .2 : Prefault reactance diagram

To find E_g and V_{pf}:

Here the generator is not delivering any load current and so the induced emf of the generator wiil be same as operating voltage.

E_g=6.9kV

p.u value of induced emf, $E_g = \frac{\text{Actual reactance}}{\text{Base impedance}}$

$$\frac{6.9}{6.6} = 1.0455 p.u$$

=6.9/6.6=1.0455 p.u

Actual value of prefault voltage $V_{pf} = 6.9 \times \frac{33}{6.6} = 34.5kv$

The base kv referred to HT side of transformer $= 6.6 \times \frac{33}{6.6} = 33kv$

The p.u value of the prefault voltage = $\frac{\text{Actual reactance}}{\text{Base impedance}}$

$$= \frac{34.5}{33} = 1.0455 p.u$$

=34.5/33=1.0455p.u.

To find generator reactance:

p.u reactance of the generator, $X_d = 8\% = 0.08 p.u$

To find transformer reactance:

$$X_{pu,new} = X_{pu,old} \times (\frac{kV_{b,old}}{kV_{b,new}})^2 \times (\frac{MVA_{b,new}}{MVA_{b,old}})$$

$$X_{pu,old} = 5\% = 0.05 p.u.$$

$$X_T = 0.05 \times \left(\frac{6.6}{6.6}\right)^2 \times \frac{5}{3} = 0.0833 p.u.$$

To find the feeder reactance:

Base impedance, $Z_b = \frac{kV_{b,new}^2}{MVA_{b,new}} = \frac{33^2}{5} = 217.8\Omega / phase$

Actual impedance of the feeder for a length of 15km

Z_{feed}=impedance/km*length

=(0.12+j0.48)*15=1.8+j7.2ohm/phase

=$\frac{\text{Actual impedanc e}}{\text{Base impedance}}$

$$\frac{1.8 + j7.2}{217.8}$$

=0.0083+j0.0331p.u

To find fault current:

$$Z_{th} = jX_d + jX_T + Z_{feed}$$

=j0.008+j0.0833+0.0083+j0.0331

= 0.0083+j0.1964

$$I_{th} = \frac{V_{th}}{Z_{th}} = \frac{1.0455 < 0^0}{0.1966 < 87.6^0} = 5.3179 < -87.6^0 \; p.u$$

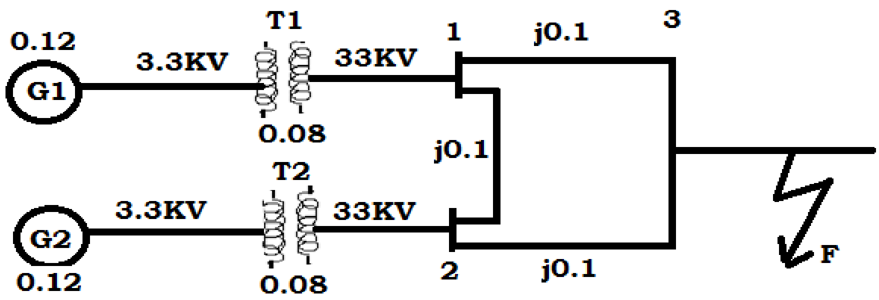
$$I_b = \frac{kVA_b}{\sqrt{3} kV_b} = \frac{5 \times 1000}{\sqrt{3} \times 33} = 87.4773 A$$

$$I_f = p.u.value of I_f \times I_b$$

$$I_f = 5.3179 < -87.6^0 \times 87.4773$$

$$I_f = 465.2 < -87.6 amps.$$

22.The power supply system is shown in fig work out the following parameter for a three phase fault on bus 3.



$(i)\ \ V_1^{'}\ and\ V_2^{'}$

$(ii) short\ circuit\ fault\ current,$

$(iii) I_{12}^{'}, I_{13}^{'} and\ I_{23}^{'}$

$(iv) I_{G1}^{'}, and\ I_{G2}^{'}$

Step1: Add the element j0.08+j012=j02 between bus 1 and ref bus - **Type 1 modification**

$$Z_{Bus} = [j0.2]$$

Step2: Add the element j0.1 between bus 1 and bus2 **Type 2 modification**

$$Z_{Bus} = \begin{bmatrix} j0.2 & j0.2 \\ j0.2 & j0.2 + j0.1 \end{bmatrix}$$

$$Z_{Bus} = \begin{bmatrix} j0.2 & j0.2 \\ j0.2 & j0.3 \end{bmatrix}$$

Step3: Add the element j1.0 between bus 1 and bus3 **Type 2 modification**

$$Z_{Bus} = \begin{bmatrix} 0.2 & 0.2 & 0.2 \\ 0.2 & 0.3 & 0.2 \\ 0.2 & 0.2 & 0.3 \end{bmatrix}$$

Step4: Add the element 0.2 between bus 2 and ref bus **Type 3 modification**

$$Z_{Bus} = Z_{Bus(old)} - \frac{1}{Z_{33} + Z_b} \begin{bmatrix} Z_{21} \\ Z_{22} \\ Z_{23} \end{bmatrix} [Z_{21} \quad Z_{22} \quad Z_{23}]$$

$$Z_{Bus(New)} = \begin{bmatrix} 0.2 & 0.2 & 0.2 \\ 0.2 & 0.3 & 0.2 \\ 0.2 & 0.2 & 0.3 \end{bmatrix} - \frac{1}{0.3 + 0.2} \times \begin{bmatrix} 0.2 \\ 0.3 \\ 0.2 \end{bmatrix} \times [0.2 \quad 0.3 \quad 0.2]$$

$$Z_{Bus(New)} = \begin{bmatrix} 0.12 & 0.08 & 0.12 \\ 0.08 & 0.12 & 0.08 \\ 0.12 & 0.08 & 0.22 \end{bmatrix}$$

$$Z_{Bus} = Z_{Bus(old)} - \frac{1}{Z_b + Z_{ii} + Z_{jj} - 2Z_{ij}} \begin{bmatrix} Z_{1i} - Z_{1j} \\ Z_{2i} - Z_{2j} \\ \vdots \\ Z_{ni} - Z_{nj} \end{bmatrix} [Z_{i1} - Z_{j1} \quad \dots \quad Z_{in} - Z_{jn}]$$

$$Z_{Bus} = Z_{Bus(old)} - \frac{1}{Z_b + Z_{22} + Z_{33} - 2Z_{23}} \begin{bmatrix} Z_{1i} - Z_{1j} \\ Z_{2i} - Z_{2j} \\ \vdots \\ Z_{ni} - Z_{nj} \end{bmatrix} [Z_{i1} - Z_{j1} \quad \dots \quad Z_{in} - Z_{jn}]$$

$$Z_{Bus} = \begin{bmatrix} 0.12 & 0.08 & 0.12 \\ 0.08 & 0.12 & 0.08 \\ 0.12 & 0.08 & 0.22 \end{bmatrix} - \frac{1}{0.1 + 0.12 + 0.22 - 2 \times 0.08} \times \begin{bmatrix} -0.04 \\ 0.04 \\ -0.14 \end{bmatrix} \times [-0.04 \quad 0.04 \quad -0.14]$$

$$Z_{Bus} = \begin{bmatrix} 0.1143 & 0.0857 & 0.1000 \\ 0.0857 & 0.1143 & 0.1000 \\ 0.1000 & 0.1000 & 0.1500 \end{bmatrix}$$

If the short circuit fault on node 3 then,

$$I_3^{'} = \frac{V_3^{'}}{j0.15} = -j6.66$$

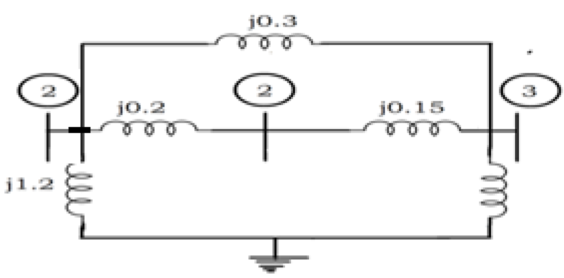
$$V_1^f = V_i^0 - Z_{ir} \times \frac{V_r^0}{Z_f + Z_r}$$

$$V_1^f = V_1^0 - Z_{13} \times \frac{V_r^0}{Z_{33}} = 1 - j0.10 \times \frac{1}{j0.15} = 0.33$$

$$V_2^f = V_2^0 - Z_{23} \times \frac{V_r^0}{Z_{33}} = 1 - j0.10 \times \frac{1}{j0.15} = 0.33$$

If the two voltages are equal there would be no transfer of current from node 1 fault

23. Determine the Z bus for the network shown in fig where all impedance are in p.u



Solution

Step1: Bus 1(New)to the ref bus (type 1 modification)

$$Z_{Bus} = [j1.2]$$

Step2:Connecting an impedance $Z_{21} = j0.2$ from new bus 2 to old bus 1(type 2 modification) j=1

$$Z_{Bus}(New) = \begin{bmatrix} Z_{Bus}(old) & Z_{1j} \\ Z_{j1} & Z_{jj} + Z_b \end{bmatrix}$$

$$= \begin{bmatrix} j1.2 & j1.2 \\ j1.2 & j1.4 \end{bmatrix}$$

Step3: Connecting an impedance $Z_{31} = j0.3$ from new bus 3(new) to old bus 1(type 2 modification)

$$= \begin{bmatrix} Z_{Bus}(old) & \dots & Z_{1j} \\ \vdots & \vdots & Z_{2j} \\ Z_{j1} & Z_{j2} & Z_{jj} + Z_b \end{bmatrix}$$

$$Z_{Bus}(New) = \begin{bmatrix} j1.2 & j1.2 & j1.2 \\ j1.2 & j1.4 & j1.2 \\ j1.2 & j1.2 & j1.5 \end{bmatrix}$$

Step 4: Connecting $Z_{3r} = j1.5$ from new bus 3 (old) to ref bus

$$Z_{Bus}(New) = Z_{Bus}(old) - \frac{1}{Z_{jj} + Z_b} \begin{bmatrix} Z_{1j} \\ Z_{2j} \\ Z_{3j} \end{bmatrix} [Z_{j1} \quad Z_{j2} \quad Z_{j3}]$$

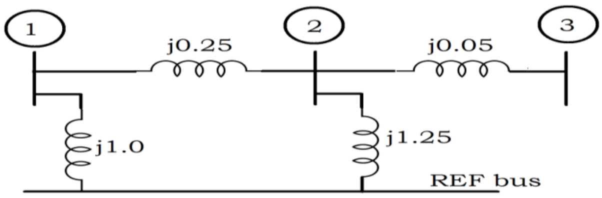
$$Z_{Bus}(New) = \begin{bmatrix} j0.72 & j0.72 & j0.6 \\ j0.72 & j0.92 & j0.6 \\ j0.6 & j0.6 & j0.75 \end{bmatrix}$$

Step 5: Adding impedance $Z_b = j0.15$ between old buses (2) and (3) i=2, j=3

$$Z_{Bus}(New) = Z_{Bus}(old) - \frac{1}{Z_{22} + Z_{33} + Z_b - 2Z_{23}} \begin{bmatrix} Z_{12} - Z_{13} \\ Z_{22} - Z_{23} \\ Z_{32} - Z_{33} \end{bmatrix} [(Z_{21} - Z_{31}) \quad (Z_{22} - Z_{32}) \quad (Z_{23} - Z_{33})]$$

$$Z_{Bus}(New) = \begin{bmatrix} j0.6968 & j0.6581 & j0.6290 \\ j0.6581 & j0.7548 & j0.6674 \\ j0.6290 & j0.6258 & j0.7157 \end{bmatrix}$$

24. Find the bus impedance matrix for the following system whose reactance's are marked in p.u



Step1: Adding an impedance $Z_b = j1.0$ From bus 1 (New) to ref bus (Type 1 modification)

$$Z_{bus} = [j1.0]$$

Step2: Adding an impedance $Z_{12} = j0.25$ from New bus 2 to old bus 1 (Type 2 modification)

$$Z_{bus} = \begin{bmatrix} j1.0 & j1.0 \\ j1.0 & j1.25 \end{bmatrix}$$

Step3: Adding $Z_{2r} = j1.25$ from bus 2 (old) to ref bus-(Type 3 modification) j=2

$$Z_{Bus}(New) = Z_{Bus}(old) - \frac{1}{Z_{jj}+Z_b}\begin{bmatrix} Z_{1j} \\ \vdots \\ Z_{3j} \end{bmatrix}[Z_{j1} \quad \dots \quad Z_{nj}]$$

$$= \begin{bmatrix} j1.0 & j1.0 \\ j1.0 & j1.25 \end{bmatrix} - \frac{1}{Z_{jj}+Z_b}\begin{bmatrix} Z_{1j} \\ \vdots \\ Z_{3j} \end{bmatrix}[Z_{j1} \quad \dots \quad Z_{nj}]$$

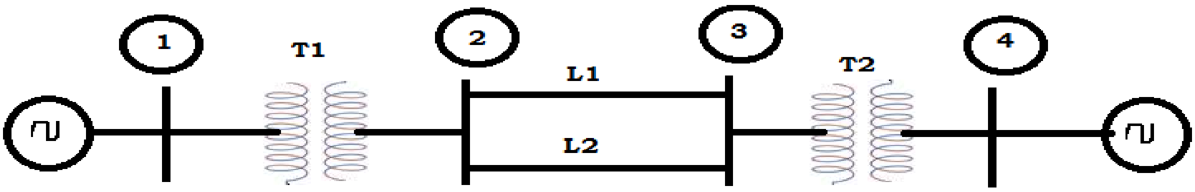
$$= \begin{bmatrix} j0.6 & j0.5 \\ j0.5 & j0.625 \end{bmatrix}$$

Step4: Adding $Z_{23} = j0.05$ from bus3 (new) to old bus2. j=2

$$= \begin{bmatrix} Z_{Bus}(old) & \dots & Z_{1j} \\ \vdots & \vdots & Z_{2j} \\ Z_{j1} & Z_{j2} & Z_{jj}+Z_b \end{bmatrix}$$

$$= \begin{bmatrix} j0.6 & j0.5 & j0.5 \\ j0.6 & j0.625 & j0.625 \\ j0.5 & j0.625 & j0.675 \end{bmatrix}$$

25.A symmetrical fault occurs at bus 4 for the system. Determine the fault current using Z Bus building algorithm.(May/June-2016)(Nov/Dec 2017)

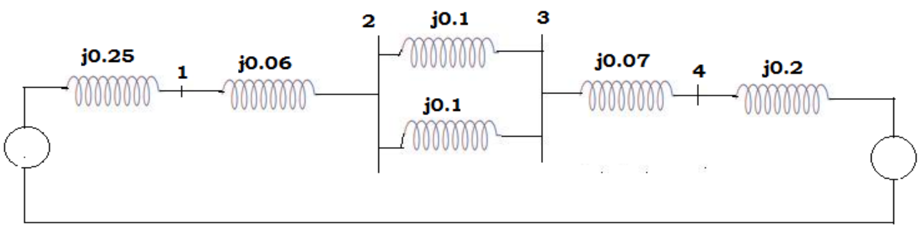


$\boldsymbol{G_1, G_2 = 25\%, 20\%; 20KV, X^+ = 25\%}$

$\boldsymbol{Transformer1, Transformer2: X_{leakage} = 6\%, 7\%}$

$\boldsymbol{L_1, L_2; X^+ = 10\%}$

Sequence diagram:



Solution:

Step1: Adding an impedance j0.25 between ref bus and bus 1 [Type 1 modification]

$$Z_{bus} = [j0.25]$$

Step2: Adding an impedance $Z_{12} = j0.06$ from New bus 2 to old bus 1 (Type 2 modification)

$$Z_{bus} = \begin{bmatrix} j0.25 & j0.25 \\ j0.25 & j0.31 \end{bmatrix}$$

Step3: Adding an impedance $Z_{12} = j0.05$ from New bus 3 to old bus 2 (Type 2 modification)

$$Z_{bus} = \begin{bmatrix} j0.25 & j0.25 & j0.25 \\ j0.25 & j0.31 & j0.31 \\ j0.25 & j0.31 & j0.36 \end{bmatrix}$$

Step4: Adding an impedance $Z_{12} = j0.07$ from New bus 4 to old bus3 (Type 2 modification

$$Z_{bus} = \begin{bmatrix} j0.25 & j0.25 & j0.25 & j0.25 \\ j0.25 & j0.31 & j0.31 & j0.31 \\ j0.25 & j0.31 & j0.36 & j0.36 \\ j0.25 & j0.31 & j0.36 & j0.43 \end{bmatrix}$$

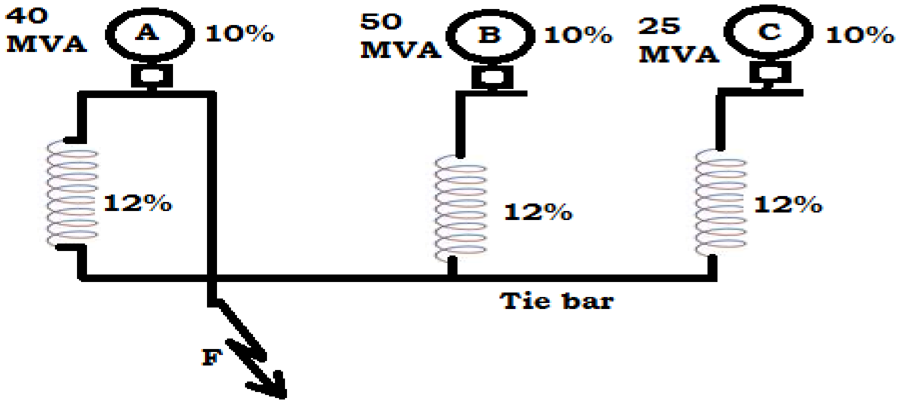
Step5: Adding an impedance $Z_{12} = j0.2$ from old bus4 and ref bus (Type 2 modification

$$Z_{bus} = \begin{bmatrix} j0.25 & j0.25 & j0.25 & j0.25 \\ j0.25 & j0.31 & j0.31 & j0.31 \\ j0.25 & j0.31 & j0.36 & j0.36 \\ j0.25 & j0.31 & j0.36 & j0.43 \end{bmatrix} - \frac{1}{j0.43 + j0.2} \begin{bmatrix} j0.25 \\ j0.31 \\ j0.36 \\ j0.43 \end{bmatrix} [j0.25 \quad j0.31 \quad j0.36 \quad j0.43]$$

$$Z_{bus} = \begin{bmatrix} j0.25 & j0.25 & j0.25 & j0.25 \\ j0.25 & j0.31 & j0.31 & j0.31 \\ j0.25 & j0.31 & j0.36 & j0.36 \\ j0.25 & j0.31 & j0.36 & j0.43 \end{bmatrix} - \frac{1}{j0.63} \begin{bmatrix} -0.0625 & -0.0775 & -0.09 & -1075 \\ -0.0775 & -0.096 & -0.1116 & -0.1333 \\ -0.09 & -0.1116 & -0.1296 & -0.1548 \\ -0.1075 & -0.1333 & -0.1548 & -0.1849 \end{bmatrix}$$

$$Z_{bus} = \begin{bmatrix} j0.1507 & j0.1269 & j0.1071 & j0.0793 \\ j0.1269 & j0.1574 & j0.1328 & j0.0984 \\ j0.1071 & j0.1328 & j0.1548 & j0.1142 \\ j0.0793 & j0.0984 & j0.1142 & j0.1369 \end{bmatrix}$$

26.Three 6.6KV Generators A, B, and C each of 10% leakage reactance and MVA ratings 40,50 and 25 respectively are interconnected electrically, as shown, by a tie bar through current limiting reactors. Each of 12% reactance based up on the rating of the machine to which it is connected .A three-phase feeder is supplied from the bus bar of generator A at a line voltage of 6.6 KV .the feeder has a resistance of 0.06Ω/phase and an inductive reactance of 0.12Ω/phase. Estimate the maximum MVA that can be fed into a symmetrical short circuit at the far end of the feeder.

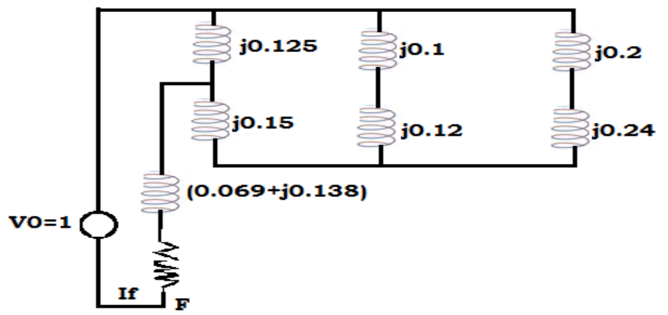


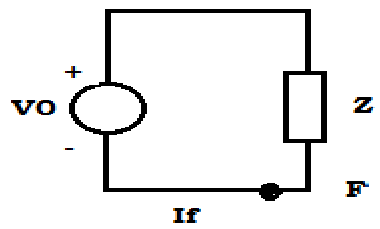
Solution:

Choose as base 50MVA, 6.6KV

$$\text{Feeder impedance} = \frac{(0.06 + j0.12) \times 50}{(6.6)^2}$$
$$= (0.069 + j0.138)\text{p.u}$$
$$\text{Gen A reactance} = \frac{0.1 \times 50}{40} = 0.125 \text{ pu}$$
$$\text{Gen B reactance} = 0.1\text{pu}$$
$$\text{Gen C reactance} = \frac{0.1 \times 50}{25} = 0.2 \text{ pu}$$
$$\text{Reactor A reactance} = \frac{0.12 \times 50}{40} = 0.15 \text{ pu}$$
$$\text{Reactor B reactance} = 0.12\text{pu}$$
$$\text{Reactor C reactance} = \frac{0.12 \times 50}{25} = 0.24\text{pu}$$

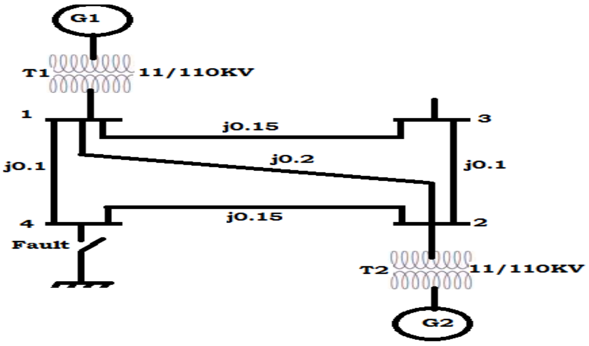
Assume no load prefault conditions i.e. prefault currents are zero,
Post fault current can then be calculated by the circuit model,
The circuit is easily reduced to that.



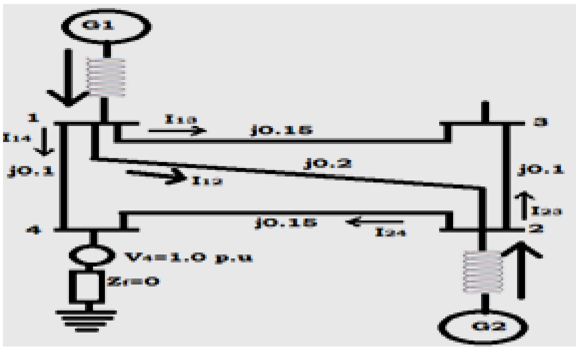


$$Z = (0.069 + j0.138) + j0.125 \| (j0.15 + j0.22 \| j0.44)$$
$$= 0.069 + j0.226$$
$$= 0.236\angle 73°$$
$$\text{SC MVA} = V^0 I^f = V^0\left(\frac{V^0}{Z}\right) = \frac{1}{Z}\text{pu(since } V^0 = 1\text{pu)}$$
$$= \frac{1}{Z} \times (\text{MVA})_{\text{Base}}$$
$$= \frac{50}{0.236} = 212 \text{ MVA}$$

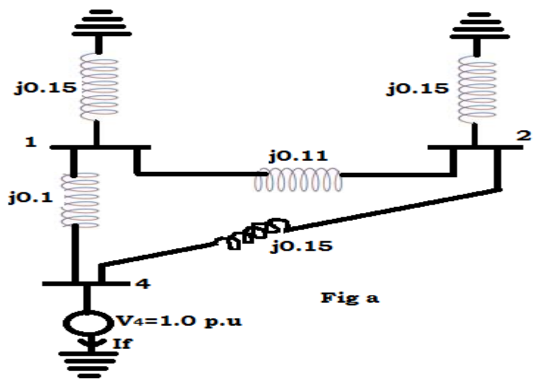
27. Consider the four bus system, buses 1 and 2 are generator buses and 3 and 4 are load buses. The generators are rated 11KV, 100MVA, with transient reactance of 10% each. Both the transformer is 11/110KV, 100MVA with a leakage reactance of5%. The reactance of lines to a base of 100 MVA,110KV.obtain the short circuit solution for a three-phase solid fault on bus 4(load bus) Assume prefault voltages to be 1 p.u And prefault current to be zero.



Solution:
Change in voltages and current caused by a short circuit can be calculated from the circuit model.



Fault current I^f is calculated by systematic network reduction.
Fig e



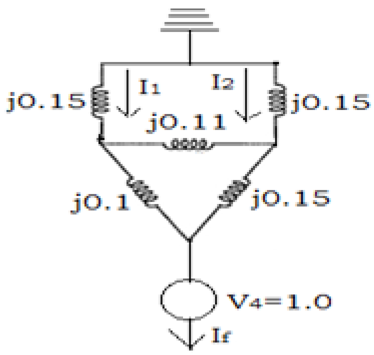


Fig (b)

Fault current is $I^f = \frac{1.0}{j0.13560} = -j7.37463\ p.u$ Fig d,

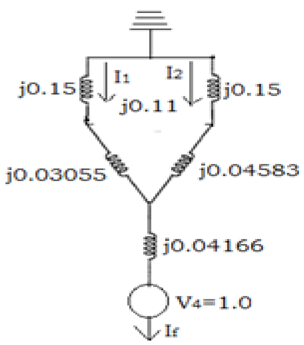


Fig (C)

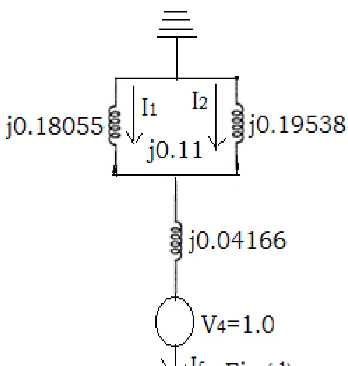


Fig (d)

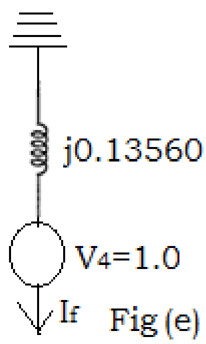


Fig (e)

$$I_1 = I^f \times \frac{j0.19583}{j0.37638} = -j3.83701\ p.u$$

$$I_2 = I^f \times \frac{j0.18055}{j0.37638} = -j3.53762\ p.u$$

Let us compute the voltage changes for buses 1,2 and 3 from fig b.

$$\Delta V_1 = 0 - (j0.15)(-j3.83701) = -j0.57555\ p.u$$

$$\Delta V_2 = 0 - (j0.15)(-j3.53762) = -j0.53064\ p.u$$

Now

$$V_1^f = 1 + \Delta V_1 = 0.42445\ p.u$$

$$V_2^f = 1 + \Delta V_2 = 0.46936\ p.u$$

$$I_{13} = \frac{V_1^f - V_2^f}{j0.15 + j0.1} = j0.17964\ p.u$$

$$\Delta V_3 = 0 - [(j0.15)(-j3.83701) + (j0.15)(j0.17964)]$$

$$= -0.54860\ p.u$$

$$\mathrm{V^f} = 1 - 0.54860 = 0.4514\mathrm{p.u}$$

$$V_4^f = 0$$

Short circuit MVA at bus 4 $(SC\ MVA)_4 = 7.37463 \times 100 = 737.643\ MVA$

UNIT IV

2 Marks

1 .Name the fault in which positive negative and zero sequence components current are equal?

In single line to ground fault the positive and negative sequence and zero sequence component current are equal.

2 .Name the fault in which positive and negative sequence component current is equal to zero sequence current in magnitude. (May /June 2012).

Double line-to-ground fault

3. Name the various unsymmetrical faults in a power system? (Apr/may-2008)

The unsymmetrical faults in power systems are,

Single line to ground fault

Line to line fault

Double line to ground fault

Open conductor fault.

4. Define negative sequence impedance? (May/June-2012, Nov/Dec-2011)

The negative sequence impedance of equipment is the impedance offered by the equipment to the flow of negative sequence current.

5. Name the fault which does not have zero sequence current flowing? (Nov/Dec-2011)

In line to line faults the zero sequence current does not flow.

6. Name the fault involving ground?

The fault involving grounds are,

- Single line to ground fault.
- Double line to ground fault.
- Three phase fault.

7. Define positive sequence impedance?

The positive sequence impedance of equipment is the impedance offered by the equipment to the flow of positive sequence currents.

8. In what type of fault the positive sequence component of current is equal in magnitude but opposite in phase to negative sequence components of current?

Line to line fault.

9. In which fault the negative and zero sequence current are absent?

In three phases fault the negative and zero sequence current are absents.

10. Write the boundary condition in single line to ground faults?(Nov/Dec 2013)

The boundary condition are $V_a = 0$; $I_b=I_c=0$

11. What is the boundary condition in line to line fault?

$I_a = 0$; $I_b+I_c=0$; $V_b=V_c$

12. Write down the boundary condition in double line to ground fault?

$I_a=0$; $V_b=0$; $V_c=0$

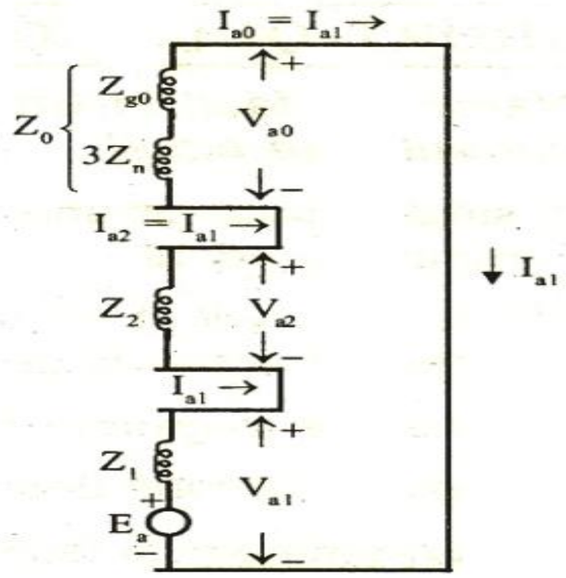
13. Give the boundary condition for the 3 phase fault? (May/June-2012)

$I_a+I_b+I_c=0$;

$V_a=V_b=V_c=0$.

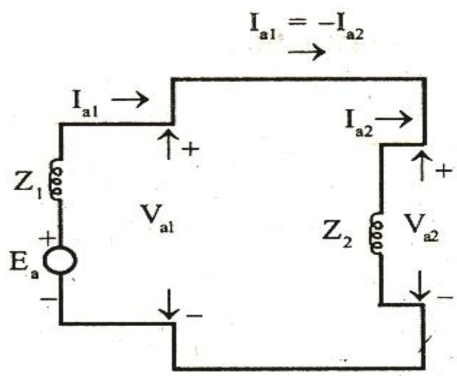
14. Draw the condition of sequence networks for a single line to ground fault at the terminal of an unloaded generator?

Connection of sequence network of an unloaded generator for line to ground fault on phase a



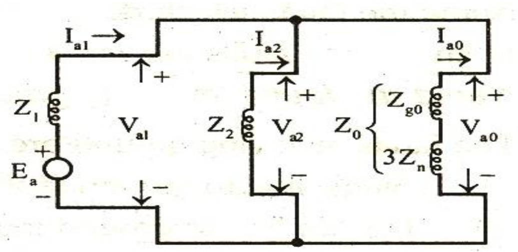
15. Draw the connection of sequence network for a line to line fault at the terminals of an unloaded generator?

Connection of sequence network of an unloaded generator for line to ground fault on phase b and c.

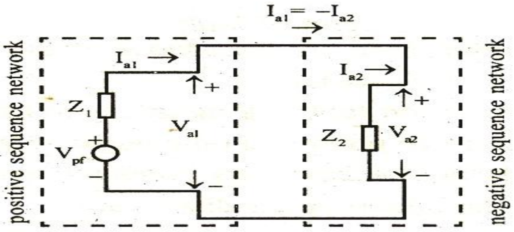


16. Draw the connections of sequence network for a double line to ground fault at the terminal of an unloaded generator?

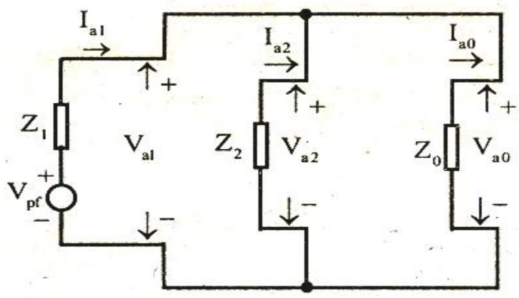
Connection of the sequence network of an unloaded generator for a double line to ground fault on phase b and c.



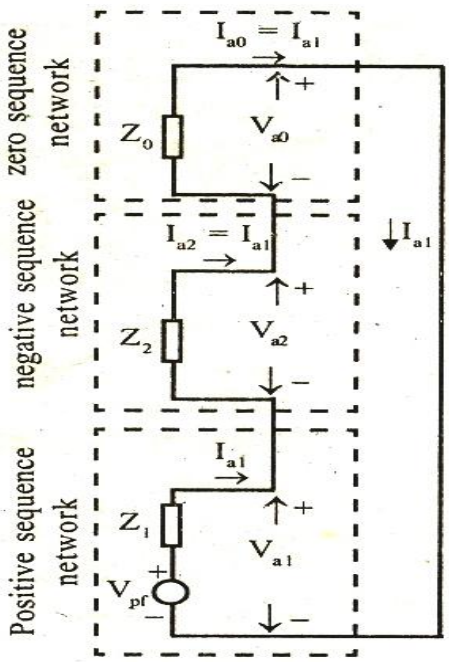
17. Draw the connections of sequence network for line to line fault without fault impedance?



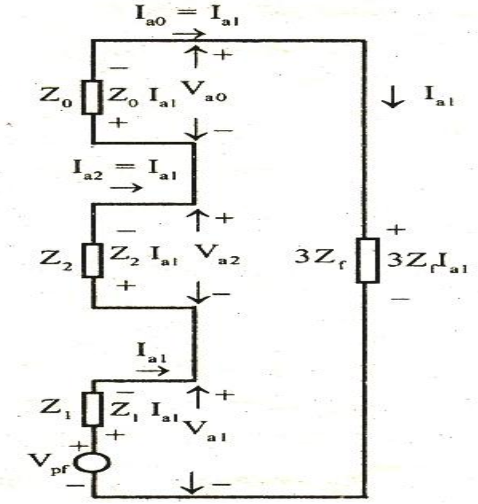
18. Draw the connections of sequence network for double line to line fault without fault impedance?



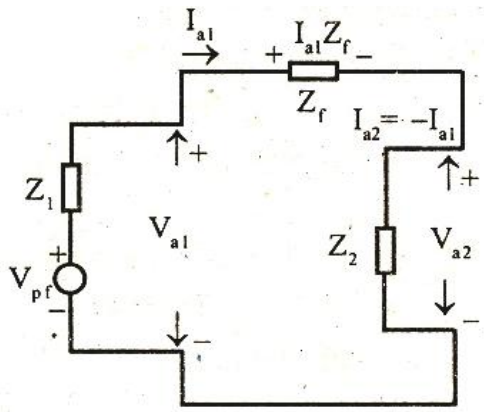
19. Draw the connections of sequence network for single line to line fault without fault impedance? (April/May-2005)



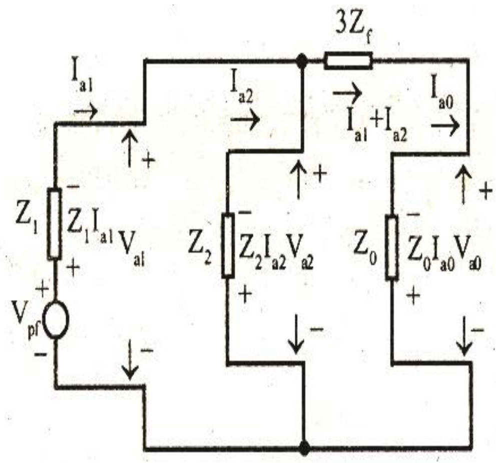
20. Draw the connections of sequence network for single line to line fault through fault impedance? (April/May-2005)



21. Draw the connections of sequence network for line to line fault through impedance?



22. Draw the connections of sequence network for double line to line ground fault through impedance?



23. Write the matrix notation of the operator which relates the phasor the V_a, V_b and V_c with V_{a0}, V_{a1} and V_{a2}. (May/June-2012)

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix}$$

24. Write the symmetrical components of three phase system? (Apr/May-2011, Nov/Dec-2015,May/June-2016)

The symmetrical components of three phase system,

- Positive sequence components.
- Negative sequence components.
- Zero sequence components.

25. List the symmetrical and unsymmetrical faults? (May/June-2006)

The three phase fault is the only symmetric fault.

The unsymmetrical faults are,

- Line to line fault.
- Line to ground fault.
- Double line to ground fault.
- One or two open conductor faults

26. **What are symmetrical components? (Nov/Dec 2014)**

An unbalanced system of N related vectors can be resolved into N systems of balanced vectors. The N-sets of balanced vectors are called symmetrical components. Each set consists of N vectors which are equal in length and having equal phase angles between adjacent vectors.

27. What is meant by symmetrical fault? (Apr/May 2018)

The fault is called symmetrical fault if the fault current is equal in all the phases. This fault conditions are analyzed on per phase basis using thevenin's theorem or using bus impedance matrix. The three phase fault is the only symmetrical fault.

28. What is sequence operator?(Nov/Dec-2015)

We define a new complex operator α which has a magnitude of unit and when operated on any complex number rotates it anti-clockwise by an angle of $120\,°i.e.1\angle 120\,° = -0.5 + j0.866$

29. What are Positive sequence components?

The positive sequence components of a 3 phase unbalanced vectors consists of 3 vectors of equal magnitude, displaced from each other by 120° in phase and having the same phase sequence as the original vectors.

30. What are negative sequence components?

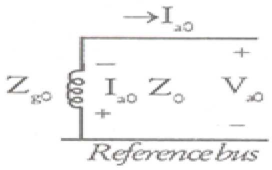
The negative sequence components of a 3 phase unbalanced vectors consists of 3 vectors of equal magnitude, displaced from each other by 120°

in phase and having the phase sequence opposite to that of the original vectors.

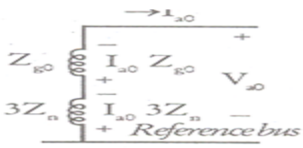
31. What are Zero sequence components?

The Zero sequence components of a 3 phase unbalanced vectors consists of 3 vectors of equal magnitude, and zero phase displacement from each other.

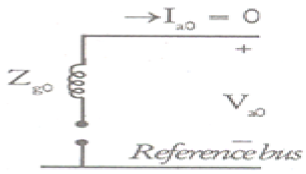
32. Draw the zero sequence networks of a generator when the neutral is grounded and when it is ungrounded? (Apr/May 2017)



Neutral is solidly ground



Neutral ground through reactance



Neutral is ungrounded

33. What are the features of zero sequence currents? (May /June 2014)(Nov 2017)

- The zero sequence currents of all three phases are equal in magnitudes and are in phase with each other.
- The zero sequence currents flow only through the faulted line to ground via the neutral.

34. Write the symmetrical component currents of phase 'a' in terms of three phase currents. (May /June 2014,May/June-2016) (Apr/May 2017)(Nov 2017)

$$I_{a0} = \frac{1}{3}[I_a + I_b + I_c];\ I_{a1} = \frac{1}{3}[I_a + \alpha I_b + \alpha^2 I_c]; I_{a2} = \frac{1}{3}[I_a + \alpha^2 I_b + \alpha I_c]$$

35. What are Sequence impedances and Sequence networks? (Nov/Dec 2014)(Apr/May 2018)

The Sequence impedances are impedances offered by the circuit elements to positive, negative and zero sequence currents.

The Single phase equivalent circuit of power system formed by using impedances of any one sequence only is called Sequence networks for the particular Sequence.

36. Derive the expression for neutral grounding reactance such that the single line to ground fault current is less than the three phase fault current? (Apr/May 2015)

$$\text{Fault current in an L} - \text{G fault}\ \ I_{L-G}^{F} = \frac{3|E_a|}{2X_1 + X_0 + 3X_n}$$

$$\text{Fault current in symmetrical fault}\ I_{sym} = \frac{3|E_a|}{3X_1}$$

$$I_{L-G}^{F} = I_{sym}; \frac{3|E_a|}{2X_1 + X_0 + 3X_n} = \frac{3|E_a|}{3X_1}$$

$$2X_1 + X_0 + 3X_n > 3X_1$$

$$3X_n = \frac{1}{3}(X_1 - X_0)$$

$$X_1 = \text{positive sequence reactance}$$

X_2 = Negative sequence reactance
X_0 = zero sequence reactance
E_a = Phase voltage

37. Give the reason why, the negative sequence impedance of a transmission line as equal to positive sequence impedance of the line? (Apr/May 2015) (Nov/Dec 2016)

For static devices such as transmission lines, the phase sequence has no effect on the impedance, because the voltage and currents encounter the same geometry of the line, irrespective of the sequence. Thus positive and negative sequence impedances are equal.

i.e.,Z_1=Z_2

PART-B

1. Explain about Symmetrical components. (Nov/Dec 2014)

The majority of faults in power system are asymmetrical. To analyze an asymmetrical fault. An unbalanced three phase circuit has to be solved, by using symmetrical component.

3 phase unbalanced current (or) voltage are transformed into three sets of balanced voltage (or) currents called as symmetrical components.

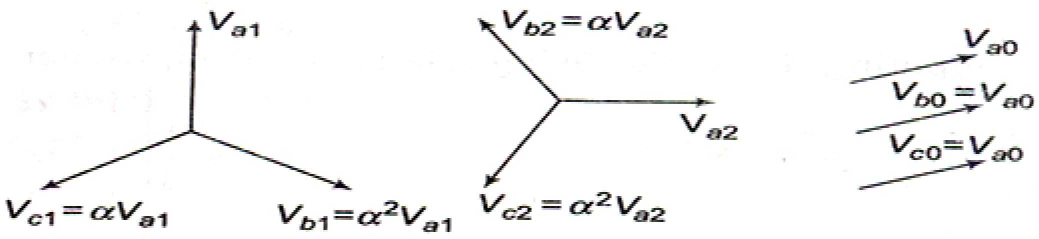
GENERAL PRINCIPLES:

Any set of unbalanced 3 phases (voltage (or) current) can be transformed into 3 balanced sets.

BALANCED SETS ARE:

1. A positive sequence set of three symmetrical voltage (all equal magnitude and displaced by 120°) having same phase sequence abc as original set detonated by V_{a1},V_{b1},&V_{c1}.
2. A negative sequence set of three symmetrical voltage having the phase sequence opposite to that of original set and denoted by V_{a2},V_{b2}&V_{c2}.
3. A zero sequence set of 3 phase voltages, all equal in magnitude and in phase with each other and denoted by V_{ao},V_{bo}&V_{co}.

Positive, negative and zero sequence set are known as symmetrical components; 3 phase voltage obtained by adding symmetrical components.



$V_a = V_{a1}+V_{a2}+V_{ao}$

$V_b = V_{b1}+V_{b2}+V_{bo}$

$V_c = V_{c1}+V_{c2}+V_{co}$

FORTESCUE'S THEROEM:

The fortescue's theorem states that 3 phase unbalanced phasor of a 3 phase system can be resolved in to three components of balanced phasor.

Let V_a, V_b, V_c be a set of three phase unbalanced voltage vectors.

Let V_{a1}, V_{b2}, V_{c1} = Positive sequence components of voltages.

V_{a2}, V_{b2}, V_{c2} = Negative sequence components of voltages.

V_{a0}, V_{b0}, V_{c0} = Zero sequence components of voltages.

Now the unbalanced voltage vectors are related to sequence component voltages by the following equations.

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ a^2 & a & 1 \\ a & a^2 & 1 \end{bmatrix} \begin{bmatrix} V_{a1} \\ V_{a2} \\ V_{a0} \end{bmatrix} -------- 1$$

$$V_p = [A][V_s]$$

$$\begin{bmatrix} V_{a1} \\ V_{a2} \\ V_{a0} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & a & a^2 \\ 1 & a^2 & a \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} -------- 2$$

$$V_{a1} = \frac{1}{3}[V_a + aV_b + a^2V_c]$$

$$V_{a2} = \frac{1}{3}[V_a + a^2V_b + aV_c]$$

$$V_{a0} = \frac{1}{3}[V_a + V_b + V_c]$$

$$V_{b1} = a^2V_{a1} \& V_{c1} = aV_{a1} -------- 4$$

$$V_{b2} = aV_{a2} \& V_{c2} = a^2V_{a2} -------- 5$$

$$a = 1\angle 120^0 \& a^2 = 1\angle 240^0 --------- 6$$

Let I_a, I_b, I_c be a set of three phase unbalanced current vectors.

Let I_{a1}, I_{b2}, I_{c1} = Positive sequence components of Currents.

I_{a2}, I_{b2}, I_{c2} = Negative sequence components of Currents.

I_{a0}, I_{b0}, I_{c0} = Zero sequence components of Currents.

Now the unbalanced currents vectors are related to sequence component Currents by the following equations.

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} -------- 1$$

$$\begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} -------- 2$$

$$I_{a0} = I_{b0} = I_{c0} -------- 3$$

$$I_{b1} = a^2 I_{a1} \& I_{c1} = aI_{a1} -------- 4$$

$$I_{b2} = aI_{a2} \& I_{c2} = a^2 I_{a2} -------- 5$$

$$a = 1\angle 120^0 \& a^2 = 1\angle 240^0 --------- 6$$

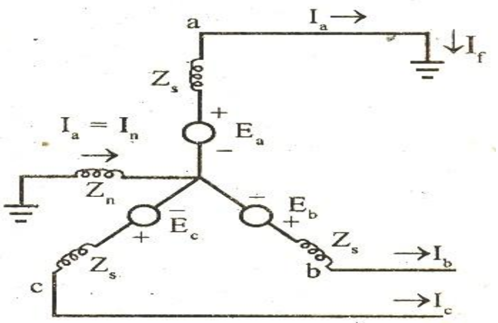
2.SEQUENCE IMPEDANCES AND NETWORKS OF SYNCHRONOUS MACHINE:

An unloaded synchronous machine (generator (or) motor) grounded through reactor (impedanceZ_n).

E_a, E_b and E_c – induced Emfs of the three phases when fault takes place at machine terminal,

I_a, $I_b$and I_c– Line current. Whenever fault involves ground current $I_N = I_a + I_b + I_c$ flow to neutral from ground via Z_N,

Unbalanced line current can be resolved into their symmetrical components $I_{a1} + I_{a2} + I_{a0}$.



POSITIVE SEQUENCE IMPEDENCE NET WORK:

Synchronous machine having symmetrical winding, if induces E MF of positive sequence only.[no negative, zero sequence voltage induced in it] when the machine carries positive sequence current only. This mode of operation is balanced mode.

Sub transient reactance ($X_d^{''}$)

Transient reactance ($X_d^{'}$)

Steady state reactance (X_d)

Positive sequence impedance of the machine is

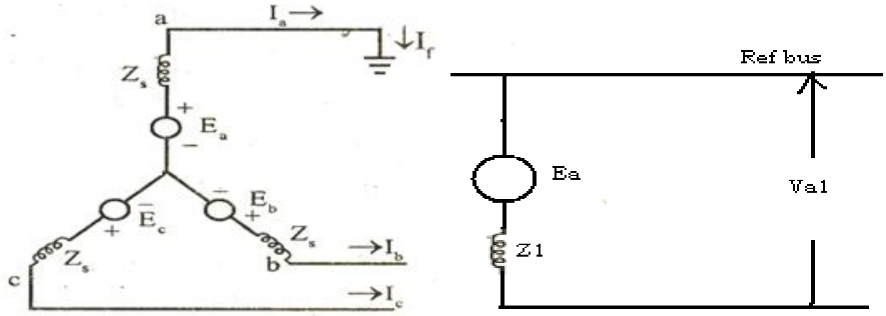
$Z_1 = jX_d^{''}$ (if 1 cycle transient)

$= jX_d^{'}$ (if 3-4 cycle transient)

$= jX_d$ (Steady state value)

Positive sequence voltage of terminal a with respect to reference bus

$$V_{a1} = E_a - Z_1 I_{a1}$$



NEGATIVE SEQUENCE IMPEDANCCE AND NW:

Synchronous machine has zero negative sequence induce voltages with flow of negative sequence currents in the stator a rotating filed is created which rotates in the opposite direction to positive sequence field.

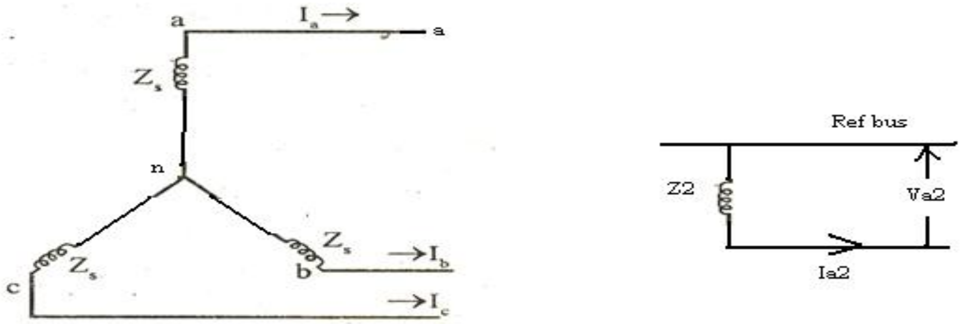
Double synchronous speeds with respect to rotor current at double the stator frequency are therefore induced in rotor Field and damper winding.

In sweeping over the rotor surface the negative sequence MMF is alternately presented by the machine with consideration given to the damper windings.

$$Z_2 = \frac{jX_q'' + X_d''}{2}; |Z_2| < |Z_1|$$

Negative sequence voltage of terminal a with respect to reference bus

$$V_{a2} = -Z_2 I_{a2}$$



ZERO SEQUENCE IMPEDANCE AND NETWORK:

There is no zero sequence voltage are induced in a synchronous machine. Flows of zero sequence current create three MMF which are in time phase but distributed in space phase by 120°. The resultant air gap field caused by zero sequence current is zero.

Rotor winding present leakage reactance only to the flow of zero sequence current $Z_{0g} < Z_2 < Z_1$

Zero sequence voltage of terminal a with respect to ground (ref bus)

Current flowing the impedanceZ_n between neutral& ground is $I_n = 3I_{a0}$

$V_{a0} = -3Z_n I_{a0} - Z_{0g} I_{a0}$

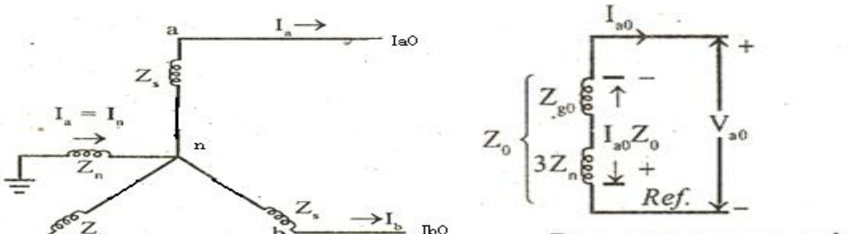
$\quad = -(3Z_n I_{a0} + Z_{0g}) I_{a0}$ $\qquad Z_{0g}$ – zero sequence impedance per phase

Total zero sequence impedance

$$Z_0 = 3Z_n + Z_{0g}$$

Zero sequence voltage of point a with respect to ref bus

$$V_{a0} = -Z_0 I_{a0} \ ; E_{a0} = 0$$



Zero sequence network of a generator

3. What are the assumptions to be made in short circuit studies? (May/June-2016)(Nov/Dec 2017)

(i) The normal loads, line charging capacitances and other shunt connections to be grounded are neglected. This is based on the fact that the faulted circuit has predominantly lower impedance than the shunt impedances. The saving in computational effort as a result of this assumption justifies the slight loss in accuracy.

(ii)the generator is represented by a voltage source in series with a reactance that is taken as the subtransient or transient reactance. Such a representation is adequate to compute the magnitudes of current in the first 3-4 cycles after the fault occurrence.in addition,all these voltages are assumed to be equal.

(iii)All the transformers are considered to be at their nominal taps.

(iv)the resistance of transmission lines are smaller than the reactances by a factor of five or more,they are neglected.this obviates the need for complex arithmetic and the system will then consist of voltage sources and reactances only.

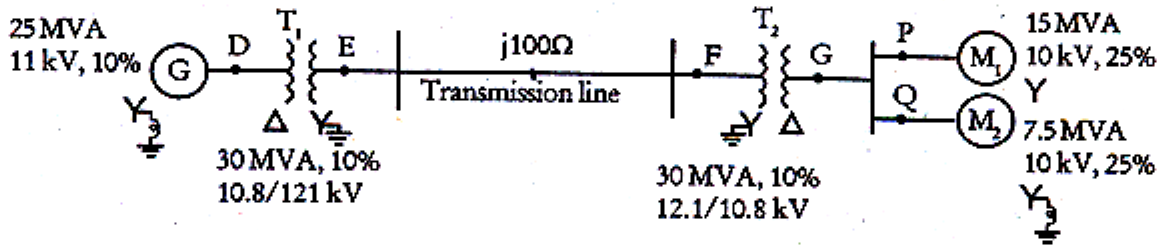
4.A 25MVA,11KV, three phase generator has sub transient reactance of 20%.the generator supplies two motor over a transmission line with transformer both ends as shown in one line diagram. The motor have rated inputs of 15 and 7.5 MVA, both rated 10KV with 25% sub transient reactance the three phase transformer are both rated 30 MVA,10.8/121 KV, connection.

$\Delta - Y$With leakage reactance of 10% each, series reactance of line is 100Ω.

Draw the positive and negative sequence network of the system with reactance marked in p.u.

Assume the negative sequence reactance of each machine is equal to sub transient reactance. Select generator rating as base on generator circuit. (Apr/May 2018)

Given Data:



To find:
Positive sequence, negative sequence
Formula used:

$$Z_{new} = Z_{old} \times \left(\frac{MVA_{new}}{MVA_{old}}\right) \times \left(\frac{KV_{new}}{KV_{old}}\right)^2$$

$$Z_{new} = Z \times \frac{MVA}{(KV)^2}$$

$$Z_n = 3Z_0$$

Solution:[Base value=25MVA,11KV]

$$\text{Transmission line voltage } = 11 \times \frac{121}{10.8} = 123.2KV$$

$$\text{Motor voltage Base } = 123.2 \times \frac{10.8}{121} = 11KV$$

Reactance of transformer, transmission line and motor converted to p.u.base.

$$\text{Transformer reactance } T_1; Z_{new} = Z_{old} \times \left(\frac{MVA_{new}}{MVA_{old}}\right) \times \left(\frac{KV_{new}}{KV_{old}}\right)^2$$

$$= 0.1 \times \left(\frac{25}{30}\right) \times \left(\frac{10.8}{11}\right)^2$$

$$= 0.0803pu$$

$$\text{Transmission line reactance} = Z \times \frac{MVA}{(KV)^2}$$

$$= 100 \times \frac{25}{(123.2)^2}$$

$$= 0.164PU$$

$$\text{Reactance of motor 1;}. Z_{new} = Z_{old} \times \left(\frac{MVA_{new}}{MVA_{old}}\right) \times \left(\frac{KV_{new}}{KV_{old}}\right)^2$$

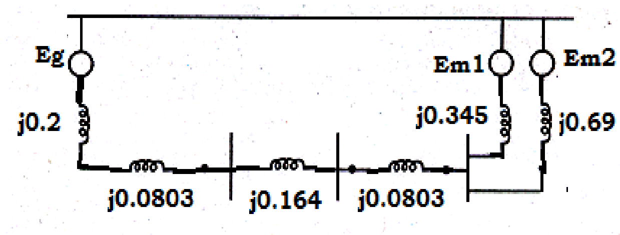
$$= 0 \cdot 25 \times \left(\frac{25}{11}\right) \times \left(\frac{10}{11}\right)^2$$

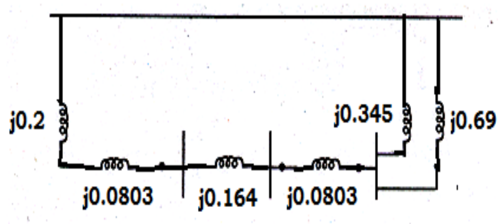
$$= 0 \cdot 344 \text{ pu}$$

$$\text{Reactance of motor 2;}. Z_{new} = Z_{old} \times \left(\frac{MVA_{new}}{MVA_{old}}\right) \times \left(\frac{KV_{new}}{KV_{old}}\right)^2$$

$$= 0 \cdot 25 \times \left(\frac{25}{7 \cdot 5}\right) \times \left(\frac{10}{11}\right)^2$$

$$= 0 \cdot 69 \text{ pu}$$





Positive sequence reactance Negative sequence reactance

Negative sequence reactance is equal to positive sequence reactance omission of voltage source.

5.Draw the zero sequence network for the system .Assume zero sequence reactance for generator and motor of 0.06pu. Current limiting reactance of 2.5Ω each are connected in neutral of generator and motor no:2,the zero sequence reactance of transmission line is 300Ω.

Zero sequence reactance of Transformer $T_1; Z_{new} = Z_{old} \times \left(\frac{MVA_{new}}{MVA_{old}}\right) \times \left(\frac{KV_{new}}{KV_{old}}\right)^2$

$$= 0.1 \times \left(\frac{25}{30}\right) \times \left(\frac{10.8}{11}\right)^2$$

$$= 0.0803 \text{ Both } T_1 \text{and } T_2$$

Generator reactance given by 0.06

$$\text{Zero sequence reactance of motor } M_1; Z_{new} = Z_{old} \times \left(\frac{MVA_{new}}{MVA_{old}}\right) \times \left(\frac{KV_{new}}{KV_{old}}\right)^2$$

$$= 0 \cdot 06 \times \left(\frac{25}{15}\right) \times \left(\frac{10}{11}\right)^2$$

$$= 0 \cdot 082 \text{pu}$$

$$\text{Zero sequence reactance of motor } M_1; Z_{new} = Z_{old} \times \left(\frac{MVA_{new}}{MVA_{old}}\right) \times \left(\frac{KV_{new}}{KV_{old}}\right)^2$$

$$= 0 \cdot 06 \times \left(\frac{25}{7.5}\right) \times \left(\frac{10}{7.5}\right)^2$$

$$= 0 \cdot 165 \text{pu}$$

$$\text{Reactance of current limiting reactor} = z \times \frac{MVA}{(KV)^2}$$

$$= 2 \cdot 5 \times \frac{25}{11^2}$$

$$= 0 \cdot 516 \text{PU}$$

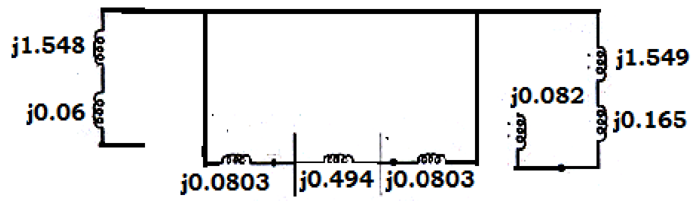
$$\text{current limiting reactor in zero sequence network} Z_n = 3 \times Z_0$$

$$Z_n = 3 \times 0 \cdot 516 \text{PU}$$

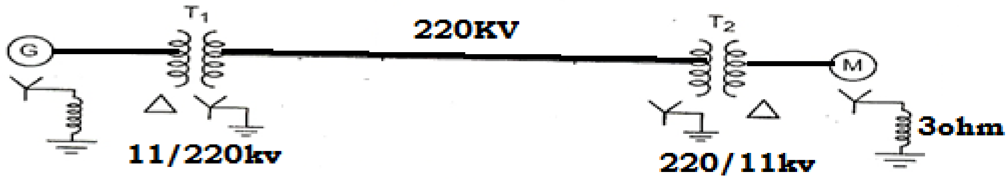
$$= 1.549 \text{ pu}$$

$$\text{Zero sequence reactance of transmission line } = z \times \frac{MVA}{KV^2}$$

$$= 300 \times \frac{25}{(123.2)^2} = 0.494 \text{ PU}$$



6.Power system network shown in Fig. Draw zero sequence networks for this system.[Nov/Dec-13]



Given Data:

$\mathbf{G_1 = 50MVA, 11KV, X_0 = 0.08\ pu}$

$\mathbf{T_1 = 50MVA, 11/220KV, X_0 = 0.1pu}$

$\mathbf{G_2 = 30MVA, 11KV, X_0 = 0.07\ pu}$

$\mathbf{T_2 = 30MVA, 11/220KV, X_0 = 0.09\ pu}$

Zero sequence impedance of transmission line is $\mathbf{555.6\Omega}$

To find:

Draw the zero sequence reactance diagram.

Formula used:

$$Z_{pu} = z \times \frac{MVA}{(KV)^2}$$

Solution:

$$\text{Base MVA} = 50$$

$$\text{Base voltage} = 11KV \text{ For LT side}$$

$$= 220KV \text{ For HT side}$$

$$\text{P.u. impedance of transmission line}; Z_{pu} = z \times \frac{MVA}{(KV)^2}$$

$$= 555.6 \times \frac{50}{(220)^2}$$

$$= j0.547pu$$

$$\text{P.u. Reactance of } T_2 = X_0 \times \frac{MVA_B}{MVA_{Act}}$$

$$= 0.09 \times \frac{50}{30} = j0.15$$

$$\text{P.u. Reactance of } T_1 = X_0 \times \frac{MVA_B}{MVA_{Act}}$$

$$= 0.1 \times \frac{50}{50} = j0.1$$

$$\text{P.u. Reactance of } G_1 = X_0 \times \frac{MVA_B}{MVA_{Act}}$$

$$= 0.08 \times \frac{50}{50} = j0.08$$

$$\text{P.u. Reactance of } G_2 = X_0 \times \frac{MVA_B}{MVA_{Act}}$$

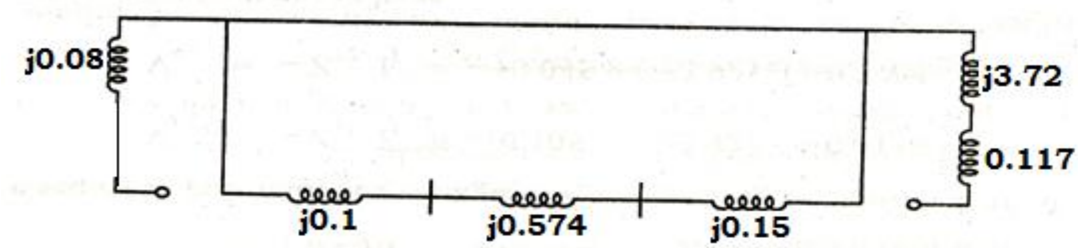
$$= 0.07 \times \frac{50}{30} = j0.117 \text{ P.u.}$$

Impedance of neutral reactor $Z_0 = z \times \frac{MVA}{(KV)^2}$

$$Z_0 = 3 \times \frac{50}{(11)^2} = 1.239$$

$$Z_n = 3 \times Z_0 = 3 \times 1.239 = 3.72$$

Zero sequence reactance diagram:



7.Derive an expression for total power in a three phase system in terms of sequence components of voltage and currents [Nov/Dec-2012,2015]

Power invariance of symmetrical components:

The symmetrical components of transmission line is power invariant, which means that the sum of powers of the three symmetrical components equal the three phase power.

Total complex power in a three phase circuit is.

$$S = P + jQ = V_p^T I_P^*$$

$$= V_a I_a^* + V_b I_b^* + V_c I_C^*$$

$$S = [AV_S]^T [AV_S]^*$$

$$= V_S^T A^T A^* I_S^*$$

$$A^T A^* = \begin{bmatrix} 1 & a^2 & a \\ 1 & a & a^2 \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} 1 & 1 & 1 \\ a & a^2 & 1 \\ a^2 & a & 1 \end{bmatrix}$$

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

$$= 3[U];\ U = \text{unity matrix}$$

$$S = P + jQ = 3V_s^T\ VI_S^*$$

$$= 3V_s^T\ I_S^*$$

$$= 3V_{a1} I_{a1}^* + 3V_{a2} I_{a2}^* + 3V_{a0} I_{a0}^*$$

$$= \text{Sum of symmetrical component powers}$$

$$= 3[\text{per phase positive sequence complex power}]$$

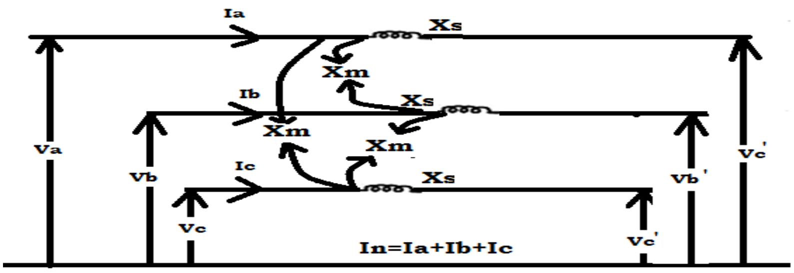
$$+ [\text{per phase Negative sequence complex power}]$$

$$+ [\text{per phase Zero sequence complex power}]$$

This is the transformation from 3-phaseunbalanced system to balanced symmetrical components system is power invariant.

8. Discuss in detail about the sequence impedance of transmission lines [Nov/Dec-12]

A fully transposed line carrying unbalanced currents, the return path for I_n is sufficiently away for the mutual effect to be ignored.



$$X_s = \text{Selfreactance of each line}$$

$$X_m = \text{mutual reactance of any line pair}$$

Apply KVL:

$$V_a - V_a' = jX_S I_a + jX_m I_b + jX_m I_c$$

$$V_b - V_b' = jX_m I_a + jX_s I_b + jX_m I_c$$

$$V_c - V_c' = jX_m I_a + jX_m I_b + jX_s I_c$$

In matrix form

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} - \begin{bmatrix} V_a' \\ V_b' \\ V_c' \end{bmatrix} = j \begin{bmatrix} X_S & X_m & X_m \\ X_m & X_s & X_m \\ X_m & X_m & X_s \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

$$V_p - V_p' = ZI_P$$

$$A(V_S - V_S') = ZAI_S$$

$$(V_S - V_S') = A^{-1}ZAI_S$$

$$A^T ZAI_S = \frac{1}{3}\begin{bmatrix} 1 & a^2 & a \\ 1 & a & a^2 \\ 1 & 1 & 1 \end{bmatrix} \times \begin{bmatrix} jX_S & jX_m & jX_m \\ j\,X_m & jX_s & jX_m \\ jX_m & jX_m & jX_s \end{bmatrix} \begin{bmatrix} 1 & 1 & 1 \\ a & a^2 & 1 \\ a^2 & a & 1 \end{bmatrix}$$

$$\begin{bmatrix} V_1 \\ V_2 \\ V_0 \end{bmatrix} - \begin{bmatrix} V_1' \\ V_2' \\ V_0' \end{bmatrix} = \begin{bmatrix} X_S - X_m & 0 & 0 \\ 0 & X_S - X_m & 0 \\ 0 & 0 & X_S + 2X_m \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_0 \end{bmatrix}$$

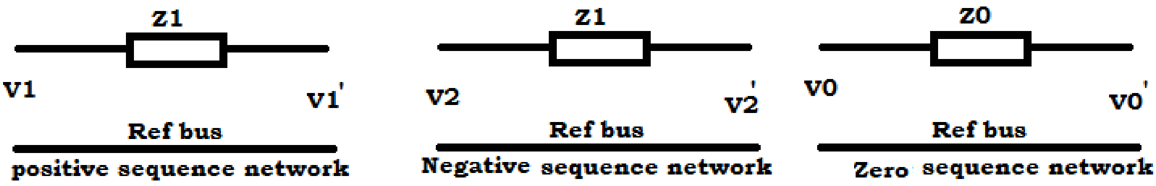
$$= \begin{bmatrix} Z_1 & 0 & 0 \\ 0 & Z_2 & 0 \\ 0 & 0 & Z_0 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_0 \end{bmatrix}$$

$$Z_1 = j(X_S - X_m) - \text{positive sequence impedance}$$

$$Z_2 = j(X_S - X_m) - \text{Negative sequence impedance}$$

$$Z_0 = j(X_S + 2X_m) - \text{Zero sequence impedance}$$

We conclude that a fully transposed transmission line has:
1.Equal positive and negative sequence impedances,
2.zero sequence impedance much larger than the positive (or negative) sequence impedance it is approximately 2.5 times.



If the mutual wire has an impedance $Z_{n,}$ than

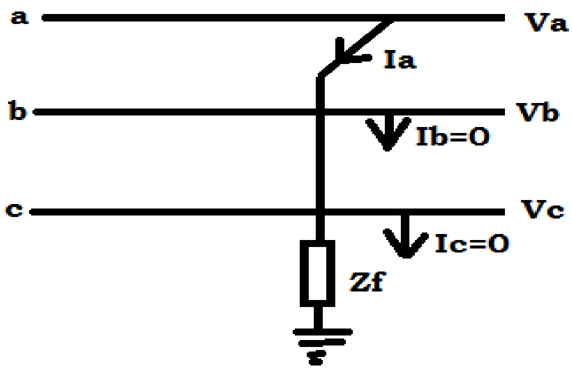
$$Z_1 = Z_2 = X_S - X_m$$

$$Z_0 = X_S + 2X_m + 3Z_n$$

9 . Analysis of line to Ground fault

Draw the sequence network connection for a single line to ground fault at any point on a power system and obtain the expression for fault current. (Nov/Dec 2017)(Apr/May 2018)

Consider a L_G fault on phase a through fault impedance Z_f shown in fig



Boundary conditions:

$$I_b = I_c = 0$$

$$V_a = Z^f I_a \text{[voltage at fault point]}$$

Transformation by symmetrical component

$$\begin{bmatrix} I_{a1} \\ I_{a2} \\ I_{a0} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & a & a^2 \\ 1 & a^2 & a \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} I_a \\ I_b = 0 \\ I_c = 0 \end{bmatrix}$$

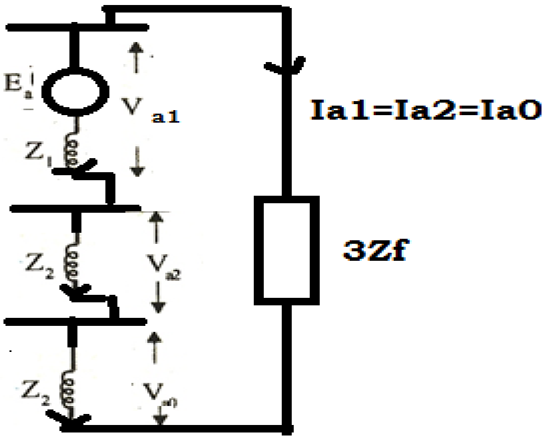
$$I_{a1} = I_{a2} = I_{a0} = \frac{1}{3} I_a \dots\dots\dots\dots (1)$$

$$I_a = \text{fault current} = 3I_{a1}$$

$$V_a = Z^f I_a$$

$$v_{a1} + V_{a2} + V_{a0} = 3I_{a1} Z^f \dots\dots\dots (2)$$

Connection of sequence networks:



Fault current $I_a = I_f = 3I_{a1} = 3I_{a2} = 3I_{a0}$

$$I_a = I_f = \frac{3E_a}{Z_1 + Z_2 + Z_3 + 3Z_f}$$

$$\therefore \text{Fault per phase voltage}, V_a = 3I_{a1}Z_f$$

$$= 3I_aZ_f$$

$$V_a = \left(\frac{3E_a}{Z_1 + Z_2 + Z_3 + 3Z_f}\right)Z_f$$

From the interconnected sequence network,

$$V_{a1} = E_a - I_{a1}Z_1$$

$$V_{a2} = -I_{a2}Z_2\ ; E_a = 0$$

$$V_{a0} = -I_{a0}Z_0\ ; E_a = 0$$

Voltage of healthy phase (b& c) can be found as

$$V_b = V_{b1} + V_{b2} + V_{b0}$$

$$V_b = \alpha^2 V_{a1} + \alpha V_{a2} + V_{a0}$$

$$V_c = V_{c1} + V_{c2} + V_{c0}$$

$$V_c = \alpha V_{c1} + \alpha^2 V_{c2} + V_{c0}$$

Line voltage are given by

$$V_{bc} = V_b - V_c$$

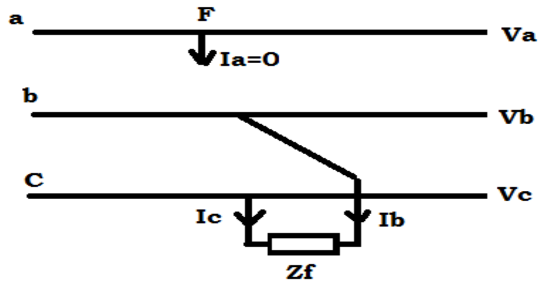
$$V_{ab} = V_a - V_b$$

$$V_{ca} = V_c - V_a$$

10.Derive the necessary equation to determine fault current for a line-to-line fault. Draw a diagram showing the interconnection of sequence networks [nov/Dec-13,May/June-2016] (Nov/Dec 2016)(Apr/May 2017)

Analysis of L-L fault

Line to Line fault at F in a power system on phase b and c through fault impedanceZ_f shown in diagram .



Boundary conditions:

$$I_a = 0$$

$$I_b = -I_c$$

$$V_b - V_c = Z^f I_b$$

$$\text{Fault current } I_f = I_b$$

Transformation:

The symmetrical components of fault current are:

$$\begin{bmatrix} I_{a1} \\ I_{a2} \\ I_{a0} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & a & a^2 \\ 1 & a^2 & a \\ 1 & 1 & 1 \end{bmatrix}\begin{bmatrix} 0 \\ I_b \\ -I_b \end{bmatrix}$$

$$I_{a1} = \frac{1}{3}[0 + \alpha I_b - \alpha^2 I_b]$$

$$= \frac{1}{3}(\alpha - \alpha^2)I_b$$

$$I_{a2} = \frac{1}{3}(\alpha^2 I_b - \alpha I_b)$$

$$= \frac{1}{3}(\alpha^2 - \alpha)I_b$$

$$I_{a1} = -I_{a2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$I_{a0} = 0$$

$$I_{a1} = \frac{1}{3}(\alpha - \alpha^2)I_b$$

$$= \frac{1}{3}\{(-0.5 + j0.866) - (-.5 - j0.866)I_b\}$$

$$= \frac{1}{3}[j1.732]I_b$$

$$= \frac{1}{3}j\sqrt{3}I_b$$

$$I_{a1} = \frac{j}{\sqrt{3}}I_b$$

$$\sqrt{3}\, I_{a1} = jI_b$$

$$I_b = -j\sqrt{3}\, I_{a1} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The symmetrical component of voltage at fault point F

$$\begin{bmatrix} V_{a1} \\ V_{a2} \\ V_{a0} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & a & a^2 \\ 1 & a^2 & a \\ 1 & 1 & 1 \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c = V_b - Z_f I_b \end{bmatrix}$$

$$V_{a1} = \frac{1}{3}[V_a + aV_b + a^2(V_b - Z_f I_b)]$$

$$= \frac{1}{3}[V_a + aV_b + a^2V_b - a^2 Z_f I_b]$$

$$3V_{a1} = [V_a + (a + a^2)V_b - a^2 Z_f I_b]$$

$$V_{a2} = \frac{1}{3}[V_a + a^2V_b + a(V_b - Z_f I_b)]$$

$$= \frac{1}{3}[V_a + a^2V_b + aV_b - aZ_f I_b$$

$$3V_{a2} = [V_a + (a^2 + a)V_b - aZ_f I_b$$

$$3[V_{a1} - V_{a2}] = (a - a^2)Z_f I_b$$

Sub $I_b = -j\sqrt{3}\, I_{a1}$

$$3[V_{a1} - V_{a2}] = (a - a^2)Z_f\left(-j\sqrt{3}\, I_{a1}\right)$$

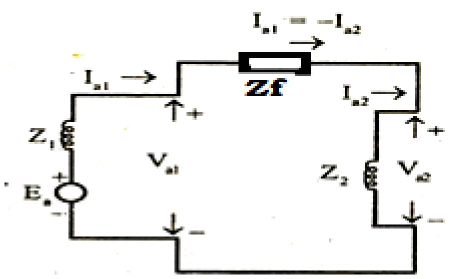
$$= (-0.5 + j0.866) - (-.5 - j0.866)Z_f\left(-j\sqrt{3}\, I_{a1}\right)$$

$$3[V_{a1} - V_{a2}] = j\sqrt{3}Z_f\left(-j\sqrt{3}\, I_{a1}\right)$$

$$3[V_{a1} - V_{a2}] = 3Z_f\, I_{a1}$$

$$[V_{a1} - V_{a2}] = Z_f\, I_{a1} \ldots\ldots\ldots\ldots (3)$$

Interconnection



The equation 1 and 3 suggest the parallel connection of positive, negative sequence network through fault impedanceZ_f

$I_{a0} = 0$ zero sequence network is unconnected.

Fault current $I_b = -j\sqrt{3}I_{a1}$

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

$$V_{a1} = E_{a1} - I_{a1}Z_1$$

$$V_{a2} = -I_{a2}Z_2; E_{a2} = 0$$

$$V_{a0} = 0$$

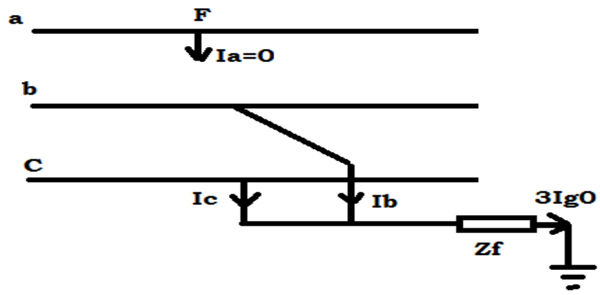
$$V_a = V_{a1} + V_{a2} + V_{a0}$$

$$V_b = a^2V_{a1} + aV_{a2} + V_{a0}$$

$$V_c = aV_{c1} + a^2V_{c2} + V_{c0}$$

11.Derive the sequence network connection for a double line to ground (LL-G) fault at any point in a power system and from that obtain an expression for fault current [NOV/DEC-2012,May/June-2016](Nov/Dec 2017)

Double line to ground fault at F in a power system, the fault has impedance Z_f as shown.



Boundary conditions:

Current and voltage (to ground) conditions at fault are $I_a = 0$

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

$$V_b = V_c = (I_b + I_c)Z_f$$

Fault current $I_f = I_b + I_C$

Transformation:

$$I_a = 0 \text{ Means } I_{a1} + I_{a2} + I_{a0} = 0$$

$$I_{a0} = \frac{1}{3}[I_a + I_b + I_c] \dots\dots\dots\dots (1)$$

$$= \frac{1}{3}[I_b + I_c] = \frac{1}{3}I_f$$

$$I_f = 3I_{a0} \dots\dots\dots\dots (2)$$

Sequence component of voltage are,

$$\begin{bmatrix} V_{a1} \\ V_{a2} \\ V_{a0} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \\ 1 & 1 & 1 \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

$$V_{a1} = \frac{1}{3}[V_a + (\alpha + \alpha^2)V_b] \dots\dots\dots\dots (3)$$

$$V_{a2} = \frac{1}{3}[V_a + (\alpha^2 + \alpha)V_b]$$

$$V_{a0} = \frac{1}{3}[V_a + 2V_b]$$

$$V_{a0} - V_{a1} = \frac{1}{3}\{[V_a + 2V_b] - [V_a + (\alpha + \alpha^2)V_b]\}$$

$$= \frac{1}{3}[2V_b - (\alpha + \alpha^2)V_b]$$

$$= \frac{1}{3}[2 - \alpha - \alpha^2]V_b$$

$$= \frac{1}{3}[2 - (-0.5 + j0.866) - (-0.5 - j0.866)]V_b$$

$$= \frac{1}{3}[2 + 0.5 - j0.866 + 0.5 + j0.866]V_b$$

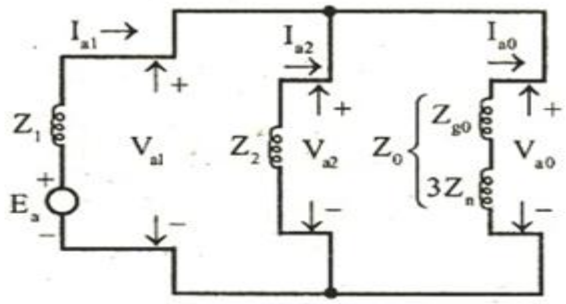
$$= \frac{1}{3}[3]V_b$$

$$V_{a0} - V_{a1} = V_b$$

Know $I_f = I_b = I_C$

$$I_f = 3I_{a0}$$
$$I_f = \frac{V}{Z_f}$$
$$V_{a0} - V_{a1} = 3I_{a0}Z_f \ldots\ldots\ldots\ldots(4)$$

The above equation 1,3,and 4 suggest the interconnection of sequence network is



From interconnected network, the thevenin's equivalents

$$I_{a1} = \frac{E_a}{Z_1 + Z_2// Z_0 + 3Z_f}$$
$$= \frac{E_a}{Z_1 + \left(\frac{Z_2 \times Z_0 + 3Z_f}{Z_2 + Z_0 + 3Z_f}\right)}$$
$$V_{a1} = E_a - I_{a1}Z_1$$
$$V_{a2} = V_{a1}$$
$$V_{a2} = E_a - I_{a2}Z_2$$
$$I_{a2} = -\frac{V_{a2}}{Z_2}$$
$$I_{a2} = -I_{a1} \times \frac{Z_2}{Z_2 + Z_0 + 3Z_f}$$
$$V_{a0} = -I_{a0}Z_0$$
$$V_a = V_{a1} + V_{a2} + V_{a0}$$
$$V_b = \alpha^2 V_{a1} + \alpha V_{a2} + V_{a0}$$
$$V_c = \alpha V_{a1} + \alpha^2 V_{a2} + V_{a0}$$
$$V_b = V_c = I_f Z_f$$

Similarly

$$I_a = I_{a1} + I_{a2} + I_{a0} = 0$$
$$I_b = \alpha^2 I_{a1} + \alpha I_{a2} + I_{a0}$$
$$I_c = \alpha I_{a1} + \alpha^2 I_{a2} + I_{a0}$$

12.A 30MVA, 11kv, 3Phase synchronous generator has a direct subtransient reactance of 0.25 p.u. the negative and zero sequence reactance are 0.35 and 0.1 p.u respectively. The neutral of generator is solidly grounded. Determine the subtransient current in the generator and the line to line voltages for subtransient conditions when a single line to ground fault occurs at the generator terminals with the generator operating unloaded at rated voltage. (Nov/Dec-2015)
(Nov/Dec 2016)

Given Data

$$E_a = 1 \text{ p.u}$$

Direct subtransient reactance $X_d'' = Z_1 = j0.25$ p.u

$$X_2 = Z_2 = j0.35 \text{ p.u}$$

$$X_0 = Z_0 = j0.1 \text{ p.u}$$

$$Z_f = 0$$

Formula used:

$$\text{Faul current } I_f = I_a = \frac{3E_a}{Z_0 + Z_1 + Z_2 + 3Z_f}$$

$$I_f = I_a = \frac{3 \times 1.0}{j0.1 + j0.25 + j0.35 + 0} = -j4.2857 \text{ p.u}$$

$$\text{Base current} = \frac{MVA_{Base}}{\sqrt{3} \times KV_{Base}} \times 10^3 = \frac{30}{\sqrt{3} \times 11} \times 10^3 = 1574.59A$$

$$\text{Faul current in A} = \text{Faul current in p.u}(I_f) \times \text{Base current}$$

Solution:

$$\text{Faul current in A} \mid I_f \mid = 4.2857 \times 1574.59 = 6748.22A$$

The symmetrical components of the voltages from point "a" to ground are:

$$I_{a0} = I_{a1} = I_{a2} = \frac{E_a}{Z_0 + Z_1 + Z_2 + 3Z_f} = \frac{1.0}{j0.1 + j0.25 + j0.35} = -j1.4286 \text{ p.u}$$

$$V_{a0} = -I_{a0} Z_0 = -(j0.1)(-j1.4286) = -0.143 \text{ p.u}$$

$$V_{a1} = E_a - I_{a1} Z_1 = 1.0 - (j0.25)(-j1.4286) = 0.643 \text{ p.u}$$

$$V_{a2} = -I_{a2} Z_2 = -(j0.35)(-j1.4286) = -0.50 \text{ p.u}$$

Line voltages are

$$V_a = V_{a0} + V_{a1} + V_{a2} = -0.143 + 0.643 - 0.50 = 0$$

$$\begin{aligned} V_b = V_{a0} + \alpha^2 V_{a1} + \alpha V_{a2} &= -0.143 + 1\angle -120° \times 0.643 + 1\angle 120° \times (0.50) \\ &= -0.143 + (-0.5 - j0.866) \times 0.643 + (-0.5 + j0.866) \times (-0.5) \\ &= -0.215 - j0.989 \text{ p.u} \end{aligned}$$

$$\begin{aligned} V_c = V_{a0} + \alpha V_{a1} + \alpha^2 V_{a2} &= -0.143 + 1\angle 120° \times 0.643 + 1\angle -120° \times (0.50) \\ &= -0.143 + (-0.5 + j0.866) \times 0.643 + (-0.5 - j0.866) \times (-0.5) \\ &= -0.215 + j0.989 \text{ p.u} \end{aligned}$$

Line to Line voltages are:

$$V_{ab} = V_a - V_b = 0 - (-0.215 - j0.989 \text{ p.u}) = 0.215 + j0.989 = 1.012\angle 77.7°$$

$$V_{bc} = V_b - V_c = (-0.215 - j0.989) + (-0.215 + j0.989) = 0 + j1.978 = 1.978\angle 270°$$

$$V_{ca} = V_c - V_a = (-0.215 + j0.989) + 0 = 1.012\angle 102.3°$$

The above line voltages are expressed in per unit of the base voltage to neutral. Therefore, the post fault line voltages expressed in Kilovolts are.

$$V_{ab} = 1.012\angle 77.7° \times \frac{11}{\sqrt{3}} = 6.427\angle 77.7° KV$$

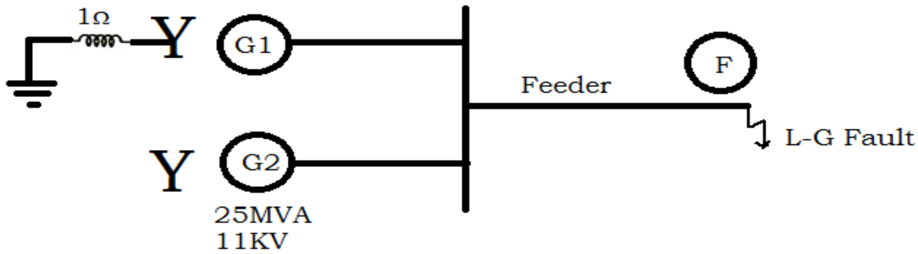
$$V_{bc} = 1.978\angle 270° \times \frac{11}{\sqrt{3}} = 12.562\angle 270°$$

$$V_{ca} = 1.012\angle 102.3° \times \frac{11}{\sqrt{3}} = 6.427\angle 102.3°$$

13.Two 25 MVA, 11 KV synchronous generators are connected to common bus bar which supplies a feeder. Star point of one of the generator is grounded through a resistor of 1 ohm while that of other is isolated. A line to ground fault occur at far end of feeder. Determine (i) fault current (ii) voltage to ground of sound phase of feeder (iii) voltage of star point of grounded generator with respect to ground.

Given data:

Sequence impedance	Generator	Feeder
Positive Sequence	−j o.2	j 0.4
Negative Sequence	−j 0.15	j 0.4
Zero Sequence	−j 0.08	j 0.8



Solution:

$$\text{MVA}_B = 25, \;\; \text{KV}_B = 11$$

$$R_n = Z \times \frac{\text{MVA}}{(\text{KV})^2} = 1 \times \frac{25}{(11)^2} = 0.2066 \text{ PU}$$

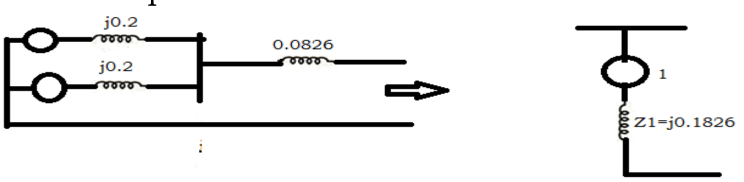
<u>Feeder reactance in PU</u>

$$\text{Positive sequence } = Z \times \frac{\text{MVA}}{(\text{KV})^2} = j\,0.4 \times \frac{25}{(11)^2} = j\,0.0826 \text{ PU}$$

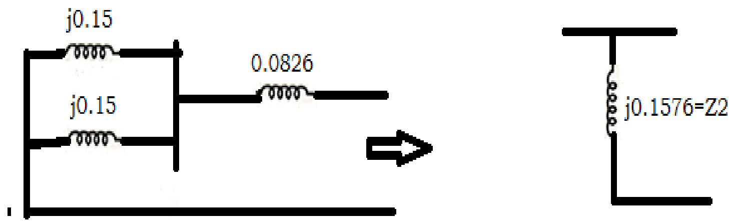
$$\text{Negative Sequence} = Z \times \frac{\text{MVA}}{(\text{KV})^2} = j\,0.4 \times \frac{25}{(11)^2} = j\,0.0826 \text{ PU}$$

$$\text{Zero Sequence} = Z \times \frac{\text{MVA}}{(\text{KV})^2} = j\,0.8 \times \frac{25}{(11)^2} = j\,0.16528 \text{ PU}$$

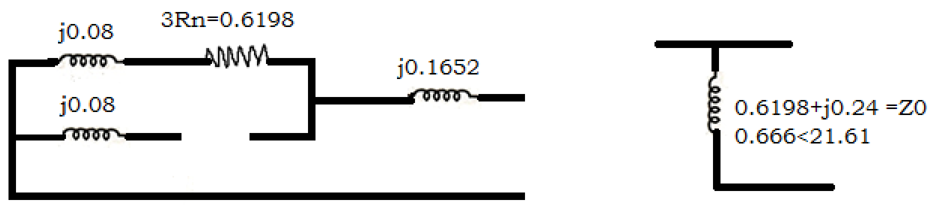
Positive sequence network



Negative sequence network



Zero sequence network



For L – G Fault the sequence network connected in series

$$I_{a1} = I_{a2} = I_{a0} = \frac{E}{Z_1 + Z_2 + Z_0} = \frac{1\angle 0}{j0.182 + j0.1576 + j0.24 + 0.6198}$$

$$= 1.177\angle -43.10 \text{ p.u}$$

Fault Current $I_f = 3I_{a1} = 3 \times 1.177\angle -43.10 = 3.533\angle -43.10 \text{ p.u}$

$$= 3.533\angle -43.10 \text{ p.u}$$

$$V_{a1} = E_{a1} - I_{a1} Z_1$$

$$= 1\angle 0 - (1.177\angle -43.1)(j\,0.1826)$$

$$= 0.8674\angle -10.42$$

$$V_{a2} = -I_{a2} Z_2$$

$$= -(1.177\angle -43.1)(j\,0.1576)$$

$$= 0.1854\angle 46.9$$

$$V_{a0} = -I_{a0} Z_0$$

$$= -(1.177\angle -43.1)(0.6198 + j0.24)$$

$$= -(1.177\angle -43.1)(0.6646\angle 21.167)$$

$$= 0.782\angle 158.06$$

$$\therefore\ V_b = a^2 V_{a1} + aV_{a2} + V_{a0}$$

$$= 1\angle 240 \times 0.867\angle -10.42 + 1\angle 120 \times 0.1854\angle 46.9 + 0.782\angle 158.06$$

$$= 1.5038\angle -167.48 \text{ p.u}$$

$$V_C = aV_{a1} + a^2 V_{a2} + V_{a0}$$

$$= 1\angle 120 \times 0.8674 - 10.42 + 1\angle 240 \times 0.1854\angle 46.9 + 0.782\angle 158.06$$

$$= 1.339\angle 135.9 \text{ p.u}$$

Voltage of star point of grounded generator w.r.t ground

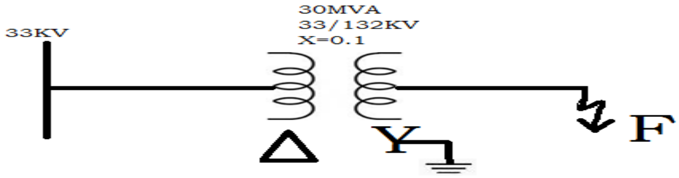
$$= 3I_{a0} \times R_n = I_f \times R_n$$

$$= 3.533\angle -43.10 \times 0.2066$$

$$= 0.7299\angle -43.1 \text{ p.u}$$

14.A 33KV bus bar has a 3 phase fault level of 1000 MVA. The negative and zero sequence source reactance's are 2/3 and 1/3 of positive sequences reactance. The zero sequence resistance is 60 Ω. A 30 MVA, 33/132 KV solidly ground Δ/Y transformer having a reactance of 0.1 of p.u is fed from 33KV bus. Find fault current and fault MVA at 132 KV bus for following faults (i) 3 phase fault, (ii) Single line to ground (iii) Line – to – Line (iv) Double line to ground fault.

Given Data



Fault level = 1000 MVA,

Formula used:

(i) $\dfrac{(KV)^2}{MVA}$ (ii) $I = \dfrac{P}{\sqrt{3} \times V}$

(i) 3ϕ fault, $I = \dfrac{V}{X}$

(ii) Single line to ground fault, $I_f = \dfrac{3E_a}{Z_1 + Z_2 + Z_0}$

(iii) Line – to – Line Fault, $I_f = \dfrac{\sqrt{3}E_a}{Z_1 + Z_2}$

(iv) Double line to ground fault $= \dfrac{E}{Z_1} + \dfrac{Z_2(Z_0 + 3Z_f)}{Z_2 + (Z_0 + 3Z_f)}$

Solution:

Let $MVA_B = 30MVA$

Positive Sequence reactance of source $= \dfrac{MVA}{\text{Fault Level}} = \dfrac{30}{1000} = 0.03$ p.u

Negative Sequence reactance of source $= \dfrac{2}{3} \times 0.03 = 0.02$ p.u

Zero Sequence reactance of source $= \dfrac{1}{3} \times 0.03 = 0.01$ p.u

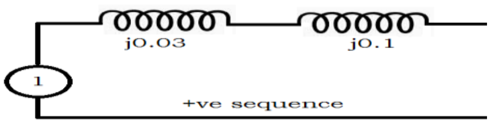
Base impedance on 33 KV Side $= \dfrac{(KV)^2}{MVA} = -\dfrac{(33)^2}{30} = 36.3\ \Omega$

Zero Sequence resistance of source $= \dfrac{60}{36.3} = 1.653$ p.u

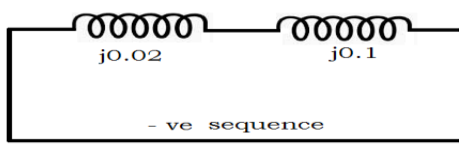
Base current for 132 KV side

$$I = \frac{P}{\sqrt{3} \times V} = \frac{30 \times 10^6}{\sqrt{3} \times 132 \times 10^3} = 131.22\ A$$

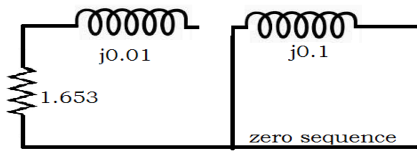
Sequence diagram



$\mathbf{X_1 = j0.13}$



$\mathbf{X_2 = j0.12}$



<u>**(a)3 ϕ fault**:</u>

$$X_1 = j0.13$$

$$\text{Fault MVA} = \frac{30}{j0.13} = 230.77 \text{ MVA}$$

$$\text{Fault Current} = \frac{V}{X} = \frac{1}{j0.13} = 7.692 \text{ p.u}$$

$$\text{Actual Fault Current} = I_{p.u} \times I_{base}$$
$$= 7.692 \times 131.22$$
$$= 1009.34 \text{ A}$$

(b)Single line to ground fault

$$I_f = \frac{3\,E_a}{Z_1 + Z_2 + Z_0} = \frac{3 \times 1\angle 0}{j0.13 + j0.12 + j0.1} = 8.571$$

$$\text{Actual Fault Current } I = I_f \times I_{Base}$$
$$= 8.571 \times 131.22$$
$$= 1124.7 \text{ A}$$

Fault Level $= \sqrt{3} \times V \times I$

$$= \sqrt{3} \times 132 \times 10^3 \times 1124.7$$
$$= 257.14 \text{ MVA (or)} 30 \times 8.571 = 257.13 \text{ MVA}$$

(c)Line – to – Line Fault

$$I_f = \frac{\sqrt{3}E}{Z_1 + Z_2} = \frac{\sqrt{3} \times 1L0}{j(0.13 + 0.12)} = 6.928 \text{ p.u}$$

$$I = I_f \times I_B = 6.928 \times 131.22 = 909.1 \text{ A}$$

Fault Level $= \sqrt{3} \times V \times I$

$$= \sqrt{3} \times 132 \times 10^3 \times 909.1$$
$$= 207.84 \text{ MVA (or)} 0.30 \times 6.928 = 207.84$$

(d) Double line to ground fault

$$I_f = \frac{E}{\left[Z_1 + \frac{Z_2(Z_0 + 3Z_f)}{Z_2 + Z_0 + 3Z_f}\right]}$$

$$= \frac{1\angle 0}{\left[j0.13 + \frac{j0.12 \times j0.1}{j0.12 + j0.1}\right]} = 5.419 \text{ p.u}$$

$$= 5.419 \times 131.2 = 711.08 \text{ A}$$

Fault Leve $= \sqrt{3} \times V \times I$

$$= \sqrt{3} \times 132 \times 10^3 \times 711.08 = 162.57 \text{ MVA}$$

15.A 50 Hz, 13.2 KV, 15 MVA, alternator has $X_1 = X_2 = 20; X_0 = 28\%$ its neutral is grounded through a reactor of 0.5Ω. Determine the initial symmetrical rms current in the grounded and in line C, when LLG Fault occurs on a phase b and c, the generator voltage is 12KV before the fault takes place.

Given data:

Alternating rating: 50 Hz, 13.2 KV, 15 MVA

$X_1 = X_2 = 20, X_0 = 8\%$

$Z_n = 0.5\Omega$

To find:

$X_n,\ I_a,\ I_c, I_g$

Formula Used:

$$X_n = Z_n \times \frac{MVA}{(KV)^2}\ ; \qquad I_a = \frac{E_a}{X_1 + \left(\frac{X_2 \times X_0}{X_2 + X_0}\right)}$$

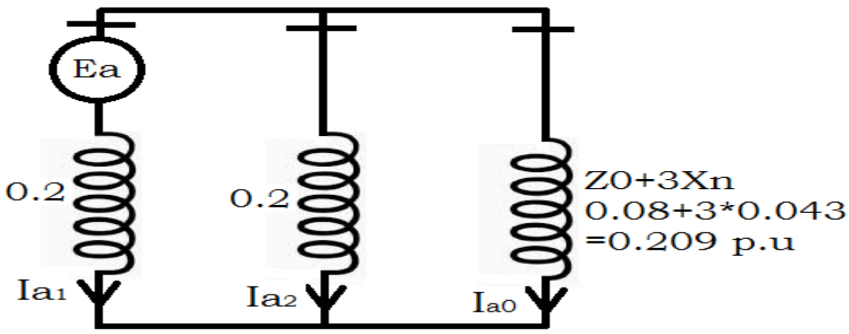
$$V_{a1} = E_{a1} - I_{a1}Z_1$$
$$V_{a2} = -I_{a2}Z_2$$
$$V_{a0} = -I_{a0}Z_0$$
$$I_c = \alpha I_{a1} + \alpha^2 I_{a2} + I_{a0}\ ; \quad I_g = 3 \times I_{a0}$$

Solution:

$MVA_B = 15, KV_B = 13.2$ (Alternating rating)

$$X_n = Z_n \times \frac{MVA}{(KV)^2} = 0.5 \times \left(\frac{15}{(13.2)^2}\right) = 0.043 \text{ p.u}$$

Sequence Network:



$$E_a = \frac{12}{13.2} = 0.909 \text{ p.u} = \frac{\text{Actual Value}}{\text{Base Value}}$$

$$I_{a1} = \frac{E_a}{j\left[0.2 + \frac{(0.2\times 0.209)}{(0.2+0.209)}\right]} = \frac{0.909}{0.3022} = -j3.00 \text{ p.u}$$

$$V_{a1} = E_{a1} - I_{a1}Z_1 = 0.909 — j3.00(j0.2) = 0.309 \text{ p.u}$$
$$V_{a2} = V_{a1} = 0.309 \text{ p.u}$$
$$V_{a2} = -I_{a2}Z_2;\ I_{a2} = -\frac{V_{a2}}{Z_2} = \frac{0.309}{j0.2} = j1.545 \text{ p.u}$$
$$V_{a0} = V_{a1} = 0.309 \text{ p.u}$$
$$V_{ao} = -I_{a0}Z_0\ ;\ I_{a0} = -\frac{V_{a0}}{Z_{a0}} = -\frac{0.309}{j0.08} = j3.863 \text{ p.u}$$

Fault Current in Line C:

$$I_c = \alpha I_{a1} + \alpha^2 I_{a2} + I_{a0} \Longrightarrow (-0.5 + j0.866)(-j3) + (-0.5 - j0.866)(j1.545) + (j3.863)$$
$$= 6.046\angle\, 49.38$$

$$I_{Base} = \frac{MVA}{\sqrt{3} \times KV} = \frac{15 \times 10^6}{\sqrt{3} \times 13.2 \times 10^3} = 656.07 \text{ A}$$

$$I_c = 6.046 \times 656.07 = 3966.65 \text{ A}$$

Fault Current in the Ground; $I_g = 3I_{a0} = 3 \times j3.863 = 11.589\angle 90^{\circ}$

$$I_g = 11.584 \times 656.07 = 7603 \text{ A}$$

16.A star connected generator has sequence reactance's $X_0 = 0.09$ p.u. $X_1 = 0.22$ p.u and $X_2 = 0.36$ p.u. the neutral point of the machine is grounded through a reactance of 0.99 p.u the machine is running on no load with rated terminal voltage when it suffers an unbalanced fault. The fault with respect to phase 'a' line to neutral voltage.

Determine:

(i)Terminal voltage in each phase of machine w.r.t ground.

(ii)Voltage of neutral point of machine w.r.t to ground.

(iii) Type of fault from the result.

Given Data:

Generator reactance; $X_1 = 0.22$,$X_2 = 0.36, X_0 = 0.09, X_n = 0.99$ p.u

Currents are: $I_a = 0, \quad I_b = 3.75\angle 150, \quad I_c = 3.75\angle 30^{\circ}$

<u>Formula Used</u>:

$$I_{a1} = \frac{1}{3}[I_a + \alpha I_b + \alpha^2 I_c]$$

$$I_{a2} = \frac{1}{3}[I_a + \alpha^2 I_b + \alpha I_c]$$

$$V_a = V_{a1} + V_{a2} + V_{a0}$$

$$V_b = \alpha^2 V_{a1} + \alpha V_{a2} + V_{a0}$$

$$V_c = \alpha V_{a1} + \alpha^2 V_{a2} + V_{a0}$$

$$V = 3I_{a0}X_0$$

Solution:

Sequence components of fault current:

$$\begin{bmatrix} I_{a1} \\ I_{a2} \\ I_{a0} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \\ 1 & 1 & 1 \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

$$I_{a1} = \frac{1}{3}(I_a + \alpha I_b + \alpha^2 I_c)$$

$$= \frac{1}{3}[0 + (1\angle 120)(3.75)\angle 150) + (1\angle 240)(3.75\angle 30)]$$

$$= 0 - j2.5 \text{ p.u}$$

$$I_{a2} = \frac{1}{3}(I_a + \alpha^2 I_b + \alpha I_c)$$

$$= \frac{1}{3}[0 + (1\angle 240 \times 3.75)\angle 150) + (120 \times 3.75\angle 30)] = j1.25 \text{ p.u}$$

$$I_{a0} = \frac{1}{3}[I_a + I_b + I_c] = [0 + 3.75\angle 150 + 3.75\angle 30] = j1.25 \text{ p.u}$$

<u>Sequence Component of voltage at fault</u>:

$$V_{a1} = E - I_{a1}Z_1 = 1\angle 0 — j2.5(j0.22) = 0.45 \text{ p.u}$$

$$V_{a2} = -I_{a2}Z_2 = — j1.25\angle(j0.36) = 0.45 \text{ p.u}$$

$$V_{a0} = -I_{a0}Z_0 = —(j1.25)[j0.36 + 3 \times 0.09] = 0.7875 \text{ p.u}$$

$$V_a = V_{a1} + V_{a2} + V_{a0} = 0.45 + 0.45 + 0.7875 = 1.6875 \text{ p.u}$$
$$V_b = \alpha^2 V_{a1} + \alpha V_{a2} + V_{a0} = 0.45\angle -120 + 0.45\angle 120 + 0.7875 = 0.3375 \text{ p.u}$$
$$V_C = \alpha V_{a1} + \alpha^2 V_{a2} + V_{a0} = 0.45\angle 120 + 0.45\angle -120 + 0.7875 = 0.3375 \text{ p.u}$$

(ii)Voltage of neutral w.r.t ground:

$$= 3I_{a0}\ X_0$$
$$= 3 \times 1.25 \times 0.09$$
$$= 0.3375 \text{ PU}$$

(iii)$\mathbf{V_b} = \mathbf{V_c} = 0.3375$ It is LLG Fault

17.A 3 phase generator is rated 20MVA, 13.8 KV and has direct axis sub transient reactance of 0.25 p.u. The negative and zero sequence reactance are 0.35 p.u and 0.1 p.u respectively. The neutral of generator is solidly grounded. Determine the sub transient current in generator and line to line voltage for sub transient condition when a single line to ground fault occurs at generator terminal neglect resistance and assume no load condition. (Apr/May 2017)

Given data:

Generator rated: 20 MVA, 13.8 KV, $X_1 = 0.25, X_2 = 0.35, X_0 = 0.1$

To find: fault current, line to line voltage at line to ground fault occurs.

Formula used:

$$I_{a1} = \frac{E_a}{Z_1 + Z_2 + Z_0}; \quad I_f = I_a = 3I_{a1}$$
$$V_{a1} = E_a - I_{a1}Z_1 \qquad V_a = V_{a1} + V_{a2} + V_{a0}$$
$$V_{a2} = -I_{a2}Z_2 \qquad V_b = \alpha^2 V_{a1} + \alpha V_{a2} + V_{a0}$$
$$V_{a0} = -I_{a0}Z_0 \qquad V_c = \alpha V_{a1} + \alpha^2 V_{a2} + V_{a0}$$

Solution:

$$I_{a1} = \frac{E_a}{Z_1 + Z_2 + Z_0} = \frac{1\angle 0}{j0.25 + j0.35 + j0.1} = -j1.43 \text{ p.u}$$
$$I_f = I_a = 3I_{a1} = 3 \times j1.43 = -j4.29 \text{ p.u}$$
$$I_{Base} = \frac{P}{\sqrt{3} \times V} = \frac{20 \times 10^6}{\sqrt{3} \times 13.8 \times 10^3} = 837A$$
$$I_f = I_B \times I_a = 837 \times -j4.29 = -j3590A$$
$$V_{a1} = E_a - I_{a1}Z_1 = 1\angle 0 — (-j1.43 \times j0.25) = 0.643 \text{ p.u}$$
$$V_{a2} = -I_{a2}Z_2 = -(-j1.43 \times j0.35) = -0.5 \text{p.u}$$
$$V_{a0} = -I_{a0}Z_0 = -(-j1.43 \times j0.1) = -0.143 \text{ p.u}$$

Line to Ground Voltage are :

$$V_a = V_{a1} + V_{a2} + V_{a0} = 0.643 - 0.5 - 0.143 = 0$$
$$V_b = \alpha^2 V_{a1} + \alpha V_{a2} + V_{a0} = 0.643(-0.5 - j0.866) - 05(-0.5 + 0.866) + (-0.143)$$

$$= (-0.2165 - j0.99)\text{p.u}$$

Line to Line Voltages:

$$V_{ab} = V_a - V_b = 0 - (-0.2165 - j0.99) = 1.01\angle\ 77.7°\ \text{p.u}$$

$$V_{bc} = V_b - V_c = (-0.2165 - j0.99) - (-0.2165 + j0.99) = 1.980\angle - 90°\ \text{p.u}$$

$$V_{ca} = V_c - V_a = -0.215 + j0.99 = 1.01\angle\ 102.3°\ \text{p.u}$$

Post Fault Line Voltage:

$$V_{ab} = 1.01\angle\ 77.7° \times \frac{13.8}{\sqrt{3}} = 8.05\angle\ 77.7$$

$$V_{bc} = 1.980\angle - 90° \times \frac{13.8}{\sqrt{3}} = 15.78\angle - 90^{\circ}$$

$$V_{ca} = 1.01\angle 102.3° \times \frac{13.8}{\sqrt{3}} = 8.05\angle 102.3\ \text{KV}$$

20.A synchronous generator has following reactance's.

$\mathbf{X_1 = 60\%}$

$\mathbf{X_2 = 25\%}$

$\mathbf{X_3 = 15\%}$

(i) **Calculate the percentage reactance to be added in the generator neutral such that the current for L.G faults does not exceed 1 p.u.**

(ii) **Calculate value of resistance to be connected in the neutral to achieve the same purpose.**

Formula Used:

(i) $$I_f(L - G) = 3I_{a1} = \frac{3\ E_a}{Z_1 + Z_2 + Z_0 + 3X_n}$$

Solution:

$$1 = \frac{3a1\angle 0}{j0.6 + j2.5 + j0.15 + j3X_n} = \frac{3}{j1.0 + j3X_n}$$

$$1 = \frac{3}{j(1.0 + j3X_n)}$$

$$j(1.0 + j3X_n) = 3$$

$$3X_n = 3 - 1.0$$

$$X_n = \frac{2}{3} = 0.66\ \text{p.u}$$

(ii) $$1 = \frac{3}{j1 + 3R_n} = \frac{3\ E_a}{Z_1 + Z_2 + Z_0 + 3R_n}$$

$$3R_n + j1 = 3$$

$$\sqrt{1 + 9R_n^2} = 3$$

$$1 + 9R_n^2 = 3^2$$

$$9R_n^2 = 9 - 1$$

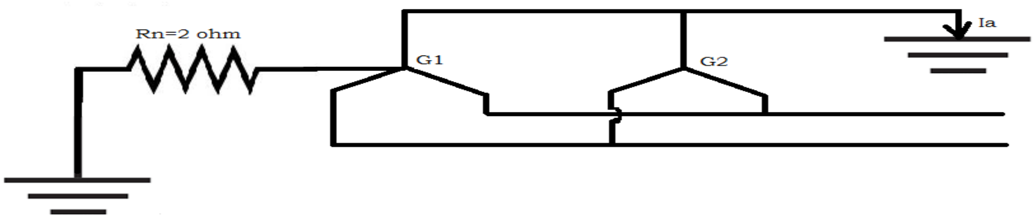
$$R_n^2 = \frac{8}{9}$$

$$R_n = \sqrt{\frac{8}{9}} = 0.9428 \text{ p.u}$$

$$= 94.28\ \%$$

18.**Two 11 KV, 20 MVA, Three phase star connected generators operate in parallel as shown in figure. The positive, negative and zero sequence reactance of each being j 0.18, j 0.15, j 0.10 p.u respectively. The star point of one of the generators is isolated and that of the other is earthed through a 2.0 Ω resistor. A single line – to – ground fault occurs at the terminal of one of the generators.**

Estimate (i) Fault Current (ii) Current in grounding resistor, & (iii) Voltage across the grounding resistor. (Apr/May 2017)



Given data:

11 KV, 20 MVA (Each)

Positive, Negative and Zero sequence

Reactance are : j0.18, j0.15, and j0.10 PU

Grounding resistor $R_n = 2.0\ \Omega$

To find:

(i) I_f, (ii) Current in grounding resistor, (iii) Voltage across the grounding resistor

Solution

Two identical generators operate in parallel

$$X_{1eq} = \frac{j0.18}{2} = j0.09, X_{2eq} = \frac{j0.15}{2} = j0.075$$

Star point of second generator is isolated; zero sequence reactance does not come in to picture.

$$Z_n = \frac{2 \times MVA}{(KV)^2} = \frac{2 \times 20}{(11)^2} = 0.3305$$

$$Z_{0eq} = j0.10 + 3Z_n;$$

$$= j0.10 + 3 \times 0.3305$$

$$Z_{0eq} = 0.99 + j0.1$$

(i)

$$I_f = I_a = 3I_{a1} = \frac{3\ E_a}{X_{1eq} + X_{2eq} + X_{0eq}}$$

$$= \frac{3\ E_a}{j0.09 + j0.075 + 0.99 + j0.1} = \frac{3}{0.99 + j0.265}$$

$$I_f = 2.827 - j0.756$$

(ii)

$$I_f = 2.827 - j0.756 = 2.927\angle -14.98$$

$$I_f = 2.927 \times \frac{MVA}{\sqrt{3} \times 11}$$
$$= 2.927 \times \frac{20}{\sqrt{3} \times 11} = 3.07 \text{ KA}$$

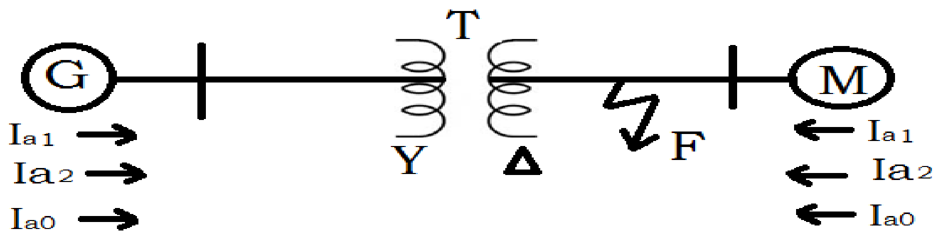
(iii)Voltage across the grounding resistor $= R_n \times \frac{MVA}{(11)^2} = 2 \times \frac{20}{(11)^2} = \frac{40}{(40)^2}$

$= 0.3305$

$$V = IR_n$$
$$= 0.3805(2.827 - j0.756)$$
$$= 0.934 - j0.249$$
$$= 0.967 \times \frac{11}{\sqrt{3}}$$
$$= 6.14 \text{KV}$$

19.A generator supplies a motor through a $Y - \Delta$ transformer. The generator is connected Y side of transformer. A fault occurs between the motor terminal and the transformer. The symmetrical components of current in the motor flowing towards the fault are

Given data:



$$I_{a1} = -0.8 - j2.6 \text{ p.u}$$
$$I_{a2} = -j2.0 \text{ p.u}$$
$$I_{a0} = -3.0 \text{ p.u}$$

Current from the transformer towards the fault

$$I_{a1} = 0.8 - j0.4 \text{ PU}$$
$$I_{a2} = -j1.0 \text{ PU}$$
$$I_{a0} = 0$$

Assume $X_1 = X_2$ for both motor and generator.

To find:

(i)Type of fault, (ii)Pre – fault current , (iii)Fault current

Formula used:

$$I_{a1} = I_{a1}(\text{gen}) + I_{a1}(\text{motor})$$
$$\text{Pre} - \text{fault current} = I_{a1}(\text{Transformer}) - I_{a2}(\text{Transformer})$$

Solution:

(i) Total sequence components of fault current are

$$I_{a1} = (-0.8 - j2.6) + (0.8 - j0.4) = -j3 \text{ PU}$$
$$I_{a2} = -j2.0 - j1.0 = -j3 \text{ PU}$$
$$I_{a0} = -j = -j3 \text{ PU}$$

$$\therefore I_{a1} = I_{a2} = I_{a0} \text{ it is line to ground fault}$$

(ii) Pre – fault current

$$= I_{a1}\,(\text{Transformer}) - I_{a2}\,(\text{Transformer})$$
$$= (0.8 - j0.4) - (-j1.0)$$
$$= (0.8 + j0.6)\text{PU}$$

(or)

$$= I_{a1}\,(\text{From motor}) - I_{a2}\,(\text{From motor})$$
$$= (-0.8 - j2.6) - (-j2.0)$$
$$= (-0.8 - j0.6) \cong (0.8 + j0.6)\text{PU}$$

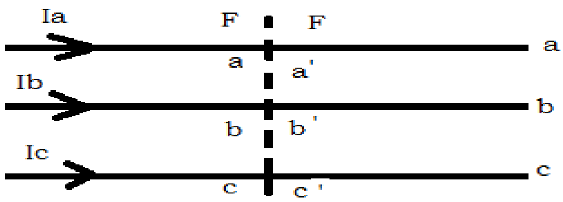
(iii) Fault current

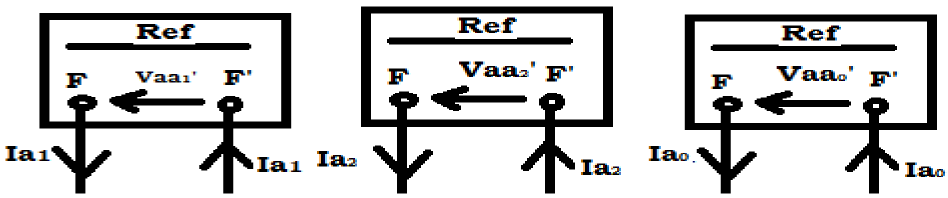
$$I_f = 3I_{a1}$$
$$= 3 \times (-j3)$$
$$I_f = -j9\text{PU}$$

20. Explain with neat diagram of open conductor fault.

Consider on no load, an open conductor fault is in series with line, line current and the series voltages between the broken ends of the conductors (F and F$'$) are to be found.

Current and voltage in an open conductor fault. The ends of line on the sides of fault are indentified as F and F$'$ while the conductor ends are identified as aa$'$, bb$'$ and cc$'$.





+ve sequence NW -ve sequence NW Zero sequence NW

Set of series current and voltage at the faults are:

$$I_P = \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix};\ V_P = \begin{bmatrix} V_{aa^1} \\ V_{bb^1} \\ V_{cc^1} \end{bmatrix}$$

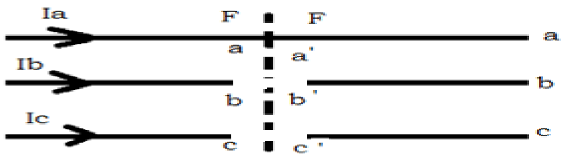
Symmetrical Components of Current and Voltages are:

$$I_b = \begin{bmatrix} I_{a1} \\ I_{a2} \\ I_{a0} \end{bmatrix};\ V_s = \begin{bmatrix} V_{aa^1 1} \\ V_{aa^1 2} \\ V_{aa^1 0} \end{bmatrix}$$

Sequence network can be suitably connected depending on the type of fault.

TWO CONDUCTOR OPEN FAULT:

Consider the conductors b and c are open as shown in figure.



Bounding Conditions:

$$V_{aa^1} = 0$$
$$I_b = I_c = 0$$

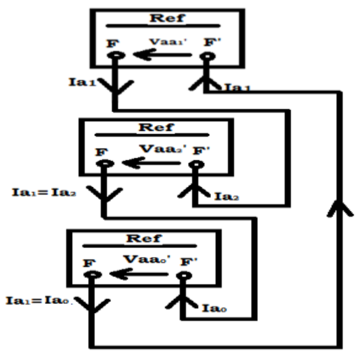
Transformation:

$$V_{aa^1 1} + V_{aa^1 2} + V_{aa^1 0} = 0$$

$$\begin{bmatrix} I_{a1} \\ I_{a2} \\ I_{a0} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \\ 1 & 1 & 1 \end{bmatrix}\begin{bmatrix} I_a \\ I_b = 0 \\ I_c = 0 \end{bmatrix}$$

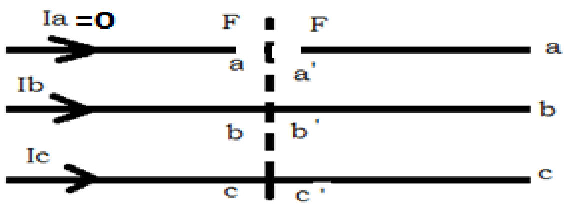
$$I_{a1} = I_{a2} = I_{a0} = \frac{1}{3} I_a$$

Interconnection:



One conductor open fault

Consider one conductor "a" open



Boundary conditions:

$$V_{bb}' = V_{cC}' = 0; I_a = 0$$

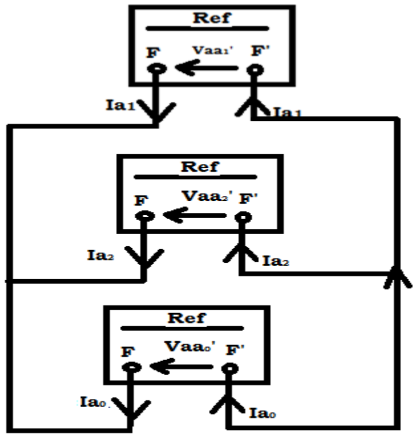
Transformation:

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

$$\begin{bmatrix} V_{aa^1 1} \\ V_{aa^1 2} \\ V_{aa^1 0} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \\ 1 & 1 & 1 \end{bmatrix}\begin{bmatrix} V_{aa'} \\ V_{bb'} \\ V_{cc'} \end{bmatrix}$$

$$V'_{aa1} = V'_{aa2} = V'_{aa0} = \frac{1}{3} V'_{aa}$$

Interconnection:



UNIT V
PART A

1. What is power system stability? (Apr/May 2018)

The stability of an interconnected power system means is the ability of the power system is to return or regain to normal or stable operating condition after having been subjected to some form of disturbance.

2. What is rotor angle stability?

Rotor angle stability is the ability of interconnected synchronous machines of a power system to remain in synchronism.

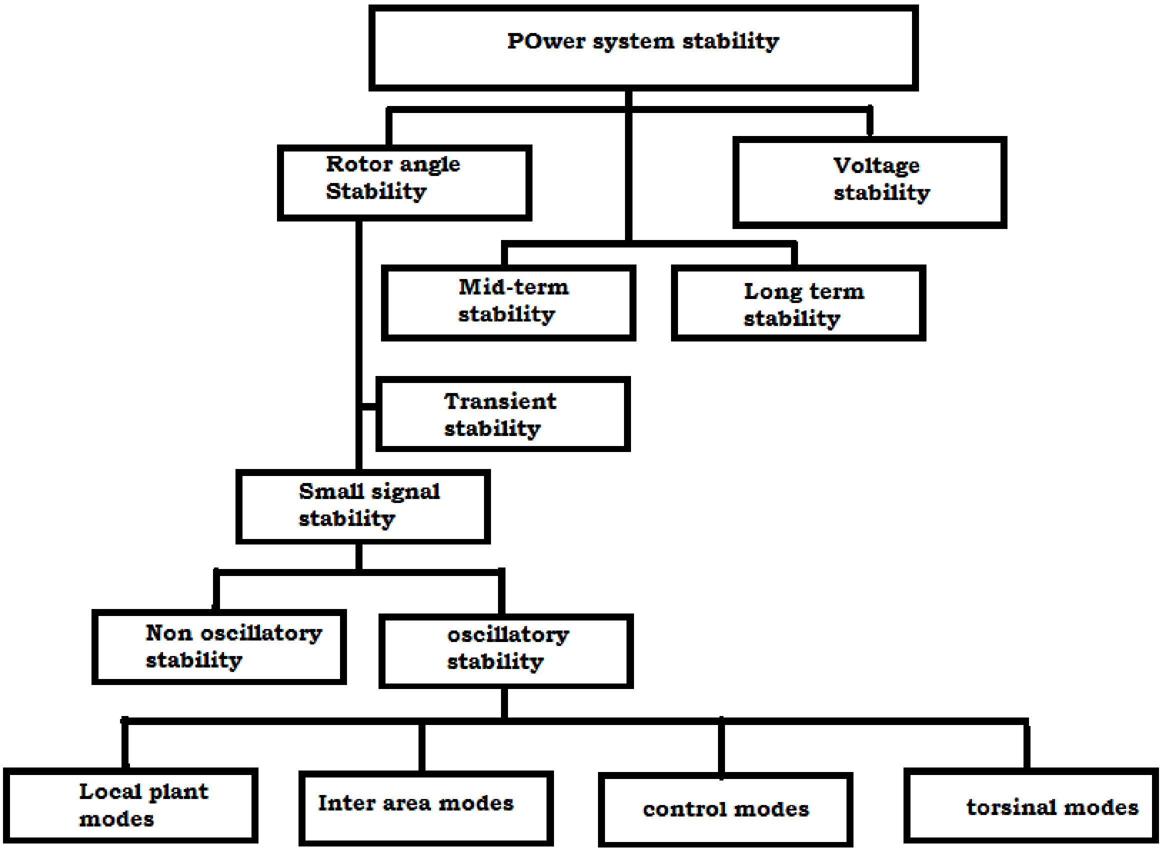
3. What is steady state stability?(or) Define steady state stability (April/May-2010)

Steady state stability is defined as the ability of the power system to bring it to a stable condition or remain in synchronism after a small disturbance.

4. What is steady state stability limit? (Nov/Dec 2014)

The steady sate stability limit is the maximum power that can be transferred by a machine to receiving system without loss of synchronism

5. How power system stability is classified? (Nov/Dec-2015)



6.What is transient stability?(or)Define transient stability(Nov/Dec-2009,May/June-2016)(Nov/Dec 2017).

Transient stability is defined as the ability of the power system to bring it to a stable condition or remain in synchronism after a large disturbance.

7. What is transient stability limit?

The transient stability limit is the maximum power that can be transferred by a machine to a fault or a receiving system during a transient state without loss of synchronism.

Transient stability limit is always less than steady state stability limit

8. Define dynamic stability with an example.(May/June 2014)

It is the ability of a power system to remain in synchronism after the initial swing (transient stability period) until the system has settled down to the new steady state equilibrium condition.

Example: Transmission system faults, sudden outage of line, sudden removal of load, sudden loss of excitation.

9. Define voltage stability?(Nov/Dec-2010)(Nov/Dec 2016)

It is the ability of a power system to maintain steady acceptable voltages at all buses in the system under normal operating conditions and after being subjected to a disturbance.

10. State the causes of voltage instability.

A system enters a state of voltage instability when a disturbance, increase in load demand, or change in system condition causes a progressive and uncontrollable drop in voltage

The main factor causing instability is the inability of the power system to meet the demand for reactive power.

11. Write the power angle equation and draw the power angle curve of a synchronous machine connected to an infinite bus and also the expression for maximum power transfer to the bus.(Dec-2008,Dec-2015)

$$P = \frac{V_s V_r}{X_T} \sin\delta$$

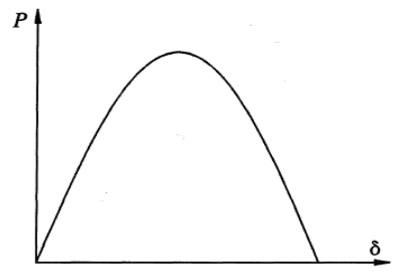
Where, P – Real Power in watts

V_s – Sending end voltage; V_r- Receiving end voltage

X_T - Total reactance between sending end receiving end

δ - Rotor angle.

Power angle curve



Maximum power transfer

$$P_{max} = \frac{V_s V_r}{X_T}$$

12. Write the expression for maximum power transfer.

$$P_{max} = \frac{V_s V_r}{X_T}$$

13. Write the swing equation for a SMIB (Single machine connected to an infinite bus bar) system. (or)

Give the expression for swing equation. Explain each term along with their units. (APR/MAY 2005) (or)

Write the swing equation and explain the terms involved in it. (Nov/Dec-2007), (April/May-2011),(Nov/Dec-2011)

$$\frac{H}{\pi f}\frac{d^2\delta}{dt^2} = P_m - P_e$$

$$M = \frac{H}{\pi f}$$

$$M\frac{d^2\delta}{dt^2} = P_m - P_e$$

Where H = inertia constant in MW/MVA

f = frequency in Hz

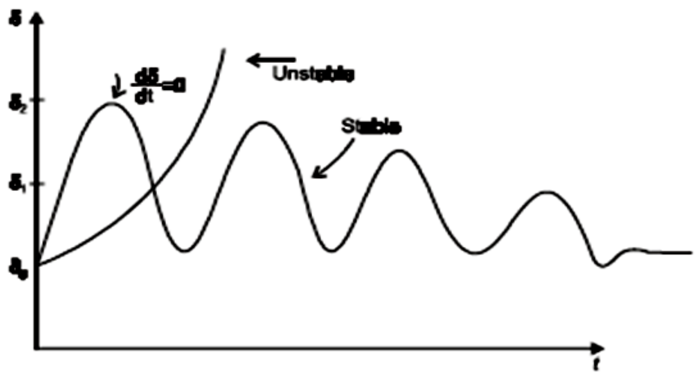
M = inertia constant in p.u

P_m= Mechanical power input to the system (neglecting mechanical losses) in p.u.

P_e = Electrical power output of the system (neglecting electrical losses) in p.u.

14. Define swing curve and **use of this curve (Nov/Dec-2013)**(Apr/May 17)

The swing curve is the plot or graph between the power angle δ and time t. From the nature of variations of δ the stability of a system for any disturbance can be determined.



15. In a 3 machine system having ratings G_1, G_2 and G_3 and inertia constants M_1, M_2 and M_3. What is the inertia constants M and H of the equivalent system.

$$M_{eq} = \frac{M_1 G_1}{G_b} + \frac{M_2 G_2}{G_b} + \frac{M_3 G_3}{G_b}$$

$$H_{eq} = \frac{\pi f M_{eq}}{G_b}$$

Where G_1, G_2, G_3 – MVA rating of machines 1, 2, and 3

G_b = Base MVA or system MVA

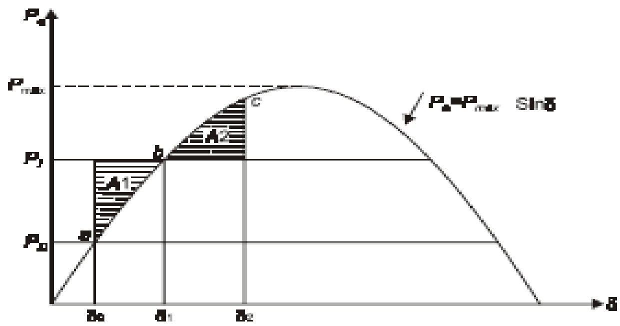
16. State the assumptions made in stability studies.

- Machines represents by classical model
- The losses in the system are neglected (all resistance are neglected)
- The voltage behind transient reactance is assumed to remain constant.
- Controllers are not considered (Shunt and series capacitor)
- Effect of damper winding is neglected.

17. State Equal Area Criterion (Nov/Dec-2011,2017, May/June-2016) (Apr/May 2017)

The equal area criterion for stability states that the system is stable if the area under P – δ curve reduces to zero at some value of δ.

This is possible if the positive (accelerating) area under P – δ curve is equal to the negative (decelerating) area under P – δ curve for a finite change in δ. hence stability criterion is called equal area criterion.



18. Define critical clearing angle. and critical clearing time(Nov/Dec2014)

The critical clearing angleδ_{cc}, is the maximum allowable change in the power angle δ before clearing the fault, without loss of synchronism.

The time corresponding to this angle is called critical clearing time,t_{cc}.It can be defined as the maximum time delay that can be allowed to clear a fault without loss of synchronism.

19. List the methods of improving the transient stability limit of a power system.

- Reduction in system transfer reactance
- Increase of system voltage and use AVR
- Use of high speed excitation systems
- Use of high speed reclosing breakers

20. What are the numerical integration methods of power system stability?

(or)What is the use of swing equation? What are the method used to solve it?(May/June-2009)

Swing equation:

$$M\frac{d^2\delta}{dt^2} = P_m - P_e$$

It is used to describe the behavior of the synchronous machine during transient period.

Methods:

i. Point by point method or step by step method
ii. Euler method
iii. Modified Euler method
iv. Runge-Kutta method(R-K method)

21. Write any three assumptions upon transient stability.

a. Rotor speed is assumed to be synchronous. In fact, it varies insignificantly during the course of the stability study.
b. Shunt capacitances are not difficult to account for in a stability study.
c. Loads are modeled as constant admittances.

22. What are the machine problems seen in the stability study.

1. Those having one machine of finite inertia machines swinging with respect to an infinite bus
2. Those having two finite inertia machines swinging with respect to each other.

23. What are the assumptions made in solving swing equation?

1) Mechanical power input to the machine remains constant during the period of electromechanical transient of interest.
2) Rotor speed changes are insignificant that had already been ignored in formulating the swing equations.
3) Effect of voltage regulating loop during the transient are ignored.

24. What is the use of swing curve?

The swing curve is the plot or graph between the power angle δ, and time, t. It is usually plotted for a transient state to study the nature of variation in δ for a sudden large disturbance. From the nature of variations of δ, the stability of a system for any disturbance can be determined.

25. Give the control schemes included in stability control techniques?

The control schemes included in the stability control techniques are:
a. Excitation systems
B.Turbine valve control
C.Single pole operation of circuit breakers
D.Faster fault clearing times

26. What is the systems design strategies aimed at lowering system reactance?

The system design strategies aimed at lowering system reactance are:
a. Minimum transformer reactance
b. Series capacitor compensation of lines
C. Additional transmission lines.

27. What are coherent machines? (APR/MAY 2004)

Machines which swing together are called coherent machines. When both ωs and δ are expressed in electrical degrees or radians, the swing equations for coherent machines can be combined together even though the rated speeds are different. This is used in stability studies involving many machines.

28. State two technique to improve stability of power system (Nov/Dec-2010)(Nov/Dec 2016)

- Using of AVR
- Use of high speed transfer reactances
- Use of high speed reclosing breaker
- Use of FACTS controller &Power system stabilizers (PSS).

29. What are various faults that increase severity of equal area criterion?

The various faults that increases severity of equal area criterion are,

- A Single line to ground fault
- A Line to line fault
- A Double line to ground fault
- A Three phase fault

30. Give the expression for critical clearing time (Nov/Dec-2007)

The expression for the critical clearing time t_{cr} is given by

$$t_{cc} = \frac{2H(\delta_{CC} - \delta_0)}{\pi f P_m}$$

Where, H is the constant

δcc is the critical clearing angle

δo is the rotor angle

Pm is the mechanical power

31. List the types of disturbances that may occur in a single machine infinite bus bar system of the equal area criterion stability

The types of disturbances that may occur are,

- Sudden change in mechanical input
- Effect of clearing time on stability
- Sudden loss of one of parallel lines
- Sudden short circuit on one of parallel lines

i) Short circuit at one end of line

ii) Short circuit away from line ends

iii) Re closure

32. Define critical clearing time. And (Nov/Dec-2008)

The critical clearing time , tcc can be defined as the maximum time delay that can be allowed to clear a fault without loss of synchronism . The time corresponding to theoretical clearing angle is called critical clearing time tcc.

33. Write the significance of critical clearing time?(Apr/May 2015)

- ➢ To find out the stability of the system
- ➢ To determine the characteristics of protections required by the power system

34. What are the assumptions that are made in order to simplify the computational task in stability studies?

The assumptions are,

• The D.C offset currents and harmonic components are neglected. The currents and voltages are assumed to have fundamental component alone.

• The symmetrical components are used for the representation of unbalanced faults.
• It is assumed that the machine speed variations will not affect the generated voltage.

35. What is Multi machine stability?

If a system has any number of machines, then each machine is listed for stability by advancing the angular position, δ of its internal voltage and noting whether the electric power output of the machine increases (or) decreases. If it increases, i.e if $\partial Pn / \partial \delta n > 0$ then machine n is stable. If every machine is stable, then the system having any number of machine is stable.

36. Differentiate between rotor angle stability and voltage stability?(Nov/Dec-2013)

Rotor angle stability	Voltage stability
Rotor angle stability is the ability of interconnected synchronous machines of a power system to remain in synchronism	It is the ability of a power system to maintain steady acceptable voltages at all buses in the system under normal operating conditions and after being subjected to a disturbance

37. What is meant by an infinite bus? (Or)Define Infinite bus in a power System (April/May-2008)(May/June 2013)

The connection or disconnection of a single small machine on a large system would not affect the magnitude and phase of the voltage and frequency. Such a system of constant voltage and constant frequency regardless of the load is called infinite bus bar system or infinite bus.

38. List the assumptions made in multi machine stability studies.

• The mechanical power input to each machine remains constant during the entire period of the swing curve computation
• Damping power is negligible
• Each machine may be represented by a constant transient reactance in Series with a constant transient voltage.
• The mechanical rotor angle of each machine coincides with δ , the Electrical phase angle of the transient internal voltage.

39. What is the significance of sub-transient reactance and transient reactance in short circuit studies?(Apr/May 2018)

The sub-transient reactance can be used to estimate the initial value of fault current immediately on the occurance of the fault. The maximum momentary short circuit current rating of the circuit breaker used for protection or fault clearing should be less than this initial fault current.

The transient reactance is used to estimate the transient stste fault current. most of the circuit breaker open their contacts only during this period. Therefore, for a circuit breaker used for clearing,its interrupting short circuit current rating should be less than the transient fault curent.

40. On what basis, do you conclude that a given synchronous machine has lost stability.(April/May – 2008)

If the power angle, $\delta > 90^\circ$ the system is said to be unstable. Then we may conclude that a given synchronous machine has lost its instability.

41. Define transient stability and transient stability limit? (Nov/Dec-2009)(May/June 2012)

Transient stability is defined as the ability of the power system to bring it to a stable condition or remain in synchronism after a large disturbance.

The transient stability limit is the maximum power that can be transferred by a machine to a fault or a receiving system during a transient state without loss of synchronism. Transient stability limit is always less than steady state stability limit.

42. A 50 Hz 4 pole turbo generator of rating 20MVA, 13.2kV has an inertia constant of H=9kW sac/kvA. Find the kinetic energy stored in the rotor at synchronous speed.

Solution: Kinetic Energy, $E_{ke} = 1/2M\omega_s$

Where $M = \frac{HS}{\pi f} and \omega_s = 2\pi f$

$E_{ke} = \frac{1}{2}\frac{HS}{\pi f}2\pi f = HS = 9 \times 20 = 180MJ(mega\ joules)$

43. Find the frequency of oscillation for a synchronous coefficient of 0.6 inertia constant H=4 and system frequency of 50Hz. (May/June 2014)

Solution:

Frequency of oscillation= $\sqrt{\frac{C}{M}}$

Where C=Synchronizing coefficient

M=Inertia constant in p.u given that c=0.6

$M\ in\ p.u = \frac{H}{\pi f} = \frac{4}{\pi \times 50} = 0.0255 p.u$

$$\text{Frequency of oscillation} = \sqrt{\frac{0.6}{0.0255}} = 4.85\frac{rad}{sec} = \frac{4.85}{2\pi} = 0.7719Hz$$

44. Define power angle. (May/June-2006) (May/June-2013)

The power angle or torque angle is defined as the angular displacement of the rotor from synchronously rotating reference frame.

45. Give the simplified power angle equation and the expression for Pmax. (May/June-2012)

The simplified power angle equation for a generator feeding energy to infinite bus is given by

$P_e = P_{max} sin\delta$

Where, $P_{max} = \frac{|E||V|}{X}$

$|E|$=Magnitude of internal emf of generator.

$|V|$=Magnitude of infinite bus voltage

X=Transfer reactance between generator and infinite bus.

δ=Power angle or torque angle

46. What are the methods available to solve the swing equation?

1. Modified Euler's method.
2. Runge-kutta method.

47. Explain stiffness electrical coefficient of synchronous machine or what is synchronous power coefficient?

The quantity $P_s = P_{max} \cos\delta_0$ is the slope of the power angle curve at δ_0

$$P_e = P_{max} sin\delta_0$$

$$P_s = \frac{\frac{dP_e}{ds}}{\delta_0} = P_{max} cos\delta_0 = \frac{EV cos\,\delta_0}{X}$$

Where P_s is known as synchronizing power coefficient or stiffness electrical of synchronous machine this plays an important role in determining the system stability.

48. The moment of inertia of a 4-pole, 100MVA, 11KV, 3-φ , 0.8 power factor, 50HZ turbo alternator is 10000kg-m^2 .calculate H and M. (Nov/Dec-2015)

$$J = 10000Kg - m^2$$

$$N_s = \frac{120f}{p} = \frac{120 \times 50}{4} = 1500rpm$$

$$n_s = \frac{N_s}{60} = \frac{1500}{60} = 25rps$$

$$\omega_s = 2\pi n_s = 50\pi$$

$$N = \frac{1}{2} J\omega_s^2$$

$$= \frac{1}{2} \times 10000 \times (2 \times \pi \times 50)^2$$

$$= 123.37\ MJ$$

$$H = \frac{N}{S} = \frac{123.37}{100} = 1.2337\ MJ/MVA$$

$$M = \frac{SH}{180f} = \frac{100 \times 1.2337}{180 \times 50}$$

$$= 0.0137\ MJ\ Sec/electrical\ degree$$

PART-B

Introduction to power system stability

1. Power system stability:(Nov/Dec 2017,Apr/May 2018)

The ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variable bounded so that practically the entire system remains intact.

Classification of power system stability:

1. Steady state stability:
2. Dynamic stability:
3. Transient stability:

Rotor angle stability:

Ability to maintain equilibrium between electromagnetic torque and mechanical torque of each synchronous machine in the system.

Basic phenomena associated with angle stability are:

(I) Imbalance between accelerating and decelerating generator torque.
(II) Negative surplus energy is stored in rotating masses.

(III) Capture range of synchronizing torque is limited by pull-out (or) power.

(IV) If the limits exceed, stability the synchronized operating may be lost.

Small-disturbance (small signal) rotor angle stability.

Ability of power system to maintain synchronism under small disturbance. The disturbance are considered to be sufficiently small that linearization of system equations is permissible for purpose of analysis.

Large – disturbance rotor angle stability (or) transient stability:

Ability of power system to maintain synchronism when subjected to a severe disturbance. Such as a short circuit on a transmission line. The resulting system response involves large excursions of generator rotor angle and influenced by non-linear power angle relationship.

Voltage stability:

Ability of PS to maintain steady voltage at all the buses in the system after subjected to disturbance from initial operating conditions it depends on ability to maintain equilibrium between load demand and load supply from the PS.

Voltage collapse:

It is the process by which the sequence of events accompanying voltage instability leads to a black out (or) abnormally low voltage in a part of power system.

Phenomenon associated with voltage stability:

1. High (reactive) loading reduces the voltage in an area.
2. Temporary load reduction.
3. Transfer capacity to the area is reduced.
4. Load demand recovers.
5. Voltage further reduced.
6. No solution to load flow, voltage collapses.

Voltage stability:

The ability of power system to maintain steady voltage at all buses in the system after being subjected to a disturbance from initial operating condition.

It depends on the ability to maintain equilibrium between load demand and load supply from power system.

Instability may occur in the form of progressive fall (or) rise of voltage of some buses.

A possible outcome of voltage instability is loss of load in an area, tripping of transmission lines other demand by their protective system.

Progressive drop in bus voltage can also associated with rotor angle instability.

Classification of voltage stability:

Large-disturbance voltage stability:-

Ability to maintain steady voltage (or) large disturbance such as system fault, loss of generation, ability to determined system & load characteristics. Involves both discrete & continuous control & protection.

Determination of (LVDS) requires. Non linear response of Power system.

Ex: Motor, under-load transformer tap changes, gen-field-current limiters.

Time: Few second to ten of minute.

Small-disturbance voltage stability:-

Subjected to a small disturbance such as internal changes in system load. Stability influenced by characteristics of load, continuous control, discrete control at a instant of time-> system equation can be linearzed,

Time : few second to tens of minute.

Short-term voltage stability:

Steady period from in the order of several seconds. Analysis require the differential equation, which involves fast acting load components, such as, IM, electronically controlled leads, HVDC converters.

Long term voltage stability:

Involves slow acting equipment such as tap changing transformer, thermostatically controlled loads generator current limiters. **Time period**: many minutes.

Frequency stability:

Ability of Ps maintain steady frequency if depends on ability to maintain equilibrium between generation and loads with minimum unintentional loss of loads.

Instability occurs in the form of frequency swings loading to tripping of generation units (or) loads.

Reliability:

The probability of its satisfaction operation over the long run. it denotes the ability to supply adequate electric service to continuous basic.

Security:

The degree of risks in its ability to survive without interruption of customer service.

Three types of power system stability:

1. Steady state stability:

The determination of upper limits of machine loadings before losing synchronism, loading is increasing gradually.

2. Dynamic stability:

Small disturbance are continuously occurring in (Ps) (variation in loading, changes in turbine speeds etc)

3. Transient stability:

For large disturbance changes to angular difference may be as large as to cause the maintain to fall out of step. This type of instability known as transient stability.

2. DYNAMICS OF SYNCHRONOUS MACHINE

The kinetic energy of the rotor at synchronous machine is

$$\text{kinetic energy } = \tfrac{1}{2}J\omega_{sm}^2 \times 10^{-6}\text{MJ}$$

$$J = rotor\ moment\ of\ inertia\ kg - m2,$$

$$\omega_{sm} = synchronous\ speed\ in\ mechanical\ rad/sec.$$

$$\omega_s = \tfrac{P}{2}\,\omega_{sm} = \text{rotor speed (electrical rad)/sec.}$$

$$\text{kinetic energy } = \frac{1}{2}\left(J\left(\frac{2}{P}\right)^2 \omega_s^2 \times 10^{-6}\right)\omega_s$$

$$= \frac{1}{2}M\omega_s$$

$$\mathrm{M} = \mathrm{J}\left(\frac{2}{\mathrm{p}}\right)\omega_s \times 10^{-6}$$

$= \text{moment of inertia in MJ} - \text{S/electrical radian.}$

Inertia constant H such that

$$\text{kinetic energy} = \text{GH(Energy stored in rotor per MVA capacity)}$$

$$GH = K.E = \frac{1}{2}M\omega_s \text{ mega jole}$$

G=machine rating (base) in MVA in 3phase.

H=inertia constant in MJ/MVA (or) MW-Sec/MVA

$$\mathrm{M} = \frac{2\mathrm{GH}}{\omega_s} = \frac{2\mathrm{GH}}{2\pi f} = \frac{\mathrm{GH}}{\pi f}\mathrm{MJ} - \text{Sec/Electrical degree.}$$

$$\mathrm{M} = \frac{\mathrm{GH}}{180f}\mathrm{MJ} - \text{s/Electrical . degree}$$

M=Also called inertia constant.

G=as base, inertia constant in pu is $\mathrm{M(pu)} = \frac{\mathrm{H}}{\pi f}\ \sec^2/\text{electrical .radin.}$

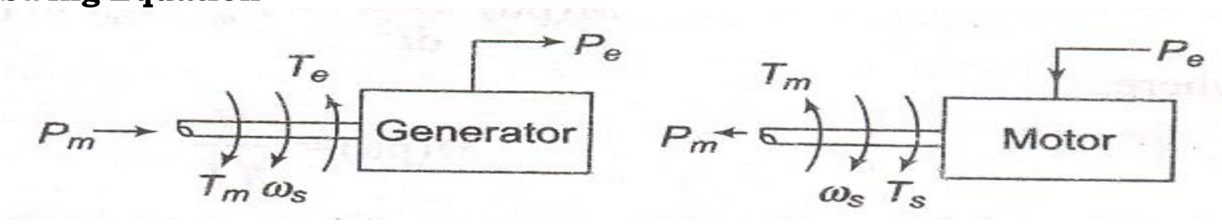
$$\mathrm{M} = \frac{\mathrm{H}}{180f}$$

Rang of inertia constant H

(i) Turbo generator=4-9MW sec/MVA
(ii) Hydro generator =2-4
(iii) Synchronous motor=2
(iv) Synchronous condenser=1-1.25

3. Derive Swing equation for single machine connected to infinite bus system. State the usefulness of this equation. State the reason for non-linearity of this equation (Nov/dec-2015) (Nov/Dec 2016)(Apr/May 2017,2018)

Swing Equation



The torque, speed and flow of mechanical and electrical power in a synchronous machine assumed that the windage, friction and iron loss, torque is negligible.

The differential equation governing the rotor dynamics is

$$\mathrm{J}\frac{d^2\theta_m}{dt^2} = \mathrm{T_m} - \mathrm{T_e} \quad \mathrm{Nm} \ldots\ldots..(1)$$

$$\theta_m = Mechanical\ angle\ in\ radian.$$

$T_m = Turbine\ torque\ in\ Nm, it\ acquires\ negative\ value\ for\ motor\ action.$

$T_e = Electromagnetic\ torque\ in\ Nm, it\ acquires\ negative\ value\ for\ motoring\ machine.$

While the rotor undergoes dynamics as per the equation: $\mathrm{J}\frac{d^2\theta_m}{dt^2} = \mathrm{T_m} - \mathrm{T_e}$.

Rotor speed changes by insignificant magnitude for time period of interest. Assume rotor speed to remain constant at synchronous speed (ω_{sm})

Multiply (ω_{sm}) on both sides of equation (1)

$$\omega_{sm}\mathrm{J}\frac{d^2\theta_m}{dt^2} = \omega_{sm}(\mathrm{T_m} - \mathrm{T_e})\ ; \theta_m \text{ Mechanical angle}$$

$$= \mathrm{P_m} - \mathrm{P_e} = \mathrm{P_a}\ \ \mathrm{Mw}$$

$$P_a = T_e \times (\omega_{sm}) = \text{Accelerating power.}$$
$$P_m = \text{Mechanical power input.}$$
$$P_e = \text{Electrical power output. Mw, stator Cu loss negilible.}$$
$$\left[J\left(\frac{2}{P}\right)^2 \omega_s\right]\frac{d^2\theta_e}{dt^2} = P_m - P_e = P_a; \quad \theta_e \text{Electrical angle}$$
$$P_m = T_m \times \omega_{sm}$$
$$P_e = T_e \times \omega_{sm}$$
$$M\frac{d^2\theta_e}{dt^2} = P_m - P_e = P_a$$
$$M = J\left(\frac{2}{P}\right)^2 \omega_s$$

Angular position of rotor with respect to synchronously rotating frame of reference

Torque angle (Or) Power angle:

$$\delta = \theta_e - \omega_s t; \textit{Rotor angle displacement from synchronously rotating referance frame.}$$
$$\frac{d^2\delta}{dt^2} = \frac{d^2\theta_e}{dt^2}$$
$$M\frac{d^2\delta}{dt^2} = P_m - P_e \text{ Mega watt}$$

$\div$ by G[MVA Rating of the machine]

$$M\frac{d^2\delta}{dt^2} = P_m - P_e = P_a \text{ which is non} - \text{linear equation}$$
$$M = \frac{H}{\pi f}$$
$$\frac{H}{\pi f}\frac{d^2\delta}{dt^2} = P_m - P_e$$

Swing equation is 2nd order differential equation $\frac{H}{\pi f}\frac{d\omega}{dt} = P_m - P_e; \frac{d\delta}{dt} = \omega - 2\pi f$

Assumption made in swing equation:

(i) Windage, friction and iron loss in the machine is negligible,
(ii) Rotor speed assumed to constant at synchronous speed.
(iii) M is assumed to constant.
(iv) Effect of damper winding is neglected, damber winding torque is proportional to $\frac{d\delta}{dt}$ and it helps the system stabilize.

Significance of swing equation:

Solution of swing equation gives a curve of δ V_s t, which is called as a swing curve. From swing curve the stability of system can be guessed.

3. Swing equation of multi machine system:

Swing equation of each machine is $\frac{H}{\pi f}\frac{d^2\delta}{dt^2} = P_m - P_e$ pu

A multi machine system base must be chosen.

$$G_{mechanical} = \text{Machine rating (base).}$$
$$G_{system} = \text{system base.}$$

The above equation

$$\frac{G_{mech}}{G_{system}}\left[\frac{H}{\pi f}\frac{d^2\delta}{dt^2}\right] = (P_m - P_e)\frac{G_{mech}}{G_{system}}$$
$$\frac{H_{mech}}{\pi f}\frac{d^2\delta}{dt^2} = P_m - P_e \text{ pu in system base.}$$

$$H_{system} = H_{mech}\left(\frac{G_{mech}}{G_{system}}\right)$$

=machine inertia constant in the system base.

Consider swing equation of two machines on a common system base,

$$\frac{H_1}{\pi f}\left(\frac{d^2\delta_1}{dt^2}\right) = P_{m1} - P_{e1} \text{ pu}$$

$$\frac{H_2}{\pi f}\left(\frac{d^2\delta_2}{dt^2}\right) = P_{m2} - P_{e2} \text{ pu}$$

Machine rotor swing together $=\delta = \delta_1 = \delta_2$

$$\frac{H_{eq}}{\pi f}\left(\frac{d^2\delta}{dt^2}\right) = P_m - P_e$$

$$P_m = P_{m1} + P_{m2}$$

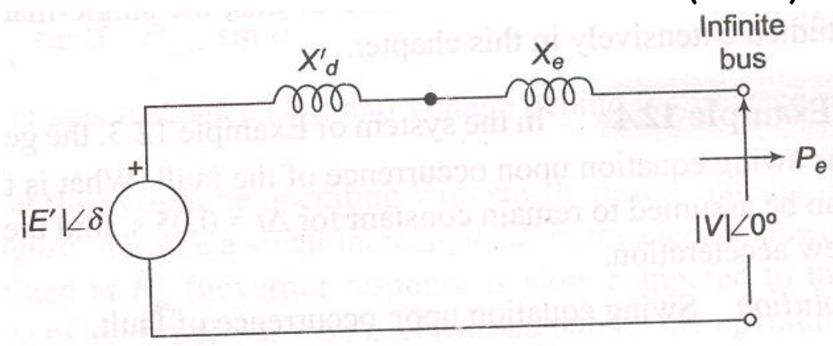
$$P_e = P_{e1} + P_{e2}$$

$$H_{eq} = H_1 + H_2$$

$$H_{eq} = \frac{H_{1,mech}G_{1,mech}}{G_{system}} + \frac{H_{2,mech}G_{2,mech}}{G_{system}}$$

This is inertia constant of multi machine system.

4. Machine connected to infinite bus bar (SMIB).



The circuit model of a single machine connected to infinite bus through a line reactance X_e.

$$X_{transfer} = X_d^{'} + X_e$$

Power angle equation:

$$P_{max} = \frac{|E_1^{'}||E_2^{'}|}{X}\sin\delta$$

$$P_e = \frac{|E||V|}{X_{transfer}}\sin\delta$$

$$P_{max} = \frac{|E||V|}{X_{transfer}}$$

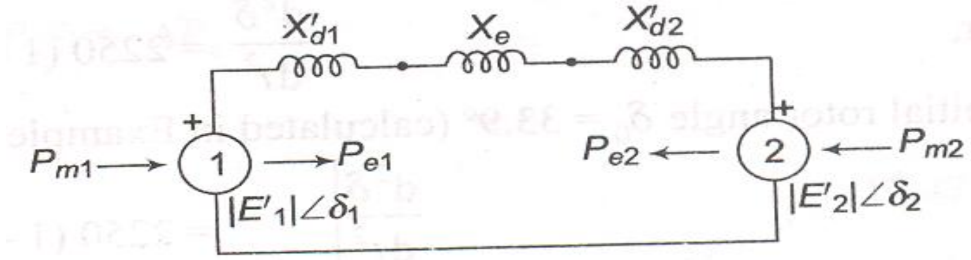
$$= P_{max}\sin\delta$$

The dynamics of this system are:

$$\frac{H}{\pi f}\frac{d^2\delta}{dt^2} = P_m - P_e \text{ pu}$$

Two machine system:

Two finite machine connected through a line (X_e),one of the Machine must be generating and other must be motoring under steady state condition,



$$P_m = P_{m1} = -P_{m2}$$

Mechanical input/out put of two machines is assumed to constant during steady state (or) dynamic condition; the electrical power output of generator must be absorbed by motor.

$$P_e = P_{e1} = -P_{e2}$$

Swing equation for two machines.

$$\frac{d^2\delta_1}{dt^2} = \pi f\left(\frac{P_{m1} - P_{e1}}{H_1}\right)$$

$$= \pi f\left(\frac{P_m - P_e}{H_1}\right) \ldots\ldots (1)$$

$$\frac{d^2\delta_1}{dt^2} = \pi f\left(\frac{P_{m2} - P_{e2}}{H_2}\right)$$

$$= \pi f\left(\frac{P_e - P_m}{H_2}\right) \ldots\ldots (2)$$

Subtracting equation (2) in (1)

$$\frac{d^2(\delta_1 - \delta_2)}{dt^2} = \pi f\left(\frac{H_1 + H_2}{H_1H_2}\right)(P_m - P_e)$$

$$\frac{H_{eq}}{\pi f}\frac{d^2\delta}{dt^2} = P_m - P_e$$

$$\delta = \delta_1 - \delta_2$$

$$H_{eq} = \frac{H_1H_2}{H_1 + H_2}$$

Electrical power interchange between two machines is given by expression:

$$P_e = \frac{|E_1'||E_2'|}{X_{d1}' + X_e + X_{d2}'}\sin\delta.$$

5.Steady state stability:

The maximum power that can be transmitted to the receiving end with out loss of synchronism.

$$M\frac{d^2\delta}{dt^2} = P_m - P_e$$

$$M = \frac{H}{\pi f} \text{ in per unit system}$$

$$P_e = \frac{|E||V|}{X_d}\sin\delta = P_{max}\sin\delta$$

$$X_d = \text{Direct axis reactance,}$$

System with steady state power transfer of $P_{e0} = P_m$ with torque angle δ_0.

Assume a small increment ΔP in electrical power with input from the prime mover remaining fixed P_m.Causing torque angle change to $(\delta_0 + \Delta\delta)$

$$\Delta P_e = \left(\frac{\partial P_e}{\partial \delta}\right)_0 \Delta\delta$$

$$M\frac{d^2\Delta\delta}{dt^2} = P_m - (P_{e0} + \Delta P_{e0}) = -\Delta P_e$$

$$M\frac{d^2\Delta\delta}{dt^2} + \left(\frac{\partial P_e}{\partial \delta}\right)_0 \Delta\delta = 0$$

$$\left[MP^2 + \left(\frac{\partial P_e}{\partial \delta}\right)_0\right]\Delta\delta = 0$$

Where $P = \frac{d}{dt}$ The system stability to small changes is determined from characteristics equation $MP^2 + \left(\frac{\partial P_e}{\partial \delta}\right)_0 = 0$ Whose roots are: $P = \mp\sqrt{\left[\frac{\left(\frac{\partial P_e}{\partial \delta}\right)_0}{M}\right]}$

$\left(\frac{\partial P_e}{\partial \delta}\right)_0$ = is positive, the roots are purely imaginary and conjugate and system behavior is oscillatory about $\delta_{0,} \left(\frac{\partial P_e}{\partial \delta}\right)_0 > 0$

$\left(\frac{\partial P_e}{\partial \delta}\right)_0 = is\ negative$,the roots are real, one positive and other negative but equal magnitude, torque angle increased without bound up on occurrence of a small power increment, the system is unstable$\left(\frac{\partial P_e}{\partial \delta}\right)_0 < 0$.

$\left(\frac{\partial P_e}{\partial \delta}\right)_0 = is\ synchronising\ co-efficient$ Also stiffness of synchronous machine.

Assume $|E||V|$ to remain constant.the system is unstable,if $\frac{|E||V|}{X}\mathbf{cos}\,\delta_0 < 0$, $\delta_0 > 90$

Maximum power transmitted without losses of stability occurs $\delta_0 = 90$

$P_{max} = \frac{|E|\,|V|}{X}$.

5.BASIC FORMULA FOR Movement of inertia, Inertia constant ,

Movement Of Inertia Of Rotor = WR^2

$W = Weight\ of\ rotating\ parts,$

$R^2 = square\ of\ the\ radius\ of\ gyration$ (twist)

$1m = 3.281\ ft$

$1Kg = 2.205\ ib(mass) = 0.0685\ slug$

$$1\ slug\ ft^2 = \frac{1}{0.0685 \times (3.281)^2} = 1.356\ kg.m^2$$

$$\text{Movement of inertia J} = \frac{WR^2}{32.2} \times 1.356$$

$$Inertia\ constant\ H = \frac{1}{2}\left(\frac{J\omega_{sm}^2 \times 10^{-6}}{MVA_{\ Rating}}\right)$$

$$= \frac{1}{2}\left(\frac{J(2\pi)\left(\frac{RPM}{60}\right)^2 \times 10^{-6}}{MVA_{\ Rating}}\right)$$

$$H = 5.584 \times 10^{-9} \frac{J(RPM)^2}{MVA_{\ Rating}}$$

$$H = \frac{5.48 \times 10^{-9} \times 1.356(WR^2)(RPM)^2}{32.2 \times MVA_{\ Rating}}$$

$$H = \frac{2.31 \times 10^{-10}(WR^2)(RPM)^2}{MVA_{\ Rating}}$$

$$Stored\ energy\ at\ rated\ speed = H \times MVA_{\ Rating}$$

$$Mechanical\ time\ T_M = 2 \times H$$

6.If the $wR^2$of rotor including turbine rotor of 555 MVA,2pole ,60HZ generating unit is 654158 1b.ft^2 compute the following.

(i) Moment of inertia J.Kg.m^2

(ii) Inertia constant H,MW-S/MVA rating,

(iii) Stored energy MW.S at rated speed.

(iv) Mechanical starting time, sec

Solution:

(i) $J = \frac{WR^2}{32.2} \times 1.356$

$$= \frac{654158 \times 1.356}{32.2} = 27{,}547.8\ Kg.m^2$$

(ii) $H = 5.48 \times^{-9} \frac{J(RPM)^2}{MVA_{\ Rating}}$

$$= 5.48 \times 10^{-9} \times \frac{27{,}547.8(3600)^2}{555} = 3.525\ MW.S/MVA$$

(iii) Stored energy at rated speed.

$$E = H \times MVA_{\ Rating}$$

$$= 3.525 \times 555 = 1956.4\ MW.s$$

(iv) Mechanical starting time$T_m = 2 \times H$

$$= 2 \times 3.525 = 7.05\ Sec$$

7.The moment of inertia of a 4-pole, 100MVA, 11KV, 3-φ , 0.8 power factor, 50HZ turbo alternator is 10000kg-m^2 .calculate H and M.(Nov/Dec-2015)

$$J = 10000Kg - m^2$$

$$N_s = \frac{120f}{p} = \frac{120 \times 50}{4} = 1500rpm$$

$$n_s = \frac{N_s}{60} = \frac{1500}{60} = 25rps$$

$$\omega_s = 2\pi n_s = 50\pi$$

$$N = \frac{1}{2}J\omega_s^2$$

$$= \frac{1}{2} \times 10000 \times (2 \times \pi \times 50)^2$$

$$= 123.37\ MJ$$

$$H = \frac{N}{S} = \frac{123.37}{100} = 1.2337\ MJ/MVA$$

$$M = \frac{SH}{180f} = \frac{100 \times 1.2337}{180 \times 50}$$

$$= 0.0137\ MJ\ Sec/electrical\ degree$$

8. $\boldsymbol{A\ 200MVA, 11\ kV, 50Hz, 4\ poleturbogeneratorhasan}$ **Inertia constant of** $\boldsymbol{6MJ/MVA}$.

(a) **Find the stored energy in the rotor at synchronous speed,**

(b) **The machine is operating at a load of 120MW when load suddenly increased to 160MW. Find rotor retardation neglect losses.**

(c) **Retardation calculated is maintained for 5 cycles. Find the change in power angle and rotor speed rpm at the end of this period.**

(d) **Another generator** $\boldsymbol{150MVA, 3000rpm}$**having** $\boldsymbol{H = 4MJ/MVA}$**is put in parallel with above generator. Find inertia constant for equivalent generator on the base of 100MVA**.

Solution:

(a) Energy stored= $GH = 200 \times 6 = 1200MJ$

(b) $\mathrm{P_a = P_m - P_e}$

$$= 120 - 160 = -40MW$$

$$\mathrm{M.\frac{d^2\delta}{dt^2} = P_m - P_e = P_a}$$

$$\mathrm{M = \frac{GH}{180f} = \frac{1200}{180 \times 50}} = 0.1333MJ.\frac{sec}{ele}.deg$$

$$0.1333\frac{d^2\delta}{dt^2} = -40$$

$$\alpha = \frac{d^2\delta}{dt^2} = \frac{-40}{0.1333} = 300ele.deg/sec^2$$

$Machine\ retardation = 300\ ele.deg/sec^2$

(c) $5\ cycle = 0.1\ sec$

$$\text{cycle} = 50\text{ Hz: T} = \tfrac{1}{f} = \tfrac{1}{50} = 0.02{:}T = 0.02 \times 5 = 0.01$$

$$\text{Change in } \delta = \frac{1}{2}\alpha(T)^2 = \frac{1}{2}(300)(0.1)^2 = -1.5\ ele.deg.$$

It is 4 pole machine, 1revolution corresponding to $4 \times 180 = 720$ ele.dge

$$\alpha = -300\left(\frac{60}{720}\right) = -25RPM/Sec$$

$$\text{synchronous speed} = \frac{120\mathrm{f}}{\mathrm{P}} = \frac{120 \times 50}{4} = 1500\ rpm$$

Rotor speed at the end of cycle $= 0.1sec \rightarrow 1500 - (2.5)(0.1) = 1497.5\ rpm$

$$\mathrm{H_{eq} = \frac{H_1G_1}{G_B} + \frac{H_2G_2}{G_B}} = \frac{6 \times 200}{100} + \frac{4 \times 150}{100} = 18\ MJ/MVA$$

9.State and explain equal area criterion. Indicate how you will apply equal area criterion to find the maximum additional load that can be suddenly added

<u>EQUAL AREA CRITERION</u>

In a system one machine is swinging with respect to an infinite bus,it is possible to study transient stability by means of a simple criterion,

Consider the swing equation $M\frac{d^2\delta}{dt^2} = P_m - P_e$

$$\frac{d^2\delta}{dt^2} = \frac{1}{M}(P_m - P_e) = \frac{P_a}{M}; P_a = accelerating\ power$$

$$M = \frac{H}{\pi f}\ \ in\ pu\ system,$$

If the system is unstable δcontinuous to increase indefinitely with time and the machine loses synchronism,

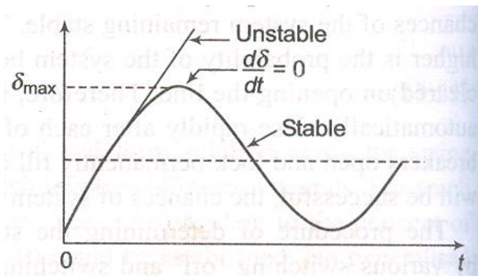
If the system is stable $\delta(t)$performs oscillates (non sinusoidal) whose amplitude decreases in actual practice because of damping terms,

The system is non linear, the nature of it's response $[\delta(t)]$ is not unique and it may exhibit instability. Depending up on the nature and severity of disturbance.

Indication of stability will be given by first swing where δ will go to a maximum and will start to reduce.

If the system is stable if $\frac{d\delta}{dt} = 0$

Is unstable if $\frac{d\delta}{dt} > 0$



Multiply both sides of swing equation by $2\frac{d\delta}{dt}$

$$2\frac{d\delta}{dt}\times\frac{d^2\delta}{dt^2} = P_m - P_e = \frac{2P_a}{M}\times\frac{d\delta}{dt}$$

Integrating the above equation;$\left(\frac{d\delta}{dt}\right)^2 = \frac{2}{M}\int_{\delta_0}^{\delta} P_a d\delta$

$$\frac{d\delta}{dt} = \left[\frac{2}{M}\int_{\delta_0}^{\delta} P_a\, d\delta\right]^{\frac{1}{2}}$$

δ_0-initial rotor angle before it begins to swing due to disturbance,

Condition for stability can be written as

$$\left[\frac{2}{M}\int_{\delta_0}^{\delta} P_a\, d\delta\right]^{\frac{1}{2}} = 0$$

$$\int_{\delta_0}^{\delta} P_a\, d\delta = 0$$

The system is stable if the area under $P_{a(accelerating\, power)} V_s\ \delta$ curve reduces to zero at some value of δ.

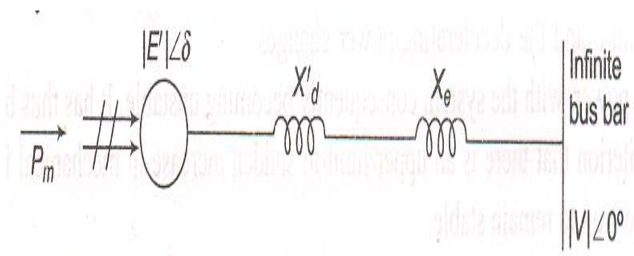
Positive accelerating area under $P_a - \delta$ curve must equal to negative (decelerating) area. Is called equal area criterion of stability.

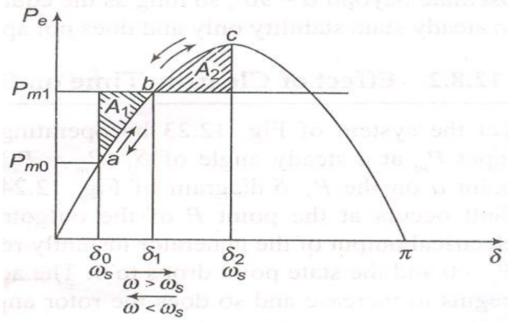
10. TRANSIENT STABILITY (May/June-2016) (Apr/May 2017)(Nov/Dec 2017)

For large disturbance changes to angular difference may be as large as to cause the maintain to fall out of step. This type of instability known as transient stability.

(i) Sudden change in mechanical power input.

Consider a synchronous generator supplying a power to infinite bus through a reactive network as shown.





$$P_e = \frac{|E'||V|}{X_d' + X_e} \sin\delta = P_{max} \sin\delta$$

Initial condition:

Machine operating under steady state with $P_{m0} = P_{e0} = P_{max} sin\delta_0$

(i)Accelerating power $P_a = P_{m1} - P_e$ causes the rotor speed to increase $(\omega > \omega_s)$

(ii)At point p, when $\delta = \delta_1$:$P_a = P_{m1} - P_e = P_{m1} - P_{max} sin\delta_1 = 0$

Rotor angle continuous to increase as $(\omega > \omega_s)$

(iii) P_a $becomes\ negative\ (decelerating\ power)$ And rotor speed beings to reduce. But rotor angle continuous to increase till δ_2 with corresponding operating point "c" where $(\omega = \omega_s)$

(iv)At point C decelerating area A2=Accelerating area A1.since rotor is decelerating speed reduces below $\omega_s$and rotor angle being to reduce.

(v) The system oscillates around new operating point b and settles finally at point b,$P_{m1} = P_e = P_{max} sin\delta_1$

Accelerating area $A_1 = \int_{\delta_0}^{\delta_1} (P_{m1} - P_e) d\delta$

Decelerating area $A_2 = \int_{\delta_1}^{\delta_2} (P_e - P_{m1}) d\delta$

It is possible to find δ_2 such that A1=A2and system is stable.

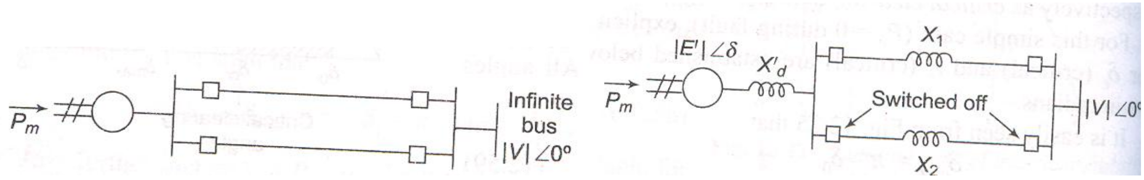
(vi) Decelerating area A2 to neutralize accelerating area A1 depends on the amount of sudden change from initial condition. There is a limit to which mechanical power can be suddenly increased. Limiting condition.A1=A2

, $\delta_2 = \delta_{max} = \pi - \delta_1 = \pi\ \sin^{-1}\left(\frac{P_{m1}}{P_{max}}\right)$.

Any further increase in mechanical power input, the area available for decelerating is less than accelerating area so that excess kinetic energy causes rotor angle $\delta$to increase beyond C. and system become unstable.

(ii) **Sudden loss of one of parallel line.**

A generator feeding inifinite bus bar over two parallel lines.



Initial condition:

The machine is operating under steady state operating conditions with $\delta = \delta_0$ and both lines.

$$P_{e1} = \frac{|E'||V|}{X_d' + X_e \| X_2} \sin\delta = P_{max1} \sin\delta$$

Now line 2 suddenly switched off

$$P_{e2} = \frac{|E'||V|}{X_d' + X_1} \sin\delta = P_{max2} \sin\delta$$

$$P_{max2} < P_{max1}$$

Operating point at initial position a moves to b, than to C and then to D, it makes oscillation about point C. and finally settles there.

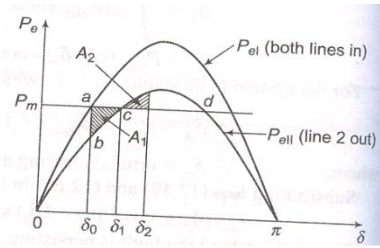
At point C generator supply same output power.

$$P_e = P_{e0} = P_{max1} \sin\delta_0 = P_{max2} \sin\delta_1$$

Rotor angle change from δ_0 to δ_1

Limiting condition:

The δ increases to δ_m where the transient stability limit has reached. Beyond this the machine will loose synchronism with one line out.



The angle δ_m can be found out by equating accelerating area A_1 and decelerating area A_2.

$$A_1 = \int_{\delta_0}^{\delta_1} (P_{e1} - P_{e2})\, d\delta = \int_{\delta_0}^{\delta_1} (P_m - P_{e2})\, d\delta$$

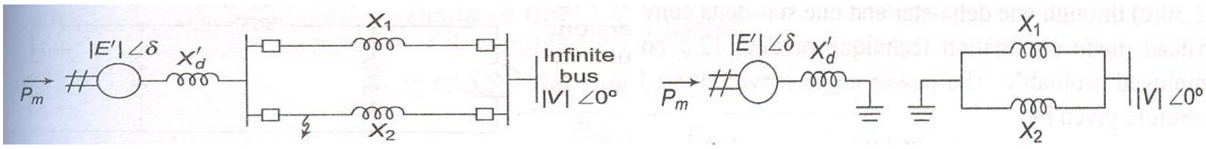
$$A_2 = \int_{\delta_1}^{\delta_m} (P_{e2} - P_m)\, d\delta$$

Where

$$P_{e1} = P_{max1} \sin\delta$$
$$P_{e2} = P_{max2} \sin\delta$$
$$\delta_0 = \sin^{-1}\left(\frac{P_{e1}}{P_{max1}}\right)$$
$$\delta_m = \pi - \sin^{-1}\left(\frac{P_{e1}}{P_{max2}}\right)$$

(iii) Three phase short circuit on one of the parallel line.

Consider a generator feeding the power to infinite bus through two parallel line.



<u>Short circuit at one end of transmission line.</u>

Consider a 3-phase short circuit at generator end of lins 2 than power angle equation are.

$$P_{e1} = \frac{|E^{'}||V|}{X_d^{'} + (X_1 parallel\ to\ X_2)} sin\delta$$

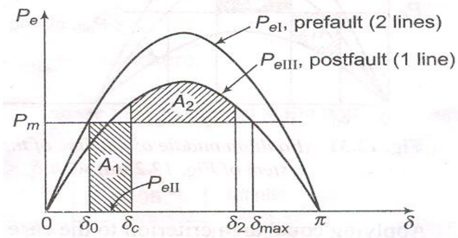
$$P_{e1} = P_{max1} sin\delta (Prefault)$$

$$P_{e2} = 0\ (During\ fault\ )$$

$$P_{e111} = \frac{|E^{'}||V|}{X_d^{'} + (X_1)} sin\delta$$

(post fault after opening line2)=$P_{max111}\,sin\delta$

Power angle curves for all above three conditions are



The fault line should be opened as early as possible so that the decelerating area A2 available is more than accelerating Area A1. And generator remains in synchronism when rotor angle reaches δ_c the faulted line is cleared.

Limiting case:$\delta\ is\ maximum.$

In limiting case,when faulted line is cleared the rotor angle is called $\delta_{cr}[critical\ clearing\ time]$

Accelerating area:$A_1 = \int_{\delta_0}^{\delta_{cr}} (P_m - P_{e11}) d\delta$

$$= \int_{\delta_0}^{\delta_{cr}} P_m d\delta = P_m(\delta_{cr} - \delta_0)$$

Decelerating area:$A_2 = \int_{\delta_{cr}}^{\delta_{max}} (P_{e111} - P_m) d\delta$

$$= \int_{\delta_{cr}}^{\delta_{max}} (P_{max111} sin\delta - P_m) d\delta$$

$$= -P_{max111} \cos\delta_{max+} P_{max111} cos\delta_{cr} - P_m(\delta_{max} - \delta_{cr})$$

Equating both areas

$$A_1 = A_2$$

$$\mathrm{P_m(\delta_{cr} - \delta_0) = -P_{max111} \cos\delta_{max} + P_{max111} cos\delta_{cr} - P_m(\delta_{max} - \delta_{cr})}$$

$$\mathrm{P_m\delta_{cr} - P_m\delta_0 = -P_{max111} \cos\delta_{max} + P_{max111} cos\delta_{cr} - P_m\delta_{max} + P_m\delta_{cr}}$$

$$\mathrm{P_{max111} cos\delta_{cr} = P_{max111} \cos\delta_{max} + P_m(\delta_{max} - \delta_0)}$$

$$\cos\delta_{cr} = \frac{P_{max111}\cos\delta_{max} + P_m(\delta_{max} - \delta_0)}{P_{max111}}$$

$$\delta_{cr} = \left(\frac{P_{max111}\cos\delta_{max} + P_m(\delta_{max} - \delta_0)}{P_{max111}}\right)$$

Where δ_{max}&δ_0 are in radians

$$\delta_0 = \sin^{-1}\left(\frac{P_m}{P_{max1}}\right)$$

$$\delta_{max} = \pi - \sin^{-1}\left(\frac{P_m}{P_{max1}}\right)$$

11. Explain the terms critical clearing angle and critical clearing time in connection with the transient stability of a power system (Nov/Dec 2017)

(iv) Effect of circuit breaker speed on transient stability and critical clearing Angle.

If the available decelerating area is greater than the accelerating area the machine will remain synchronism. The accelerating area (A1) can be reduced by reducing the angle δ_{cr} at which the CB clears the faulted line.

This is possible if CB is faster in operation. The critical clearing angle δ_{cr} is angle at which the faulted line is cleared and the machine just remains in synchronism.

If $\delta_c > \delta_{cr}$ the machine will lose the synchronism, the critical clearing angle can be calculated from the equal area criteria.

Critical clearing Time:

The time corresponding to critical clearing angle δ_{cr} (or) time interval between the time when fault takes place and the time when CB clears the fault critically is known as critical clearing time

The swing equation is

$$M\frac{d^2\delta}{dt^2} = P_m - P_e$$

$$\frac{d^2\delta}{dt^2} = \frac{P_m - P_e}{M}$$

If during the fault $P_e = 0$, than $\frac{d^2\delta}{dt^2} = \frac{P_m}{M}$

Integrating twice W.R.T t

$$\delta = \frac{P_m}{2M}t^2 + \delta_0$$

When $t = t_{cr}$ and $\delta = \delta_{cr}$

$$\delta_{cr} = \frac{P_m}{2M}t_{cr}^2 + \delta_0$$

$$t_{cr} = \sqrt{\frac{2M}{P_m}(\delta_{cr} - \delta_0)}$$

$$M = \frac{H}{\pi f}\ pu$$

$$t_{cr} = \sqrt{\frac{2M}{\pi f P_m}(\delta_{cr} - \delta_0)}$$

t_{cr} is valied only when during fault $P_e = P_{e11} = 0$

It is not zero the swing equation during fault becomes,

$$\frac{d^2\delta}{dt^2} = \frac{P_m - P_{max11}\sin\delta}{M}$$

This is a linear second order differential equation which can be solved by numerical method only.

12. Computational algorithm for obtaining swing curves using modified Euler's method.(May/June-2016)(Nov/Dec 2017)

1. Carry out a load flow study (prior to disturbance) using specified voltages and powers.
2. Compute voltage behind transient reactance of generatorsE_K°. This fixes generator emf magnitude and initial rotor angle (slack bus voltage V_1°
3. Compute Y_{bus} (during fault, postfault, line reclose)
4. Set time count $r = 0$.
5. Compute generator power output using appropriate Y_{bus} with help of the general form $P_1 = |E_1'|^2 G_{11} + |E_1'||E_2'||Y_{12}|\cos(S_1 - S_2 - Q_{12})$ this gives $P_{GK}^{(r)}$ for $t = t^{(r)}$
6. Compute $(\dot{x}_{1k}^r, \dot{x}_{2k}^r)$, $k = 1,2 \ldots \ldots n$

$$\dot{x}_{1k} = x_{2k}$$
$$\dot{x}_{2k} = \frac{\pi f}{H_k}(P_{Gk}^0 - P_{Gk}), k = 1,2 \ldots n$$

7. Compute the first estimates for $t = t^{(r+1)}$ as

$$x_{1K}^{(r+1)} = x_{1K}^{(r)} + \dot{x}_{1k}^{(r)}\Delta t, \quad k = 1,2 \ldots n$$
$$x_{2K}^{(r+1)} = x_{2K}^{(r)} + \dot{x}_{2k}^{(r)}\Delta t$$

8. Compute the first estimates of $E_K^{(r+1)}$

$$E_K^{(r+1)} = E_K^\circ\left(\cos x_{1K}^{(r+1)} + j\sin x_{1K}^{(r+1)}\right)$$

9. Compute $P_{GK}^{(r+1)}$ (appropriate Y Bus)
10. Compute $\left[\left(\dot{x}_{1K}^{(r+1)}, x_{2K}^{(r+1)}\right), K = 1,2 \ldots . n\right]$
11. Compute average values of state derivatives

$$\dot{x}_{1K.avg}^{(r)} = \frac{1}{2}\left[\dot{x}_{1K}^{(r)} + \dot{x}_{1K}^{(r+1)}\right] K = 1, 2 \ldots . n$$

12. Compute final state estimates for $t = t^{(r+1)}$

$$x_{1K}^{(r+1)} = x_{1K}^{(r)} + \dot{x}_{1K.avg}^{(r)}, \Delta t \quad K = 1,2 \ldots . n$$
$$x_{2K}^{(r+1)} = x_{2K}^{(r)} + \dot{x}_{2K.avg}^{(r)}, \Delta t$$

13. Compute final estimate E_K at $t = t^{r+1}$ using

$$E_K^{(r+1)} = |E_K^\circ|\left(\cos x_{1K}^{(r+1)} + j\sin x_{1K}^{(r+1)}\right)$$

14. Print $\left(x_{1K}^{(r+1)}, x_{2K}^{(r+1)}\right)$; $\quad K = 1,2 \ldots . n$
15. Test for time limit i.e. check if $r > r_{final}$. If not $r = r + 1$ and repeat step 5. Otherwise print result.

This algorithm easily modified to include simulation of voltage regulator, field excitation, and saturation flux path.

13. Power system stability solution of swing equation by Runge-kutta order 4 method. (Apr/May 2017)

Let a first order differential equation $\frac{dx}{dt} = f(x,t)$

1. Assume initial solution $t_0$is x_0,
2. Set step size Δt,than the solution of differential equation is given at

$$t_1 = t_0 + \Delta t \text{ as}$$

$$x_1 = x_0 + \Delta x$$

$$\Delta x = \frac{1}{6}[K_1 + 2K_2 + 2K_3 + K_4]$$

$$K_1 = f(x_0, t_0)\Delta t$$

$$K_2 = f\left(x_0 + \frac{K_1}{2}, \left[t_0 + \frac{\Delta t}{2}\right]\Delta t\right)$$

$$K_3 = f\left(x_0 + \frac{K_2}{2}, \left[t_0 + \frac{\Delta t}{2}\right]\Delta t\right)$$

$$K_4 = f(x_0 + K_3, (t_0 + \Delta t).\Delta t)$$

3. Similarly for ith generator,

$$K_{1i} = f(x_i, t_i)\Delta t$$

$$K_{2i} = f\left(x_i + \frac{K_{1i}}{2}, \left[t_i + \frac{\Delta t}{2}\right]\Delta t\right)$$

$$K_{3i} = f\left(x_i + \frac{K_{2i}}{2}, \left[t_i + \frac{\Delta t}{2}\right]\Delta t\right)$$

$$K_{4i} = f(x_i + K_{3i}, [t_i + \Delta t]\Delta t)$$

And solution $x_{i+1} = x_i + \frac{1}{6}[K_{1i} + 2K_{2i} + 2K_{3i} + K_{4i}]$

Runge-kutta method for swing equation.swing equation for I th generator is

$$\frac{d^2\delta_i}{dt^2} = \frac{\pi f}{H}(P_{mi} - P_{ei}\sin\delta_i); i = 1,2, \dots m$$

Multimachine system swing equation is written in state variable form

$$x_{1i} = \delta_i$$

$$x_{1i} = x_{2i} = f_i(\delta_i, \omega_i)$$

$$x_{2i} = \frac{\pi f}{H}(P_{mi} - P_{ei}\sin\delta_i)$$

$$x_{2i} = f_2(\delta_i, \omega_i)$$

<u>Algorithm for Runge-kutta method</u>

1. Carry out the load flow study(before transient) using specified voltage and power.
2. Find the voltage behind transient reactance of generator(E_i)
3. Compute Y_{bus} (During fault, post fault, line reclosed).
4. Set time count $\gamma = 0$ and set step size $\Delta t(t^{(0)}, t^{(1)})$....
5. Compute x_{1i}, x_{2i} from the equation

$$x_{1i} = f_1(\delta_i, \omega_i)$$

$$x_{2i} = \frac{\pi f}{H}(P_{mi} - P_{ei}\sin\delta_i)$$

$$x_{2i} = f_2(\delta_i, \omega_i)$$

6. Compute the two constant for each differential equation.

$$K_1^r = f_1(\delta_i^r, \omega_i^r)\Delta t$$
$$K_2^r = f_1(\delta_i^r + K_i^r, \omega_i^r + h_1^r)\Delta t$$
$$h_1^r = f_2(\delta_i^r, \omega_i^r)\Delta t$$
$$h_2^r = f_2(\delta_i^r + K_i^r, \omega_i^r + h_1^r)\Delta t$$

7. Compute state estimation:

$$\delta_i^{(r+1)} = \delta_i^r + \Delta\delta_i^r$$
$$\Delta\delta_i^r = \frac{1}{2}(K_1^r + K_2^r)$$
$$\omega_i^{(r+1)} = \omega_i^r + \Delta\omega_i^r$$
$$\Delta\omega_i^r = \frac{1}{2}(h_1^r + h_2^r)$$

8. Test for time limit for which swing curve is to be plotted if $r < r_{final}$ than $r = r + 1$ and repeat from step 5 above,o otherwise print resut and step,

9. Plot the curve between rotor angle(δ)and time(t)

14.Asynchronous generator of reactance 1.2PU is connected to an infinite bus bar $|V| = 1.0pu$ through transformer and a line of total reactance 0.60pu.the generator no load voltage is 1.20pu and its inertia constant is H=4MW.S/MVA. Resistance and machine damping may be assumed negligible .the system frequency is 50Hz.

Calculate the frequency of natural oscillation if the generator is loaded to(i)50%,(ii)80%of its maximum power limit.

Given Data:

$X_d = 1.2$, $|V| = 1.0pu$ X_{Tr}&$X_{Lne} = 0.60$, $|E'| = 1.20pu$,H=4MW.s/MVA,f=50HZ.

Solution:

(i)For 50% loading

$$P_e = P_{max} sin\delta_0$$
$$\frac{P_e}{P_{max}} = sin\delta_0$$
$$sin\delta_0 = 0.5\ or \delta_0 = 30°$$
$$\left[\frac{\partial P_e}{\partial\delta}\right]_{30} = \frac{|E'||V|}{X_d + X_1}\cos\delta_0$$
$$= \frac{1.2 \times 1}{1.2 + 0.6}\cos 30$$
$$= 0.577 \text{ Mw(pu)ele rad}$$
$$M = \frac{H}{\pi f} = \frac{4}{\pi \times 50} = S^2/ele.rad$$

From characteristics equation $P = \mp j\left[\frac{\left[\frac{\partial P_e}{\partial\delta}\right]_{30}}{M}\right]^{\frac{1}{2}}$ or $j\sqrt{\left[\frac{\left[\frac{\partial P_e}{\partial\delta}\right]_{30}}{M}\right]}$

$$= \mp j\left[\frac{0.577}{\frac{4}{\pi\times 50}}\right]^{\frac{1}{2}} = j4.76$$

$$\text{Frequency of oscillation} = 4.76\text{rad/sec} = \frac{4.76}{2\pi} = 0.758HZ$$

For 80% Loading

$$P_e = P_{max} sin\delta_0$$

$$sin\delta_0 = \frac{P_e}{P_{max}} = 0.8; \delta_0 = 53.1$$

$$\left[\frac{\partial P_e}{\partial \delta}\right]_{53.1} = \frac{|E^{'}||V|}{X}\cos\delta_0$$

$$= \frac{1.2 \times 1}{1.8}\cos 53.1 = 0.4\text{MW}$$

$$Chracterstics\ equation, P = \mp j\left[\frac{0.4}{\frac{4}{\pi\times 50}}\right]^{\frac{1}{2}} = j3.96$$

$$\text{Frequency of oscillation} = 3.96 rad/sec$$

$$= \frac{3.96}{2\pi} = 0.63Hz$$

15.The generator is delivering 1.0pu power to the infinite bus $|V| = 1.0PU$,with generator terminal voltage of $|V_t| = 1.0PU$calculate the generator EMF behind transient reactance find the maximum power that can be transferred under following conditions;

(a)system healthy,

(b)one line shorted(3φ *in the middle*).

(c)one line open.

Solution:

$$V_t = |V_t| = 1\angle\alpha$$

Power angle equation $\frac{|V_t||V|}{X}\sin\delta = P_e$

$$\frac{1\times 1}{0.25 + 0.1} sin\delta = 1$$

$$\delta = 20.5°$$

Current to infinite bus

$$I = \frac{|V_t|\angle\alpha - |V|\angle 0}{jX} = \frac{1\angle 20.5 - 1\angle 0}{j0.35}$$

$$= 1 + j0.18 = 1.016\angle 10.3°$$

Voltage behind transient reactance, $E^{'} = V + jIX_d$

$$E^{'} = 1\angle 0 + j(1 + j0.18)(0.6)$$

$$= 0.829 + j0.6$$

$$= 1.075\angle 33.9°$$

(a)system stability:

$$P_{max} = \frac{|E^{'}||V|}{X_{12}} = \frac{1 \times 1.075}{0.6} = 1.79PU$$

$$P_e = 1.79\sin\delta$$

(b) One line shorted in middle:

$$X_{12} = \frac{0\cdot25 \times 0\cdot35 + 0\cdot35 \times 0\cdot5 + 0\cdot5 \times 0\cdot25}{0\cdot25} = 1\cdot55$$

$$P_{max} = \frac{|E'||V|}{X_{12}} = \frac{1 \times 1.075}{1.55} = 0.694Pu$$

$$P_e = 0.694\sin\delta$$

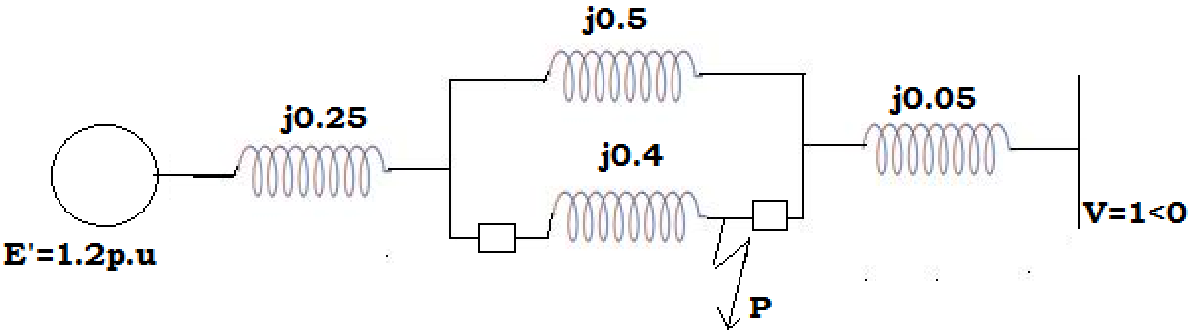
(c) One line open:

$$X_{12} = 0.25 + 0\cdot1 + 0\cdot5 = 0\cdot85$$

$$P_{max} = \frac{|E'||V|}{X_{12}} = \frac{1 \times 1.075}{0\cdot85} = 1\cdot265$$

$$P_e = 1\cdot265 sin\delta$$

16.Given system when a 3φ fault is applied at point P is shown fig



Find the critical clearing angle for clearing the fault with simultaneous opening of the breakers 1and 2.the reactance values of various components are indicated on the diagram, the generator is delivering 1.0pu power at the instant preceding the fault. (Nov/Dec 2016)(Apr/May 2018)

Solution :

1. **Normal operation (prefault)**

$$X_1 = 0.25 + \frac{0\cdot5 \times 0\cdot4}{0\cdot5 + 0\cdot4} + 0\cdot05$$

$$X_1 = 0\cdot522pu$$

$$P_{e1} = \frac{|E'||V|}{X_1}\sin\delta$$

$$= \frac{1\cdot2 \times 1}{0\cdot522}\sin\delta = 2\cdot3\sin\delta$$

Pre fault $P_{e1} = 1\cdot0$

$$1\cdot0 = 2\cdot3 sin\delta_0$$

$$\delta_0 = sin^{-1}\left(\frac{1\cdot0}{2\cdot3}\right) = 25\cdot8° = 0\cdot45 radian$$

(ii)During fault

No power is transmitted during fault

$$P_{e11} = 0$$

(iii)post fault operation (fault cleared by opening the faulted line)

$$X_{111} = 0\cdot25 + 0\cdot5 + 0\cdot05$$

$$= \mathbf{0\cdot8}$$

$$P_{eiii} = \frac{|E'||V|}{X_{iii}} \sin\delta = \frac{1 \cdot 2 \times 1 \cdot 0}{0 \cdot 8} \sin\delta_0$$

$$= 1 \cdot 5 \sin\delta$$

Maximum permissible angle δ_{max} for Area $A_1 = A_2$

$$\delta_{max} = \pi - \sin^{-1}\left(\frac{P_{m1}}{P_{max}}\right)$$

$$= \pi - \sin^{-1}\left(\frac{1}{1 \cdot 5}\right)$$

$$= 2 \cdot 41 \text{ radians}$$

Applying equalarea criteran for critical clearing angle δ_c

$$A_1 = P_m(\delta_{cr} - \delta_0)$$

$$= 1.0(\delta_{cr} - 0.45)$$

$$A_1 = \delta_{cr} - 0.45$$

$$A_2 = \int_{\delta_{cr}}^{\delta_{max}} (P_{eiii} - P_m) d\delta$$

$$= \int_{\delta_{cr}}^{2.41} (1.5\sin\delta - 1) d\delta$$

$$= [-1.5\cos\delta - \delta]_{\delta_{cr}}^{2.41}$$

$$= -1.5(\cos 2.41 - \cos\delta_{cr}) - (2.41 - \delta_{cr})$$

$$A_2 = 1.5\cos\delta_{cr} + \delta_{cr} - 1.293$$

Now $A_1 = A_2$

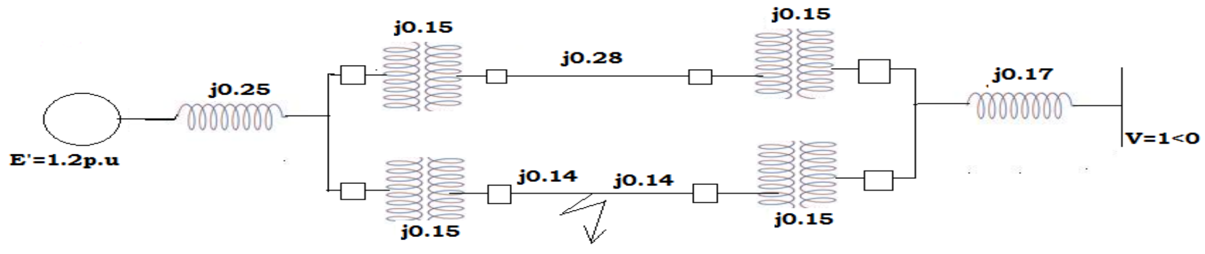
$$\delta_{cr} - 0.45 = 1.5\cos\delta_{cr} + \delta_{cr} - 1.293$$

$$1.5\cos\delta_{cr} = 0.843$$

$$\delta_{cr} = \text{Cos}^{-1}\left(\frac{0.843}{1.5}\right) = 0.973$$

$$\delta_{cr} = 0.973 = 55 \cdot 8°$$

17.Find the critical clearing angle for the system, for three phase fault at point P. the generator is delivering 1.0 PU under pre fault conditions.(May/June-2016) (Apr/May 2017)



Solution:

(i)prefault operation:

Transfer reactance between generator and infinite bus is

$$X_i = 0 \cdot 25 + 0 \cdot 17 + \frac{15 + 0 \cdot 28 + 0 \cdot 15}{2} = 0 \cdot 71$$

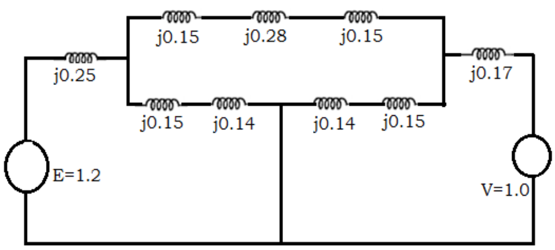
$$\therefore P_{ei} = \frac{|E'||V|}{X_i} \sin\delta$$

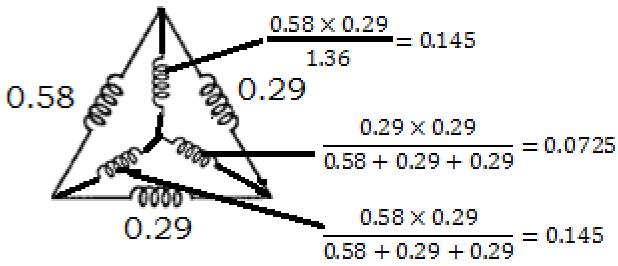
$$=\frac{1.2\times 1}{0\cdot 71}\sin\delta = 1\cdot 69\sin\delta_0$$

$$1.0 = 1.69\sin\delta_0$$

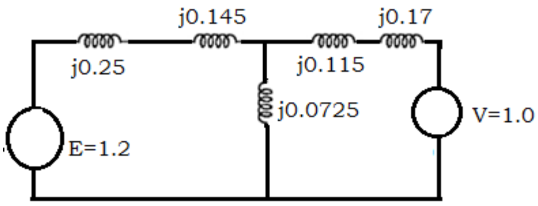
$$\delta_0 = 0.633 \text{ rad}$$

(ii)During fault:positive sequence reactance diagram during the fault is





Network after $\Delta - \mathrm{Y}$ conversion



Transfer reactance is given by

$$\mathrm{X_{ii}} = \frac{(0\cdot 25+0\cdot 145)(0\cdot 725)+(0\cdot 145+0\cdot 17)(0\cdot 0725)+(0\cdot 25+0\cdot 145)(0\cdot 145+0\cdot 17)}{0\cdot 075}$$

$$= 2.424$$

$$\mathrm{P_{ei}} = \frac{|E'||V|}{\mathrm{X_{ii}}}\sin\delta$$

$$=\frac{1\cdot 2\times 1}{2\cdot 424}\sin\delta$$

$$=0\cdot 495\sin\delta$$

(iii)post fault operation(fault line switched off)

$$\mathrm{X_{iii}} = 0\cdot 25+0\cdot 15+0\cdot 28+0\cdot 15+0\cdot 17 = 1.0$$

$$\mathrm{P_{eiii}} = \frac{|E'||V|}{\mathrm{X_{ii}}}\sin\delta = \frac{1\cdot 2\times 1}{1}\sin\delta = 1\cdot 2\sin\delta$$

$$\delta_{\max} = \pi - \sin^{-1}\left(\frac{\mathrm{P_m}}{\mathrm{P_{eiii}}}\right)$$

$$= \pi - \sin^{-1}\left(\frac{1}{1.2}\right)$$

$$\delta_{\max} = 2.156 \text{ rad}$$

Find critical clearing angle $A_1 = A_2$

$$A_1 = \mathrm{P_m}(\delta_{cr} - \delta_0)$$

$$= 1.0(\delta_{cr} - 0.633) - \int_{\delta_0}^{\delta_{cr}} 0.495\sin\delta d\delta$$

$$A_2 = \mathrm{P_m}\int_{\delta_{cr}}^{\delta_{\max}} (\mathrm{P_{eiii}} - \mathrm{P_m})d\delta$$

$$= \int_{\delta_{cr}}^{\delta_{max}} 1.2\sin\delta - 1.0(\delta_{max} - \delta_c)$$

$$= \int_{\delta_{cr}}^{\delta_{max}} 1.2\sin\delta - 1.0(\delta_{max} - \delta_c)$$

$$A_2 = \int_{\delta_{cr}}^{\delta_{max}} 1.2\sin\delta - 1.0(2.156 - \delta_c)$$

$A_1 = A_2$

$$\delta_{cr} = 0.633 - \int_{0\cdot 633}^{\delta_{cr}} 0.495\sin\delta d\delta$$

$$= \int_{\delta_{cr}}^{2.155} 1.2\mathrm{sn}\delta d\delta - 2\cdot 155 + \delta_{cr}$$

$$= -0\cdot 633 + [0\cdot 495\cos\delta]_{0.633}^{\delta_{cr}}$$

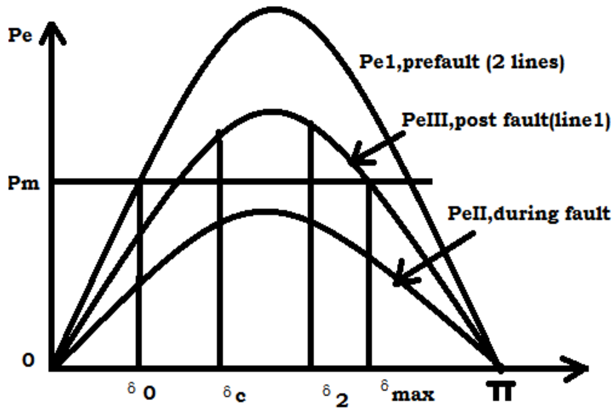
$$= -[1.2\cos]_{\delta_{cr}}^{2.155} - 2.155$$

$$\delta_{cr} = 49.1°$$

18.A generator operating at 50Hz delivers1p.u power to an infinite bus through a transmission circuit in which resistance ignored. A fault takes place reducing the maximum power transferable to 0.5p.u where before the fault, this power was 2.0p.u and after the clearance of the fault, it is 1.5 p.u .by the use of equal area criterion, determine the critical clearing angle.(May/June-2016)(Nov/Dec 2017)

Solution:

All the three power angle curves are shown fig



$$P_{maxI} = 2.0\text{p.u}, P_{maxII} = 0.5\text{p.u}, P_{maxIII} = 1.5\text{p.u}$$

Initial loading $\quad P_m = 1.0\text{p.u}$

$$\delta_0 = sin^{-1}\left(\frac{P_m}{P_{maxI}}\right) = sin^{-1}\left(\frac{1}{2}\right) = 0.523\ rad$$

$$\delta_{max} = \pi - sin^{-1}\left(\frac{P_m}{P_{maxIII}}\right)$$

$$= \pi - sin^{-1}\left(\frac{1}{1.5}\right) = 2.41\ rad$$

$$\boldsymbol{Cos\delta_{cr} = \frac{P_m(\delta_{max} - \delta_0) - P_{maxII}\cos\delta_0 + P_{maxIII}\cos\delta_{max}}{P_{maxIII} - P_{maxII}}}$$

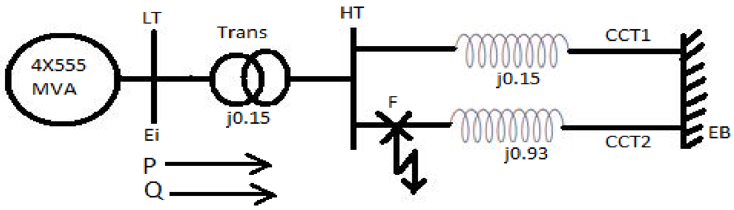
$$= \frac{1.0(2.41 - 0.523) - 0.5cos0.523 + 1.5cos2.41}{1.5 - 0.5} = 0.337$$

$\delta_{cr} = Cos^{-1}(0.337) = 70.3°$

19. the generators are modeled as a single phase equivalent generator represented by the classical model with the following parameters expressed in per unit on 2220MVA, 24KV base.

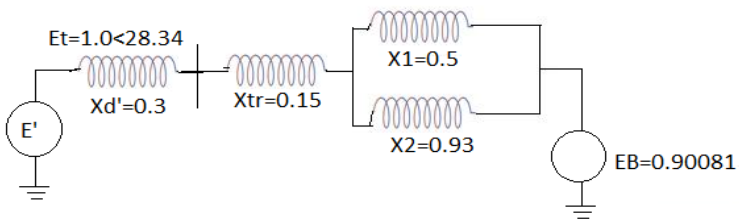
$X'_d = 0.3, H = 3.5MW.\frac{s}{MVA}\ K_D = 0$

Circuit 2 experiences a solid three phase fault at point F, and the fault is cleared by isolating the fault circuit. Determine the critical clearing time and critical clearing angle by computing the time response of the rotor angle, using numerical integration.(APR/MAY-2015)



Solution:

The generator represented by classical model, the system equivalent circuit is shown in fig.



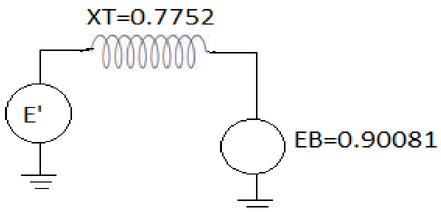
For initial operating conditions

$$E' = E_t + jX_d I_t$$

$$= 1 \cdot 0\angle 28 \cdot 34° + \frac{j(0 \cdot 3)(0 \cdot 9 - j0 \cdot 436)}{1 \cdot 0\angle - 28 \cdot 34°}$$

$$= 1 \cdot 1626\angle 41 \cdot 77$$

(i)prefault:

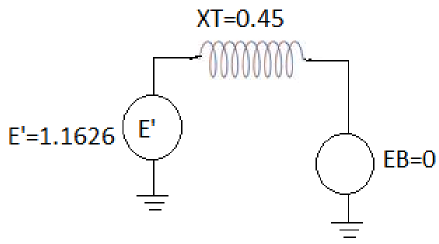


$$P_e = \frac{|E'||E_B|}{X_T}\sin\delta = \frac{1.1626 \times 0.90081}{0.7752}\sin\delta$$

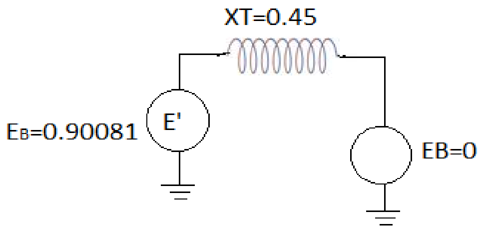
$$= 1.351\sin\delta$$

(ii)During fault:

$$P_e = 0$$



(ii)Post fault:



$$P_e = \frac{|E'||E_B|}{X_T}\sin\delta = \frac{1.1626 \times 0.90081}{0.95}\sin\delta$$
$$= 1.1024\sin\delta$$

Time response using numerical integration:

$$P(\Delta\omega_r) = \frac{1}{2H}(P_m - P_{max}\sin\delta)$$
$$= \frac{1}{2 \times 3.5}(0.9 - P_{max}\sin\delta)$$
$$P(\delta) = \omega_0\Delta\omega_r$$
$$= 377\Delta\omega_r$$

When

$$P_{max} = \begin{cases} 1.351 \text{ Before the fault} \\ 0 \text{ During the fault} \\ 1.1024 \text{ After the fault} \end{cases}$$

The initial values of δ $and\Delta\omega_e$ are $41.77°$ and 0PU respectively.

Let us consider the second order RK method.

The general formulas given the values of $\Delta\omega_r, \delta \& t$ for$(n+1)^{th}$ step of integration are as follows;

$$(\Delta\omega_r)_{n-1} = (\Delta\omega_r)_n + \frac{K_1'' + K_2''}{2}$$
$$t_{(n+1)} = t_n + \Delta t$$
$$\text{Where; } K_1' = \left[0.1286 - \frac{P_{max}}{7.0}\sin(\delta)_n\right]\Delta t$$
$$K_1'' = [377(\Delta\omega_r)_n]\Delta t$$
$$K_2' = \left[0.1286 - \frac{P_{max}}{7.0}\sin(\delta_n + K_1'')\right]\Delta t$$
$$K_2'' = [377(\Delta\omega_r)_n + K_1']\Delta t$$

Plot of δ asa function of time,for 3 values of fault clearing time t_c: $0.07s, 0.086s, 0.087s$

Corresponding values of clearing angle δ_c: $48.58°, 52.04°, 52.30°$

From the result system is stable with $t_c: 0.086s$ *and* $\delta_c: 52.04°$,

Unstable with $t_c: 0.087s$ *and* $\delta_c: 52.30°$,

Critical clearing time is $\therefore 0.086 \mp 0.0005s$
Critical clearing angle is $52.04° \mp 0.13°$

(ii)Equal area criterion:

The power angle diagrams for 3network conditions are shown. For critically stable case, the maximum swing in δ is given by,

From the concept of equal area $A_1 = A_2$

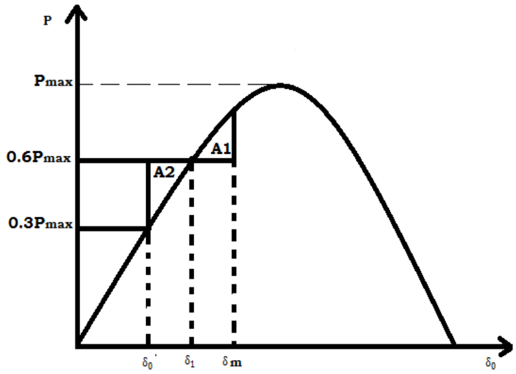
$A_1 + A_c = A_2 + A_c$

$$0.9(125.27 - 41.77)\frac{\pi}{180} = \int_{\delta_c}^{125.27} 1.1024\sin\delta d\delta$$

$1.3116 = 1.1024(\cos\delta_c + 0.5781)$

Critical clearing angle is Critical clearing angle is $\delta_c = 52.29°$

20. b) The load in the motor is 30% and the initial operating load angle be$\boldsymbol{\delta_0 i.e p_e = 0.3P_{max}}$(Nov/Dec-2015)



Generlly $\quad P_{max}\sin\delta_0 = p_e$

$$= \boldsymbol{0.3P_{max}}$$
$$\sin\delta_0 = 0.3$$
$$\delta_0 = 17.46°$$

W hen the load is doubled,$\boldsymbol{p_e = 0.3P_{max}}$

$$P_{max}\sin\delta_1 = p_e$$
$$= \boldsymbol{0.6P_{max}}$$
$$\sin\delta_1 = 0.6$$
$$\delta_1 = 36.87$$

To find the maximum value of$\delta(\delta_m)$

Using equal area criterion, $A_1 = A_2$

$$Area\ A_1 = \int_{\delta_0}^{\delta_1} (\boldsymbol{0.6P_{max}} - P_{max}\sin\delta)\, d\delta$$
$$= (\boldsymbol{0.6P_{max}(\delta_1 - \delta_0)} + P_{max}(\cos\delta)_{\delta_0}^{\delta_1}$$
$$= \boldsymbol{0.6P_{max}(\delta_1 - \delta_0)} + P_{max}(\cos\delta_1 - \cos\delta_0)$$
$$Area\ A_2 = \int_{\delta_1}^{\delta_m} (P_{max}\sin\delta - \boldsymbol{0.6P_{max}})\, d\delta$$
$$= -P_{max}(\cos\delta_m - \cos\delta_1) - \boldsymbol{0.6P_{max}(\delta_m - \delta_1)}$$

$Area\ A_1 = \ Area\ A_2$

$$\mathbf{0.6}\boldsymbol{P_{max}}(\boldsymbol{\delta_1} - \boldsymbol{\delta_0}) + \mathrm{P_{max}}(\cos\delta_1 - \cos\delta_0)$$
$$= -\mathrm{P_{max}}(\cos\delta_m - \cos\delta_1) - \mathbf{0.6}\boldsymbol{P_{max}}(\boldsymbol{\delta_m} - \boldsymbol{\delta_1})$$
$$\mathbf{0.6}(\boldsymbol{\delta_1} - \boldsymbol{\delta_0}) + (\cos\delta_1 - \cos\delta_0) = \cos\delta_1 - \cos\delta_m - \mathbf{0.6}(\boldsymbol{\delta_m} - \boldsymbol{\delta_1})$$
$$-\mathbf{0.6}\boldsymbol{\delta_0} + \cos\delta_1 - \cos\delta_0 = \cos\delta_1 - \cos\delta_m - \mathbf{0.6}\boldsymbol{\delta_m}$$
$$\cos\delta_m = \cos\delta_0 + \mathbf{0.6}(\boldsymbol{\delta_0} - \boldsymbol{\delta_m}) \times \frac{\boldsymbol{\pi}}{\mathbf{180}}$$
$$\cos\delta_m = 0.95393 + 0.1828 - \frac{0.6\pi\boldsymbol{\delta_m}}{\mathbf{180}}$$
$$\cos\delta_m = 1.1338 - 0.01047\boldsymbol{\delta_m}$$

solving for $\boldsymbol{\delta_m}$ ***by trial and errror method, we get***

$$\boldsymbol{\delta_m} > \boldsymbol{\delta_1}$$
$$\boldsymbol{\delta_m} = \mathbf{58.15}^\circ$$

Question Paper Code : 21403

B.E./B.Tech. DEGREE EXAMINATION, MAY/JUNE 2013.

Sixth Semester

Electrical and Electronics Engineering

EE 2351/EE 61/10133 EE 601 – POWER SYSTEM ANALYSIS

(Regulation 2008/2010)

(Common to PTEE 2351 Power System Analysis for B.E. (Part-Time) Fourth Semester Electrical and Electronics Engineering Regulation 2009)

Time : Three hours | Maximum : 100 marks

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. What is meant by percentage reactance?

2. Draw the equivalent circuit of a 3 winding transformer.

3. What is the necessity for slack bus?

4. What is meant by acceleration factor?

5. Distinguish symmetrical and unsymmetrical faults.

6. What is meant by fault level?

7. Define negative sequence impedance.

8. Draw the sequence network connections corresponding to L-L fault at bus.

9. Define infinite bus in a power system.

10. What is meant by power angle curve?

PART B — (5 × 16 = 80 marks)

11. (a) (i) For the system shown in figure 11 (a) (i) determine the generator voltage. Take a base of 100 MVA and 210 KV in the transmission line. (10)

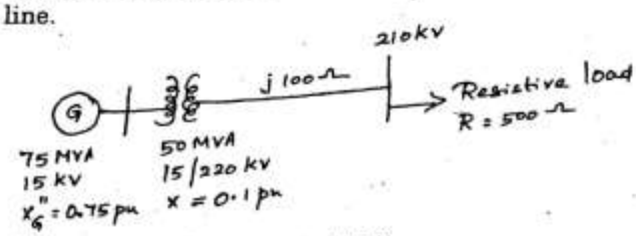


Fig. 11. (a) (i)

(ii) Why is per unit system used in power system analysis? And list its advantages. (6)

Or

(b) Form the bus impedance matrix for the network shown in fig. 11. (b) by bus building algorithm. (16)

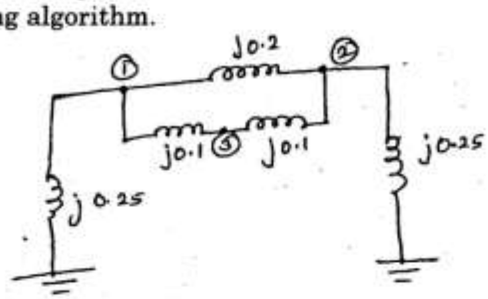


Fig. 11. (b)

12. (a) Consider the power system with the following data :

$$Y_{bus} = \begin{bmatrix} -j_{12} & j_8 & j_4 \\ j_8 & -j_{12} & j_4 \\ j_4 & j_4 & -j_8 \end{bmatrix}.$$

Bus No.	Type	Generation P	Generation Q	Load P	Load Q	Voltage Magnitude	Voltage Angle
1	Slack	–	–	–	–	1.0	0°
2	P-V	5.0	–	0	–	1.05	–
3	P-Q	0	0	3.0	0.5	–	–

Assume that the bus 2 can supply any amount of reactive power. With a flat start, perform the first iteration of power flow analysis using Newton-Raphson method. (16)

Or

(b) Discuss in detail about Gauss-Seidal load flow analysis algorithm and give steps for its implementation when Pv buses also present in the system. (16)

13. (a) A synchronous generator and motor are rated 30 MVA, 13.2 KV and both have subtransient reactances of 20%. The line connecting them has reactance of 10% on the base of machine ratings. The motor is drawing 20,000 kW at 0.8 pf leading and terminal voltage of 12.8 Kv when a symmetrical $3-\phi$ fault occurs at the motor terminals. Find the sub-transient current in the generator, motor and fault by using interval voltages of the machines. (16)

Or

(b) With a help of a detailed flowchart, explain how a symmetrical fault can be analysed using Z_{bus}. (16)

14. (a) A single line diagram of a power network is shown in Fig. 14 (a).

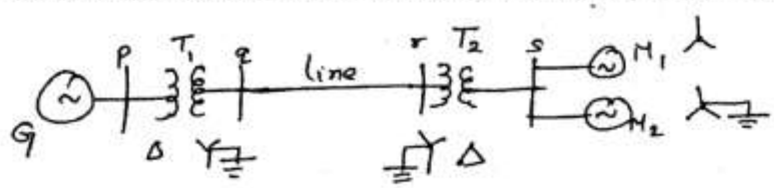


Fig. 14 (a)

The system data is given in the table 14 (a) as below:

Element	Positive sequence reactance (pu)	Negative sequence reactance (pu)	Zero sequence reactance (pu)
Generator G	0.1	0.12	0.05
Motor M_1	0.05	0.06	0.025
Motor M_2	0.05	0.06	0.025
Transformer T_1	0.07	0.07	0.07
Transformer T_2	0.08	0.08	0.08
Line	0.10	0.10	0.10

Generator grounding reactance is 0.5 pu. Draw sequence networks and calculate the fault current for a line-to-line fault on phases b and c at point q. Assume 1.0 pu prefault voltage throughout. (16)

Or

(b) Discuss in detail about the sequence impedances and networks of synchronous machines, transmission lines transformers and loads. (16)

15. (a) Derive swing equation for a single machine connected to infinite bus system. State the usefulness of this equation. State the reasons for non-linearity of this equation. (16)

Or

(b) State and explain equal area criterion and discuss how you will apply it to find the maximum additional load that can be suddenly added. (16)

Reg. No. :

Question Paper Code : 31403

B.E./B.Tech. DEGREE EXAMINATION, NOVEMBER/DECEMBER 2013.

Sixth Semester

Electrical and Electronics Engineering

EE 2351/EE 61/10133 EE 601 — POWER SYSTEM ANALYSIS

(Regulation 2008/2010)

(Common to PTEE 2351 Power System Analysis for B.E (Part-Time) Fourth Semester Electrical and Electronics Engineering Regulation 2009)

Time : Three hours Maximum : 100 marks

Answer ALL questions.

PART A — ($10 \times 2 = 20$ marks)

1. What are the functions of modern power system?

2. Name the diagonal and off - diagonal elements of bus impedance matrix.

3. Why do Y_{bus} used in load flow study instead of Z_{bus}?

4. When will the generator bus be treated as load bus?

5. What is the order of severity and occurrence of different types of fault?

6. What are the characteristics of shunt and series faults?

7. What are the observations made from the analysis of various faults?

8. Write the boundary conditions for single line to ground fault.

9. Differentiate between voltage stability and rotor angle stability.

10. Define swing curve? What is the use of this curve.

PART B — (5 × 16 = 80 marks)

11. (a) A 90 MVA 11 KV 3 phase generator has a reactance of 25%. The generator supplies two motors through transformer and transmission line as shown in figure. 11(a). The transformer T_1 is a 3 — phase transformer, 100 MVA, 10/132 KV, 6% reactance. The transformer T_2 is composed of 3 single phase units each rated, 300 MVA, 66/10 KV, with 5% reactance. The connection of T_1 & T_2 are shown. The motors are rated at 50 MVA and 400 MVA both 10 KV and 20 % reactance. Taking the generator rating as base, draw reactance diagram and indicate the reactance in per unit. The reactance of line is 100 ohms. (16)

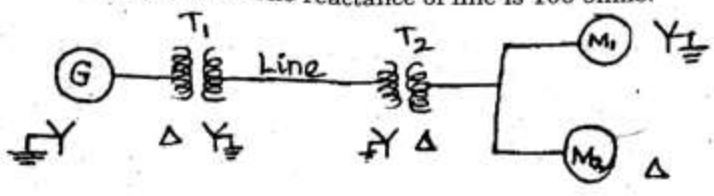


Figure. 11(a)

Or

(b) (i) Determine Y_{bus} for the 3 – bus system shown in figure. 11(b). The line series impedance as follows. (10)

Line (bus to bus)	Impedance (pu)
1 – 2	0.06 + j 0.18
1 – 3	0.03 + j 0.09
2 – 3	0.08 + j 0.24

Neglect the shunt capacitance of the lines.

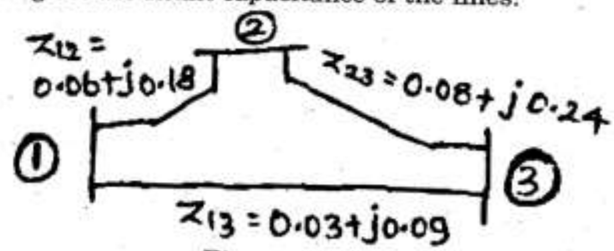


Figure. 11(b) (i)

(ii) What are impedance and reactance diagram? Explain. (6)

12. (a) A three bus power system is shown in figure. 12(a). The relevant per unit line admittance on 100 MVA base are indicated on the diagram and bus data are given in table 12. (a) Form Y_{bus} and determine the voltages at bus 2 and bus 3 after first iteration using Gauss Seidal method. Take the acceleration factor $\alpha = 1.6$. (16)

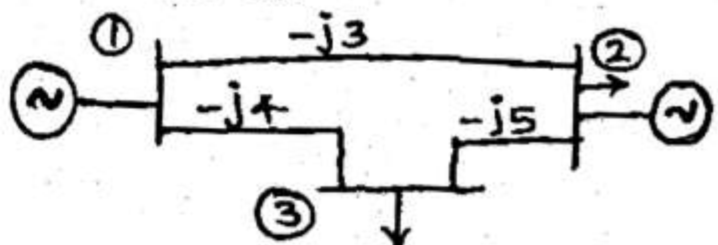


Figure. 12(a) A three – bus power system

Table: 12(a)

Bus number	Type	Generation		Load		Bus voltage	
		P_G	Q_G (MVAr)	P_L	Q_L	V (pu)	δ deg
1	Slack	?	?	0	0	1.02	0°
2	PQ	25	15	50	25	?	?
3	PQ	0	0	60	30	?	?

Or

(b) (i) Give the classification of various types of buses in a power system for load flow studies. (6)

(ii) Give the advantages and limitations of Newton Raphson method. (6)

(iii) What is meant by decoupled load flow method? (4)

13. (a) A 11 KV, 100 MVA alternator having a sub — transient reactance of 0.25 pu is supplying a 50 MVA motor having a sub — transient reactance of 0.2 pu through a transmission line. The line reactance is 0.05 pu on a base of 100 MVA. The motor is drawing 40 MW at 0.8 power factor leading with a terminal voltage of 10.95 KV when a 3-phase fault occurs at the generator terminals. Calculate the total current in the generator and motor under fault conditions. (16)

Or

(b) Figure 13. (b) Shows a generating station feeding a 132 KV system. Determine the total fault current, fault level and fault current supplied by each alternator for a 3 — phase fault at the receiving end bus. The line is 200 km long. Take a base of 100 MVA, 11 KV for LV side and 132 KV for HT side. (16)

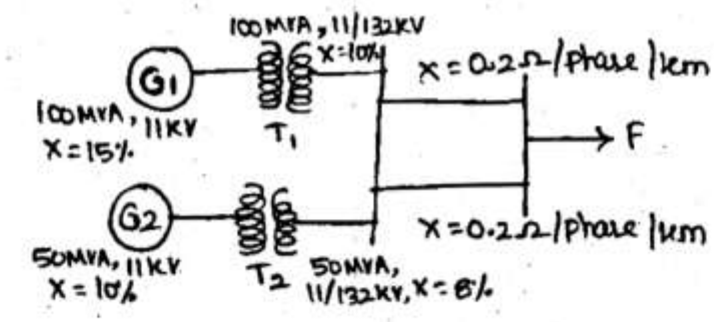


Figure. 13(b)

14. (a) Derive the necessary equation to determine the fault current for a Line - to - Line fault. Draw a diagram showing the interconnection of sequence networks. (16)

Or

(b) Figure. 14(b) Shows a power system network. Draw zero sequence network for this system. The system data is as under.

Generator G_1	50 MVA	11 KV,	$X_0 = 0.08$ pu
Transformer T_1	50 MVA	11/220 KV	$X_0 = 0.1$ Pu
Generator G_2	30 MVA	11 KV,	$X_0 = 0.07$ Pu
Transformer T_2	30 MVA	11/220 KV	$X_0 = 0.09$ pu

Zero sequence reactance of line is 555.6 ohms. Choose base MVA 50 and base voltage 11 KV for LT side and 220 KV for HT side. (16)

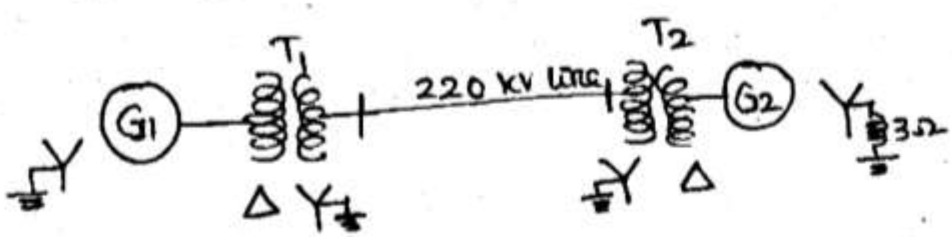


Figure. 14(b) Power System Network

15. (a) (i) Distinguish between steady state, transient and dynamic stability. (6)

(ii) Derive the swing equation of a synchronous machine. (10)

Or

(b) (i) Explain the methods of improving power system stability. (10)

(ii) Explain the terms critical clearing angle and critical clearing time *in* connection with the transient stability of a power system. (6)

Reg. No. [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]

Question Paper Code : 51443

B.E./B.Tech. DEGREE EXAMINATION, MAY/JUNE 2014.

Sixth Semester

Electrical and Electronics Engineering

EE 2351/EE 61/10133 EE 601 – POWER SYSTEM ANALYSIS

(Regulation 2008/2010)

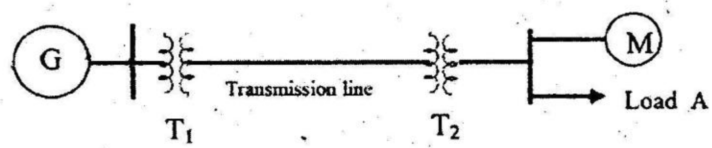
(Common to PTEE 2351 Power System Analysis for B.E. (Part-Time)
Fourth Semester Electrical and Electronics Engineering Regulation 2009)

Time : Three hours | Maximum : 100 marks

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. Draw the impedance diagram for the given single line representation of the power system.



2. What are the types of load modeling?

3. What is the role of swing bus in power flow study?

4. At what condition generator bus is treated as load bus?

5. Give the frequency of various faults occurrence in ascending order.

6. Define bolted fault.

7. What are the features of zero sequence current?

8. Write the symmetrical component currents of phase 'a' in terms of three phase currents.

9. Define dynamic stability with an example.

10. Find the frequency of oscillation for a synchronizing co-efficient of 0.6, inertia constant H = 4 and system frequency of 50 Hz.

PART B — (5 × 16 = 80 marks)

11\. (a) The single line diagram of a power system is shown in figure. 11. (a) along with components data. Determine the new per unit values and draw the reactance diagram. Assume 25 MVA, and 20KV as new base on generator G_1. (16)

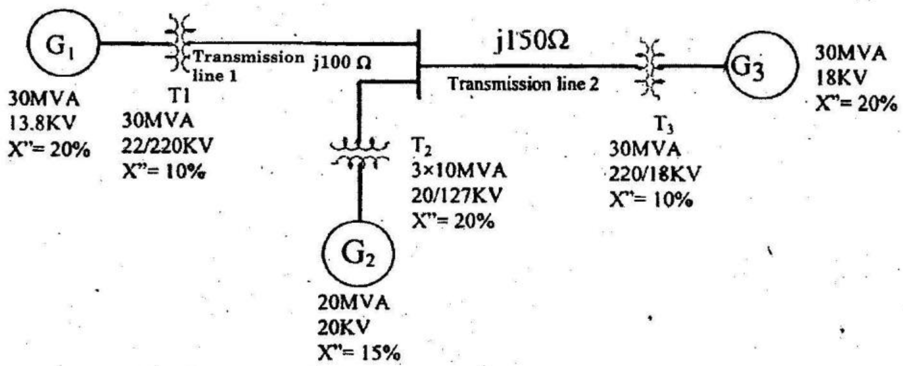


Figure 11. (a)

Or

(b) Describe the Z_{Bus} building algorithms in detail by using a three bus system. (16)

12\. (a) (i) Formulate the power flow equation for n bus system. (4)

(ii) Give the detailed flow chart for newton raphson method. (12)

Or

(b) Describe the step by step procedure for load flow solution from Gauss siedal method, if PV and PQ buses are present along with slack bus. (16)

13\. (a) A generator is connected through a five cycle circuit breaker to a transformer is rated 100MVA, 18KV with reactances $X_d''=20\%$, $X_d'=25\%$ and $X_d=110\%$. It is operated on no-load and at rated voltage. When a 3 phase fault occurs between the breaker and the transformer, find,

(i) Short circuit current in circuit breaker

(ii) The initial symmetrical rms current in the circuit breaker

(iii) The maximum possible dc component of the short circuit current in the breaker

(iv) The current to be interrupted by the breaker

(v) The interrupting MVA. (16)

Or

(b) With the help of a detailed algorithm, explain how a symmetrical fault can be analysed using Z_{Bus}. (16)

14. (a) A 25 MVA, 13.2 KV alternator with solidly grounded neutral has a sub transient reactance of 0.25 p.u. The negative and zero sequence reactances are 0.35 and 0.01 p.u. respectively. If a double line–to–ground fault occurs at the terminals of the alternator, determine the fault current and line-to-line voltages at the fault. (16)

Or

(b) Obtain the expression for fault current for a line to line fault taken place through an impedance Z_b in a power system. (16)

15. (a) Derive the swing equation of synchronous generator connected to infinite bus from the rotor dynamics, and extend the derivation for two parallel connected coherent and incoherent machines. (16)

Or

(b) Describe the algorithm for modified Euler method of finding solution for power system stability problem studies. (16)

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Reg. No. :

Question Paper Code : 91446

B.E./B.Tech. DEGREE EXAMINATION, NOVEMBER/DECEMBER 2014.

Sixth Semester

Electrical and Electronics Engineering

EE 2351/EE 61/10133 EE 601 — POWER SYSTEM ANALYSIS

(Regulation 2008/2010)

(Common to PTEE 2351/10133 EE 601 Power System Analysis for B.E. (Part–Time) Fourth Semester Electrical and Electronics Engineering Regulation 2009/2010)

Time : Three hours | Maximum : 100 marks

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. What are the main divisions of power system?

2. What is the need for per unit value?

3. What is load flow or power flow study?

4. Define voltage controlled bus.

5. What is the need for short circuit study?

6. What is symmetrical fault?

7. What are symmetrical components?

8. What is sequence networks?

9. Define critical clearing time and critical clearing angle.

10. What is steady state stability limit?

PART B — (5 × 16 = 80 marks)

11. (a) (i) Explain structure of modern power system with neat sketch. (8)

(ii) Describe about the representation of loads. (8)

Or

(b) (i) Obtain the per unit impedance diagram of the power system of fig shown below :

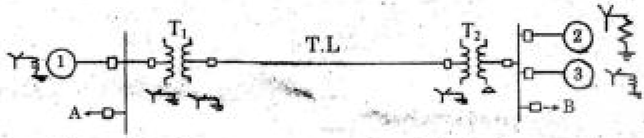


Fig one line diagram representation of a simple power system

Generator No 1:30 MVA, 10.5 Kv, $X''=1.6$ ohms

Generator No. 2:15 MVA, 6.6 Kv, $X''=1.2$ ohms

Generator No 3:25 MVA, 6.6 Kv, $X''=0.56$ ohms

Transformer T_1(3 phase): 15 MVA, 33/11 Kv, X = 15.2 ohms per phase on high tension side.

Transformer T_2(3 phase): 15 MVA, 33/6.2 Kv, X = 16 ohms per phase on high tension side.

Transmission line : 20.5 ohms/phase.

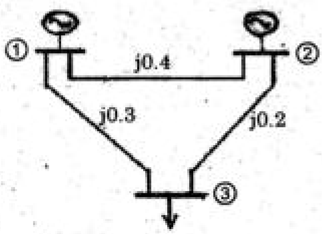
Load A: 15MW, 11 Kv, 0.9 lagging power factor.

Load B: 40MW, 6.6 Kv, 0.85 lagging power factor. (12)

(ii) Draw the per unit equivalent circuit of single — phase transformer? (4)

12. (a) (i) Write a note on classification of buses. (6)

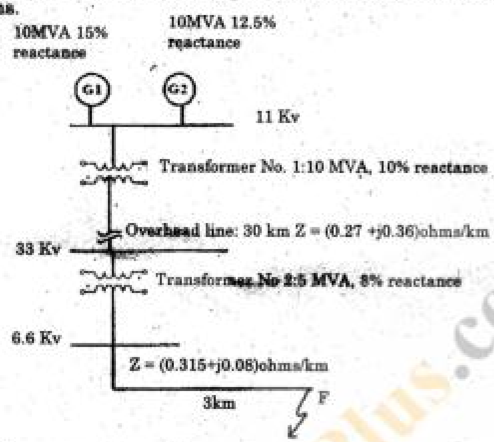
(ii) Fig shown below a three bus power system Bus.1: slack bus V= $1.05\angle 0^\circ$ p.u, Bus 2: PV Bus $|V|=1.0$ p.u, $P_g=3$ p.u. Bus 3: PQ Bus $P_L=4$ p.u, $Q_L=2$ p.u. carry out one iteration of load flow solution by Gauss Seidel method. Neglect limits on reactive power generation? (10)



Or

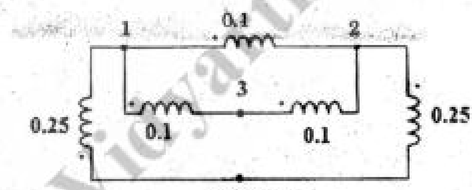
(b) Develop an algorithm and draw the flow chart for the solution of load flow problem using N-R method. (16)

13. (a) For the radial network shown below a three–phase fault occurs at F. Determine the fault current and the line voltage at 11kv bus under fault conditions.



Or

(b) For the 3–bus network fig shown below obtain Z bus by building algorithm.



14. (a) Explain about concept of symmetrical component. (16)

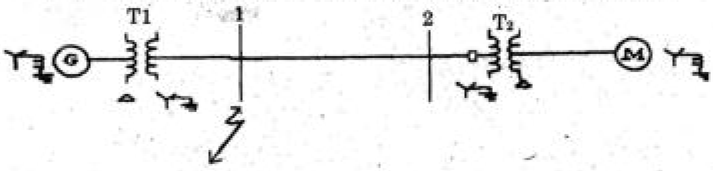
Or

(b) A single line to ground fault occurs on the bus 1 of the system of fig shown below find

(i) Current in the fault

(ii) SC current in phase a of generator

(iii) Voltage of the healthy phases of the bus 1 using Z_{Bus} method.



 91446

Given : Rating of the each machine 1200 KVA, 600V, with $X = X_2 = 10\%$, $X_0 = 5\%$ each three phase transformer is rated 1200 KVA, $600 - \Delta / 3300V - Y$ with leakage reactance of 5% the reactance of the transmission line are $X_1 = X_2 = 20\%$ and $X_0 = 40\%$ on a base of 1200 KVA, 3300V, the reactance's of the neutral grounding reactors are 5% on the KVA and voltage base of the machine. (16)

15. (a) Explain the equal area criteria for the following applications : (16)

(i) Sustained fault

(ii) Fault with subsequent clearing.

Or

(b) Derive the swing equation from the basic principles. Why it is non-linear? (16)

Reg. No. :

Question Paper Code : 71509

B.E./B.Tech. DEGREE EXAMINATION, APRIL/MAY 2015.

Sixth Semester

Electrical and Electronics Engineering

EE 2351/EE 61/10133 EE 601 – POWER SYSTEM ANALYSIS

(Regulation 2008/2010)

(Common to PTEE 2351/10133 EE 601 Power System Analysis for B.E. (Part–Time) Fourth Semester Electrical and Electronics Engineering Regulation 2009/2010)

Time : Three hours Maximum : 100 marks

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. A 400 kV transmission line has a surge impedance of $400\,\Omega$. What would be its surge impedance loading?

2. The ABCD constants of a three 345 kV transmission line are A = D = 0.98182 + j0.0012447, B = 4.035 + j58.947, C = j0.00061137. The line delivers 400 MVA at 0.8 lagging power factor at 345 kV. Determine the sending end voltage.

3. Distinguish between the Newton-Raphson and Gauss-seidel methods of load flow analysis.

4. Why is bus impedance matrix preferred for fault analysis?

5. What for Short circuit capacity (SCC) should be known at any bus. Write down the expression for SCC.

6. For a system, the bus impedance matrix was found to be $Z = j\begin{bmatrix} 0.0450 & 0.0075 & 0.030 \\ 0.0075 & 0.06375 & 0.030 \\ 0.030 & 0.030 & 0.0210 \end{bmatrix}$. The impedances are in per unit. A three phase symmetrical fault occurs at bus 3 through a fault impedance of $Z_f = j0.19$ per unit. Find out the post fault voltage at bus 2 assuming zero prefault current.

7. Derive the expression for neutral grounding reactance such that the single line to ground fault current is less than the three phase fault current.

8. State the reason why, the negative sequence impedance of a transmission line is taken as equal to positive sequence impedance of the line.

9. A four pole, 60-Hz synchronous generator has a rating of 200 MVA, 0.8 power factor lagging. The moment of inertia of the rotor is 45,100 kg-m^2. Determine M and H.

10. What is the significance of critical clearing time?

PART B — (5 × 16 = 80 marks)

11. (a) A 230 kV transmission line has a per phase series impedance of Z = 0.05 + j0.45 Ω per km and a per phase shunt admittance of Y = j3.4 × 10^{-6} siemens per km. the line is 80 km long. Using the nominal π model, determine the ABCD constants, sending end voltage and current, voltage regulation, the sending end power and the transmission efficiency when the line delivers 306 MW, unity power factor at 220 V.

Or

(b) Using the method of building algorithm find the bus impedance matrix for the network shown in figure 1.

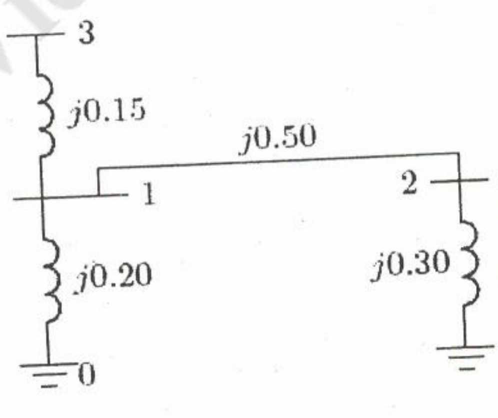


Fig. 1

12. (a) Figure 2, shows the one line diagram of a simple three bus power system with generation at buses at 1 and 2. The voltage at bus 1 is V = 1 + j0.0 V per unit. Voltage magnitude at bus 2 is fixed at 1.05 p.u. with a real power generation of 400 MW. A load consisting of 500 MW and 400 MVAR is taken from bus 3. Line admittances are marked in per unit on a 100 MVA base. For the purpose of hand calculations, line resistances and line charging susceptances are neglected.

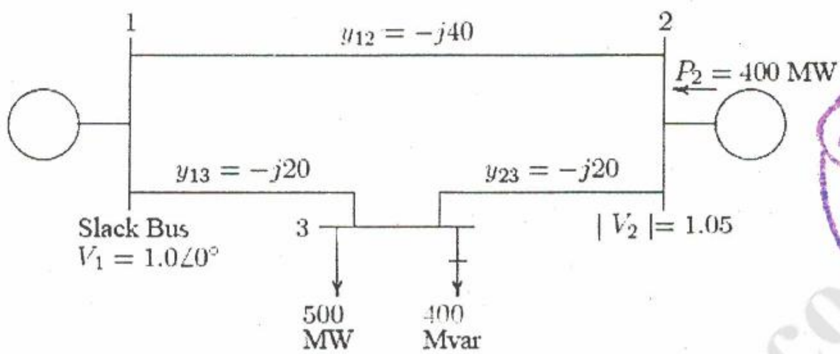


Fig. 2

Using Newton-Raphson method, start with the initial estimates of $V_2^{(0)} = 1.05 + j0.0$ and $V_3^{(0)} = 1.05 + j0.0$, and keeping $|V_2| = 1.05$ p.u., determine the phasor values V_2 and V_3. Perform two iterations.

Or

(b) In the power system network shown in figure 3, bus 1 is slack bus with $V_1 = 1.0 + j0.0$ per unit and bus 2 is a load bus with $S_2 = 280$ MW + j60 MVAr. The line impedance on a base of 100 MVA is Z = 0.02 + j0.04 per unit. Using gauss-seidel method, determine V_2. Use an initial estimate of $V_2^{(0)} = 1.0 + j0.0$ and perform four iterations. Also find S_1 and the real, reactive power loss in the line, assuming that the bus voltages have converged.

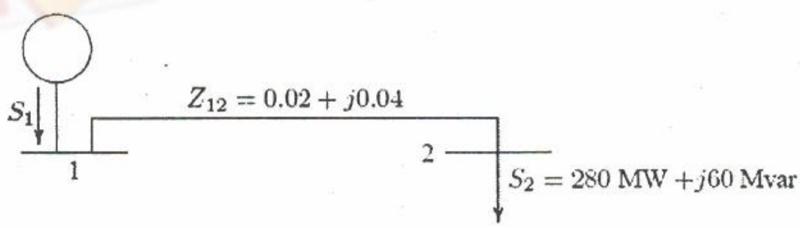


Fig. 3

13. (a) Two generators are connected in parallel to the low voltage side of a 3 phase delta star transformer as shown in figure 4. Generator 1 is rated 60,000 kVA, 11 kV. Generator 2 is rated 30,000 kVA, 11 kV. Each generator has a sub-transient reactance of $X_d'' = 25\%$. The transformer is rated 90,000 kVA at 11 kV-Δ/66 kV-Y with a reactance of 10%. Before a fault occurred, the voltage on the high tension side of the transformer is 63 kV. The transformer is unloaded and there is no circulating current between the generators. Find the sub-transient current in each generator when a three phase fault occurs on the ht side of the transformer.

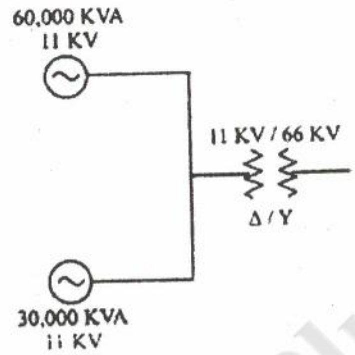


Fig. 4

Or

(b) A generator transformer unit is connected to a line through a circuit breaker. The unit ratings are :

Generator: 10 MVA, 6.6 kV: $X_d'' = 0.1$ pu, $X_d' = 0.2$ pu, and $X_d = 0.8$ pu

Transformer: 10 MVA, 6.9/33 kV, reactance 0.08 p.u

The system is operating on no load at a line voltage of 30 kV, when a three phase fault occurs on the line just beyond the circuit breaker. Find

(i) The initial symmetrical rms current in the breaker,

(ii) The maximum possible dc offset current in the breaker,

(iii) The momentary current rating of the breaker

(iv) The current to be interrupted by the breaker and the interrupting kVA, and

(y) The sustained short circuit current in the breaker

14. (a) A double line to ground fault occurs on lines b and c at point F in the system of figure 5. Find the sub transient current in phase c of the machine 1, assuming prefault currents to be zero. Both machines are rated 1200 kVA, 600 V with reactances of $X'' = X_2 = 10\%$ and $X_0 = 5\%$. Each three phase transformer is rated 1200 kVA, 600 V – Δ/300 V – Y with leakage reactance of 5%. The reactances of the transmission line are $X_1 = X_2 = 20\%$ and $X_0 = 40\%$ on a base of 1200 kVA, 3300 V. The reactances of the neutral of the grounding reactors are 5% on the kVA base of the machines.

Fig. 5

Or

(b) Calculate the sub-transient current in each phase for a dead short circuit on one phase to ground at bus 'q' for the system shown in figure 6.

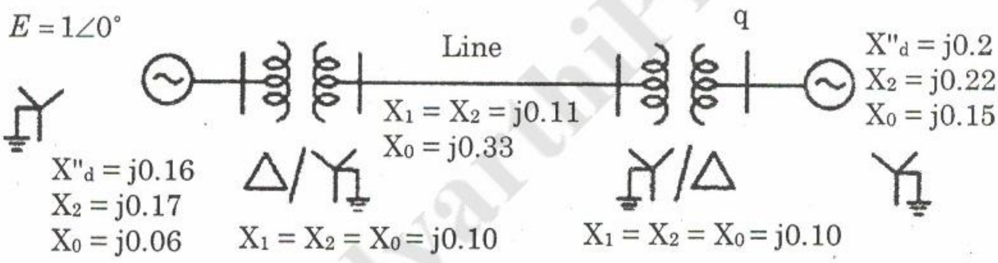


Fig. 6

15. (a) The single line diagram of a system is shown in figure 7. There are four identical generators of rating 555 MVA, 24 kV, 60 Hz supplying power infinite bus bar through two transmission circuits. The reactances shown in figure are in per unit on 2220 MVA, 24 kV base (refer to the low voltage side of the transformer). Resistances are assumed to be negligible. The initial operating conditions, with quantities expressed in per unit on 2220 MVA, 24 kV base, is as follows :

$P = 0.9$, $Q = 0.436$ (over excited), $\vec{E}_t = 1.0 < 28.34$, $\vec{E}_B = 0.90081 < 0$.

The generators are modeled as a single equivalent generator represented by the classical model with the following parameters expressed in per unit on 2220 MVA, 24 kV base.

$X'_d = 0.3$, $H = 3.5 MW.s/MVA$ $K_D = 0$.

Circuit 2 experiences a solid three phase fault at point F, and the fault is cleared by isolating the fault circuit. Determine the critical clearing time and critical clearing angle by computing the time response of the rotor angle, using numerical integration.

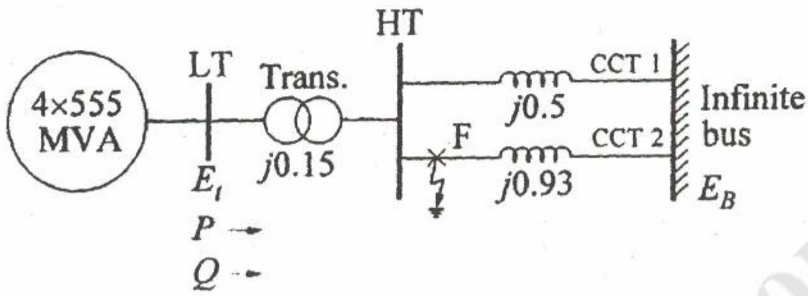


Fig. 7

Or

(b) (i) Define steady state stability and stability limit with the help of Power- Power angle curve. What are the techniques available to improve steady state stability? (6)

(ii) A 60-Hz synchronous generator has a transient reactance of 0.2 per unit and an inertia constant of 5.66 MJ/MVA. The generator is connected to an infinite bus through a transformer and a double circuit transmission line, as shown in Figure 8. Resistances are neglected and reactances are expressed on a common MVA base and are marked on the diagram. The generator is delivering a real power of 0.77 per unit to bus bar 1. Voltage magnitude at bus 1 is 1.1 p.u. The infinite bus voltage V = 1.06∠0 per unit. Determine the generator excitation voltage and obtain the swing equation.

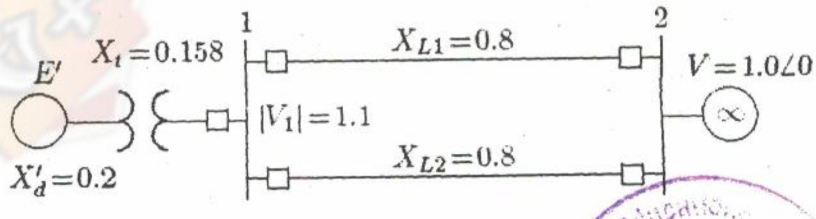


Fig. 8

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Question Paper Code : 27218

B.E./B.Tech. DEGREE EXAMINATION, NOVEMBER/DECEMBER 2015.

Fifth Semester

Electrical and Electronics Engineering

EE 6501 – POWER SYSTEM ANALYSIS

(Regulations 2013)

Time : Three hours Maximum : 100 marks

Answer ALL questions.

PART A — ($10 \times 2 = 20$ marks)

1. What is single line diagram?

2. Define per unit value.

3. What is the need for load flow study?

4. When is generator bus treated as load bus?

5. Why do faults occur in a power system?

6. What is direct axis reactance?

7. What are the symmetrical components of a three phase system?

8. What is the sequence operator?

9. How is the power system stability classified?

10. Write the power angle equation?

PART B — (5 × 16 = 80 marks)

11\. (a) Draw the reactance diagram for the power system shown in fig. 1. Neglect resistance and use a base of 50MVA and 13.8KV on generator G_1

G_1 : 20MVA, 13.8KV, X" = 20%

G_2 : 30MVA, 18.0KV, X" = 20%

G_3 : 30MVA, 20.0KV, X" = 20%

T_1 : 25MVA, 220/13.8 KV, X = 10%

T_2 : 3 Single phase unit each rated 10MVA, 127/18 KV, X = 10%

T_3 : 35MVA, 220/22 KV, X = 10%

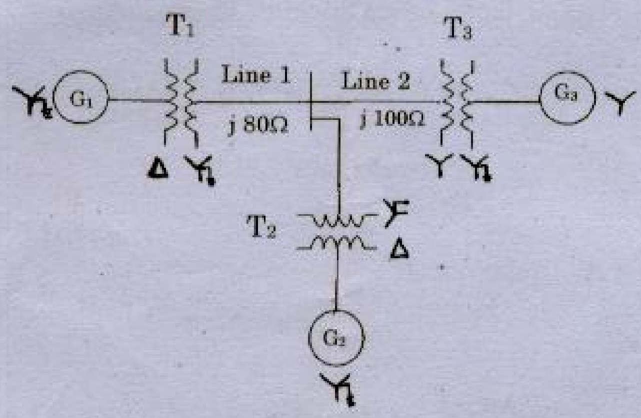

Fig. 1

Determine the new values of per unit reactance of G_1, T_1, Transmission line 1, Transmission line 2, G_2, T_2, G_3 and T_3.

Or

(b) Form Y_{bus} of the test system shown in fig.2 using singular transformation method. The impedance data is given in Table 1. Take (1) as reference node.

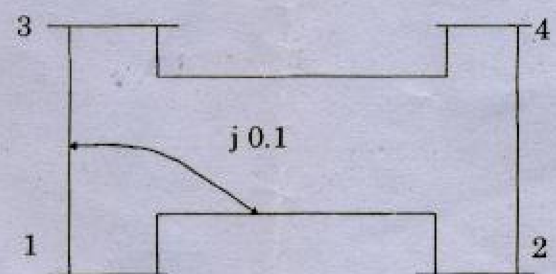

Fig. 2

Table 1

Element No	Self		Mutual	
	Bus code	Impedance	Bus code	Impedance
1	1 − 2	0.5	1 − 2	0.1
2	1 − 3	0.6		
3	3 − 4	0.4		
4	2 − 4	0.3		

12. (a) The system data for a load flow solution are given in Tables 2 and 3. Determine the voltages at the end of the first iteration using the Gauss-Seidel method. Take $\alpha = 1.6$.

Table 2 : Line admittances

Bus code	Admittance
1-2	2–j8.0
1-3	1–j4.0
2-3	0.666–j2.664
2-4	1–j4.0
3-4	2–j8.0

Table 3: Schedule of active and reactive powers

Bus Code	P in p.u	Q in p.u	V in p.u	Remarks
1	–	–	1.06	Slack
2	0.5	0.2	1+j0.0	PQ
3	0.4	0.3	1+j0.0	PQ
4	0.3	0.1	1+j0.0	PQ

Or

(b) Draw and explain the step by step procedure of load flow solution for the Gauss seidel method when PV buses are present.

13. (a) Generator G1 and G2 are identical and rated 11KV, 20MVA and have a transient reactance of 0.25 p.u at own MVA base. The transformers T1 and T2 are also identical and are rated 11/66KV, 5MVA and have a reactance of 0.06 p.u to their own MVA base. A 50km long transmission line is connected between the two generators. Calculate three phase fault current, when fault occurs at middle of the line as shown in fig. 3.

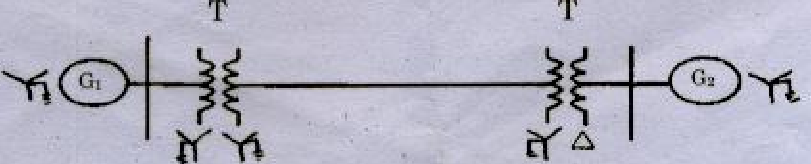

Fig. 3

Or

(b) A synchronous generator and synchronous motor each rated 30 MVA, 13.2 KV and both have subtransient reactance of 20% and the line reactance of 12% on a base of machine ratings. The motor is drawing 25 MW at 0.85 p.f leading. The terminal voltage is 12KV when a three phase short circuit fault occurs at motor terminals. Find the subtransient current in generator, motor and at the fault point.

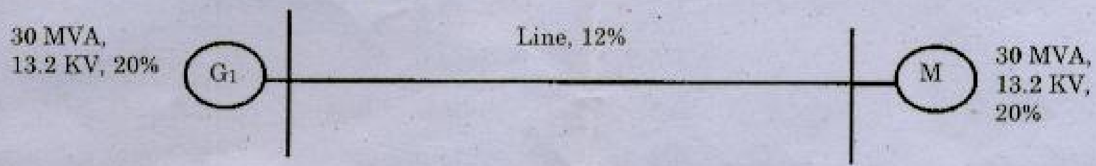

Fig.4

14. (a) Derive the expression for the three phase power in terms of symmetrical components.

Or

(b) A 30 MVA, 11 KV, 3ϕ synchronous generator has a direct subtransient reactance of 0.25 p.u. The negative and zero sequence reactance are 0.35 and 0.1 p.u respectively. The neutral of the generator is solidly grounded. Determine the subtransient current in the generator and the line to line voltages for subtransient conditions when a single line to ground fault occurs at the generator terminals with the generator operating unloaded at rated voltage.

15. (a) (i) Derive the expression for swing equation. (10)

(ii) The moment of inertia of a 4 pole, 100 MVA, 11 kV, $3-\phi$, 0.8 power factor, 50 HZ turbo alternator is 10000 kg-m^2. Calculate H and M. (6)

Or

(b) A synchronous motor is receiving 30% of the power that it is capable of receiving from an infinite bus. If the load on the motor is doubled, calculate the maximum value of δ during the swinging of the motor around its new equilibrium position.

Reg. No. | | | | | | | | | | | | |

Question Paper Code : 57320

B.E./B.Tech. DEGREE EXAMINATION, MAY/JUNE 2016

Fifth Semester

Electrical and Electronics Engineering

EE6501 – POWER SYSTEM ANALYSIS

(Regulations 2013)

Time : Three Hours **Maximum : 100 Marks**

Answer ALL questions.

PART – A (10 × 2 = 20 Marks)

1. Define per unit value of an electrical quantity and write the equation for base impedance for a three phase power system. p.46

2. Write the equation for per unit impedance if change of base occurs. P.49

3. What is the need for load flow analysis ? 220, 262

4. Mention the various types of buses in power system with specified quantities for each bus. 220

5. State and explain symmetrical fault. → 3φ fault, fault involving all 3 phase,

6. What is bolted fault or solid fault ?

7. What are the symmetrical components of a three phase system ?

8. Write down the equation to determine symmetrical currents from unbalanced current.

9. State Equal area criterion.

10. Define transient stability of a power system.

PART – B (5 × 16 = 80 Marks)

11. (a) The data for the system whose single line diagram shown in Fig.11(a) is as follows :

G1 : 30 MVA, 10.5 kV, X" = 1.6 ohms

G2 : 15 MVA, 6.6 kV, X" = 1.2 ohms

G3 : 25 MVA, 6.6 kV, X" = 0.56 ohms

T1 : 15 MVA, 33/11 kV, X = 15.2 ohms/phase on H.T side

T2 : 15 MVA, 33/6.2 kV, X=16.0 ohms/phase on L.T side

Transmission line : X = 20.5 ohms/phase

Loads : A : 40 MW, 11 kV, 0.9 p.f lagging

B : 40 MW, 6.6 kV, 0.85 p.f lagging

Choose the base power as 30 MVA and approximate base voltages for different parts. Draw the reactance diagram. Indicate pu reactance on the diagram. **(16)**

Fig. 11(a)

OR

(b) (i) Determine the Ybus matrix by inspection method for line specification as mentioned below. **(12)**

Line p-q	Impedance in p.u.	Half Line charging admittance in p.u.
1-2	0.04+j0.02	j0.05
1-4	0.05+j0.03	j0.07
1-3	0.025+j0.06	j0.08
2-4	0.08+j0.015	j0.05
3-4	0.035+j0.045	j0.02

(ii) Draw the π-model representation of a transformer with off nominal tap ratio 'α'. P.222 – PRG **(4)**

2. With a neat flow chart, explain the computational procedure for load flow solution using Gauss Seidal load flow solution. **(16)**

OR

(b) Draw the flow chart and explain the algorithm of Newton-Raphson iterative method when the system contains all types of buses. **(16)**

13. (a) A generating station feeding a 132 kV system is shown in fig. 13(a). Determine the total fault current, fault level and fault current supplied by each alternator for a 3 phase fault at the receiving end bus. The line is 200 km long. **(16)**

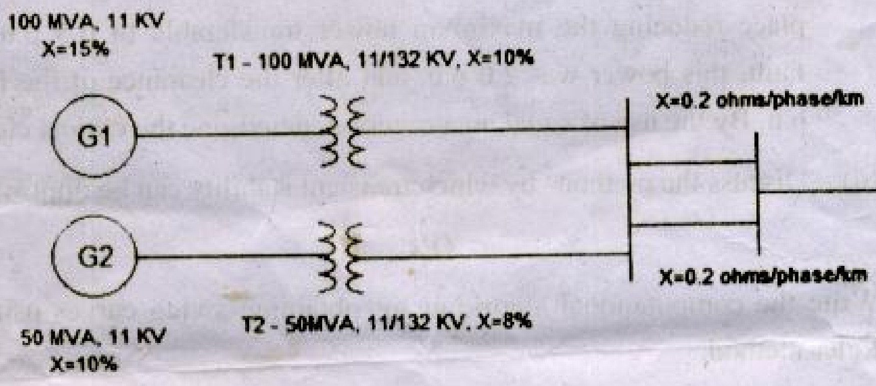

Fig.-13(a)

OR

(b) A Symmetrical fault occurs at bus 4 for the system shown in Fig 13.(b). Determine the fault current using Zbus Building algorithm. **(16)**

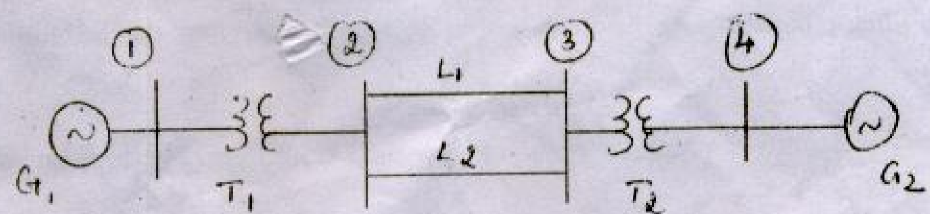

Fig.13(b)

G1, G2 : 100 MVA, 20 kV, $X^{+} = 15\%$

Transformer : $X_{leakage} = 9\%$

L1, L2 : $X^{+} = 10\%$

P.290 BRG Ex: 10.9

P.350 Exc: 11.2

0.15
0.09
0.24

573

14. (a) (i) What are the assumptions to be made in short circuit studies ? **(4)**

(ii) Deduce and draw the sequence network for LLG fault at the terminals of unloaded generator. **(12)**

OR

(b) Derive the expression for fault current in line to line fault on unloaded generator. Draw an equivalent network showing the interconnection of networks to simulate line to ground fault. **(16)**

15. (a) (i) A generator is operating at 50 Hz, delivers 1.0 p.u. power to an infinite bus through a transmission circuit in which resistance is ignored. A fault takes place reducing the maximum power transferable to 0.5 p.u. Before the fault, this power was 2.0 p.u. and after the clearance of the fault it is 1.5 p.u. By the use of equal area criterion, determine the critical clearing angle. **(10)**

(ii) Discuss the methods by which transient stability can be improved. **(6)**

OR

(b) Write the computational algorithm for obtaining swing curves using Modified Euler method. **(16)**

Reg. No. : [ ]

Question Paper Code : 80377

B.E./B.Tech. DEGREE EXAMINATION, NOVEMBER/DECEMBER 2016.

Fifth Semester

Electrical and Electronics Engineering

EE 6501 — POWER SYSTEM ANALYSIS

(Regulations 2013)

Time : Three hours Maximum : 100 marks

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. State the advantage of per unit analysis. [6, 2]

2. How are the loads represented in the reactance and Impedance diagram? [8, 3]

3. What is Jacobian matrix? [9, 3]

4. Write the need for Slack bus in load flow analysis. [1, 2]

5. What is the need for short circuit study? 42, 8

6. How the shunt and series faults are classified? 43, 8

7. Define short circuit capacity. [4, 2]

8. Why the neutral grounding impedance Zn appears as 3Zn in zero sequence equivalent circuit? 37, 8

9. Define Voltage Stability. [9, 3]

10. State few techniques to improve the stability of the power system. [28, 7]

PART B — ($5 \times 16 = 80$ marks)

11. (a) Prepare a per phase schematic of the system shown in Fig. 11(a) and show all the impedance in per unit on a 100 MVA, 132 kV base in the transmission line circuit. The necessary data are given as follows: (16)

G1 : 50MVA, 12.2kV, X = 0.15p.u (14,21)

G2 : 20MVA, 13.8kV, X = 0.15 p.u

T1 : 80MVA, 12.2/161kV, X = 0.1 p.u

T2 : 40MVA, 13.8/161kV, X = 0.1 p.u

Load : 50MVA, 0.8 pf lag operating at 154 kV

Determine the p.u impedance of the load.

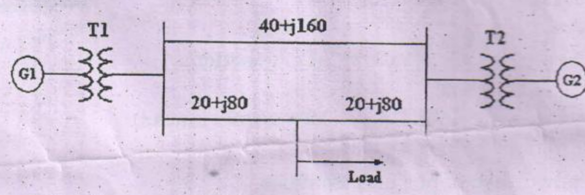

Fig. 11(a)

Or

(b) The parameters of a 4-bus system are as under :

Line starting bus	Line ending bus	Line impedance	Line charging admittance
1	2	0.2+j0.8	j0.02
2	3	0.3+j0.9	j0.03
2	4	0.25+j1.0	j0.04
3	4	0.2+j0.8	j0.02
1	3	0.1+j0.4	j0.01

Draw the network and find bus admittance matrix. [30,43] (16)

12. (a) With a neat flow chart, explain the computational procedure for load flow solution using Newton Raphson iterative method when the system contains all types of buses. [13,28] (16)

Or

(b) The Fig. 12(b) shows the one line diagram of a simple 3 bus power system with generators at buses 1 and 3.Line impedances are marked in p.u on a 100 MVA base. Determine the bus voltages at the end of second iteration using Gauss – Seidel method. (10,22) (16)

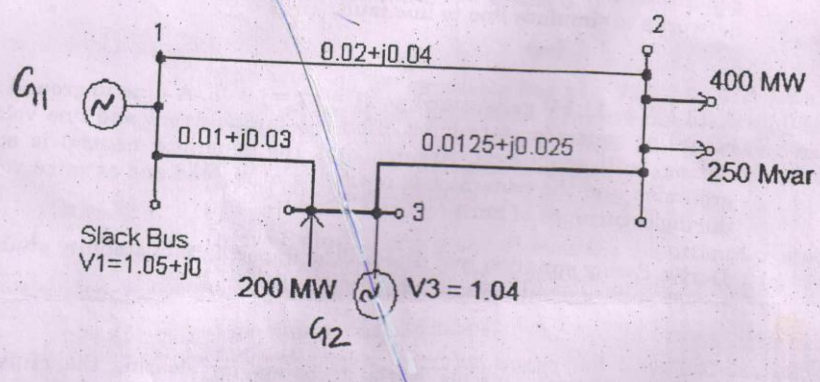

Fig. 12(b)

13. (a) For the radial network shown in Fig. 13(a) 3Φ fault occurs at point F. Determine the fault current and the line voltage at 11.8 kV bus under fault condition. [9,79]

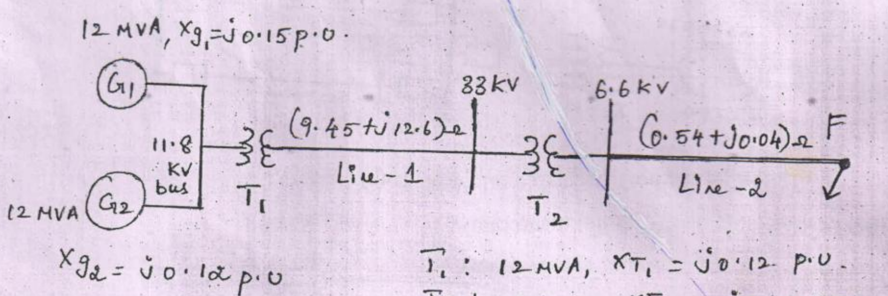

Fig. 13(a)

Or

(b) A 3 phase, 5 MVA, 6.6 kV alternator with a reactance of 8% is connected to a feeder series impedance (0.12 + j0.48) ohm/phase/km through a step up transformer. The transformer is rated at 3 MVA, 6.6 kV/33 kV and has a reactance of 5%. Determine the fault current supplied by the generator operating under no load with a voltage of 6.9 kV, when a 3 phase symmetrical fault occurs at a point 15 km along the feeder. (16)

(3.3)
(184)
type part

(19,43)

14. (a) Derive the expression for fault current in line to line fault on unloaded generator. Draw an equivalent network showing the interconnection of networks to simulate line to line fault. [12, 20] (16)

Or

(b) A 30 MVA, 11 kV generator has z1 = z2 = j 0.05. A Line to ground fault occurs at generator terminals. Find the fault current and line voltages during fault conditions. Assume that the generator neutral is solidly grounded and the generator is operating at no load and at rated voltage during occurrence of fault. [14, 24] (16)

15. (a) Derive Swing equation and discuss the importance of stability studies in power system planning and operation. [2, 13] (16)

Or

(b) Find the critical clearing angle and time for clearing the fault with simultaneous opening of the breakers when a three phase fault occurs at point P close to bus 1 as shown in Fig. 15(b). The generator is delivering 1.0 pu. power at the instant preceding the fault. [16, 29]

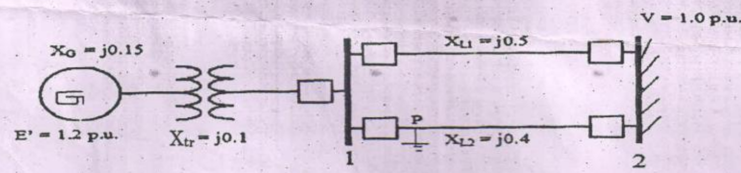

Fig. 15(b)

Reg. No. : | | | | | | | | | | | | |

Question Paper Code : 71776

B.E./B.Tech. DEGREE EXAMINATION, APRIL/MAY 2017.

Fifth Semester

Electrical and Electronics Engineering

EE 6501 — POWER SYSTEM ANALYSIS

(Regulations 2013)

Time : Three hours | Maximum : 100 marks

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. What are the advantages of per unit computation. [6,2]

2. A Y corrected generator rated at 300 MVA, 33kV has a reactance of 1.24 p.u. Find the ohmic value of the reactance. [12,4]

3. Compare Newton Raphson and Gauss Seidal methods of load flow solutions. [7, 3]

4. Write the quantities that are associated with each bus in a system. [24,5]

5. What is the significance of subtransient reactance and transient reactance in short circuit studies? 22.123, 203)

6. For a fault at a given location, rank the various faults in the order of severity. (4,5,8)

7. Express the unbalanced voltages in terms of symmetrical components. 34, 7)

8. Draw the zero-sequence network of Y/Δ transformer with neutral ungrounded. [32, 7]

9. Define swing curve. What is the use of Swing curve? [14,4]

10. State Equal Area Criterion. [17,5]

PART B — (5 × 16 = 80 marks)

11. (a) 300 MVA, 20 kV, 3Φ generator has sub transient reactance of 20%. The generator supplies 2 synchronous motors through a 64 km transmission line having transformers at both ends as shown in Fig.11.a. In this, T1 is a 3Φ transformer 350 MVA, 20/230 kV, 10% reactance & T2 is made of 3 single phase transformer of rating 100 MVA, 127/13.2 kV, 10% reactance.

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Series reactance of the transmission line is $0.5\,\Omega$/km. The ratings of 2 motors are: M1=200 MVA, 13.2 kV, 20% & M2 = 100 MVA, 13.2 kV, 20%. Draw the reactance diagram with all the reactance's marked in p.u. Select the generator rating as base values. [12, 17] (16)

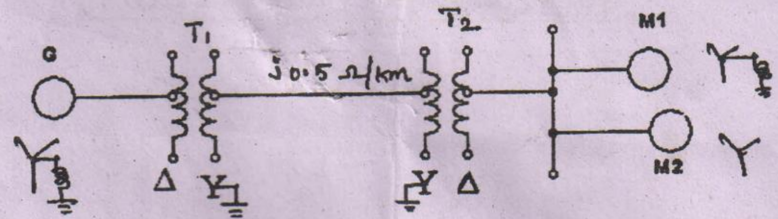


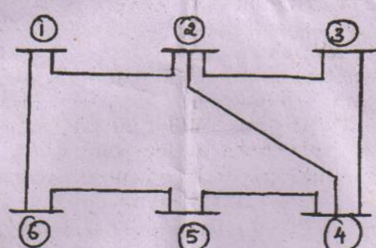
Fig.11.a.

Or

(b) Form bus admittance matrix for the data given below using Singular transformation method. Take node '6' as reference node. (16)

Elements	Bus code	X (p.u.)
1	1-2	0.04
2	1-6	0.06
3	2-4	0.03
4	2-3	0.02
5	3-4	0.08
6	4-5	0.06
7	5-6	0.05

[27, 39]



12. (a) With a neat flow chart, explain the computational procedure for load flow solution using Newton Raphson iterative method when the system contains all types of buses. [13, 28] (16)

Or

(b) Single line diagram of a simple power system, with generators at busses 1 and 3 is shown in Fig. 12.b. The magnitude of voltage at bus 1 is 1.05 p.u. Voltage magnitude at bus 3 is fixed at 1.04 p.u. with active power generation of 200 MW. A load consisting of 400 MW and 250 MVAR is taken from Bus 2. Line impedances are marked in p.u. on a 100 MVA base and the line charging susceptances are neglected.

Determine the voltage at buses 2 and 3 using Gauss-Seidal method at the end of first iteration. Also calculate Slack bus power. (15, 31)

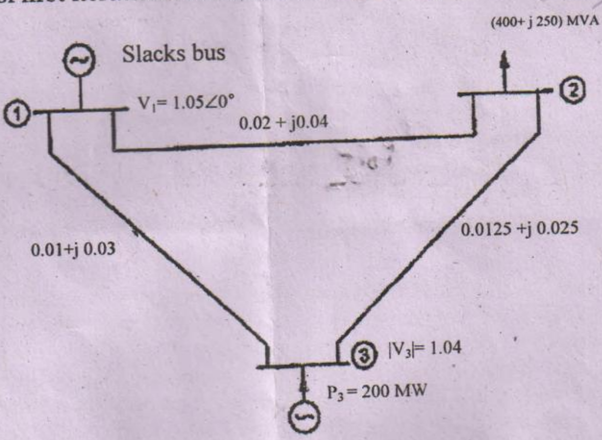


Fig.12.b.

13. (a) (i) A 3 phase. 5 MVA, 6.6 kV alternator with a reactance of 8% is connected to a feeder series impedance (0.12 + j0.48) ohm/phase/km through a step up transformer. The transformer is rated at 3 MVA, 6.6 kV/33 kV and has a reactance of 5%. Determine the fault current supplied by the generator operating under no load with a voltage of 6.9 kV, when a 3phase symmetrical fault occurs at a point 15 km along the feeder. (19, 43) (8)

(3.3) 184

(ii) Draw the detailed flowchart, which explains how a symmetrical fault can be analyzed using Z_{BUS}. [15, 36] (8)

Or

(b) A 100 MVA, 11 kV generator with X" = 0.20 p.u is connected through a transformer and line to a bus bar that supplies three identical motor as shown in Fig and each motor has X"= 0.20 p.u and X'= 0.25 p.u on a base of 20 MVA,33 kV ,the bus voltage at the motors is 33 kV when three phase balanced fault occurs at the point F. Calculate (i) Sub transient current in the fault (ii) Sub transient current in the circuit breaker B (iii) Momentary current in the circuit breaker B (iv) The current to be interrupted by C.B B in 5 cycles. [5, 14] (16)

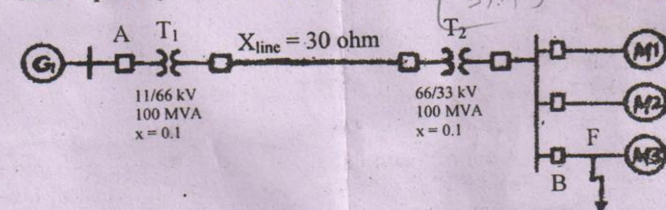


Fig.13.b.

14. (a) (i) Derive the expression for fault current in line to line fault on unloaded generator and draw an equivalent network showing the interconnection of networks. [12, 20] (10)

(ii) A 3 phase salient pole synchronous generator is rated 30 MVA, 11 kV and has a direct axis subtransient reactance of 0.25 p.u. The negative and zero sequence reactances are 0.35 and 0.1 p.u. respectively. The neutral of the generator is solidly grounded. Calculate the subtransient current in the generator when a line to line fault occurs at the generator terminals with generator operating unloaded at rated voltage. [19, 32] (6)

Or

(b) Two 11 kV, 20 MVA, three phase star connected generators operate in parallel as shown in Fig. The positive, negative and zero sequence reactance of each being respectively j 0.18, j 0.15, j 0.10 p.u. The star point of one of the generator is isolated and that of the other is earthed through a 2.0 ohm resistor. A Single line to Ground fault occurs at the terminals of one of the generators. Estimate (i) fault current (ii) current in grounded resistor and (iii) Voltage across grounding resistor. (16)

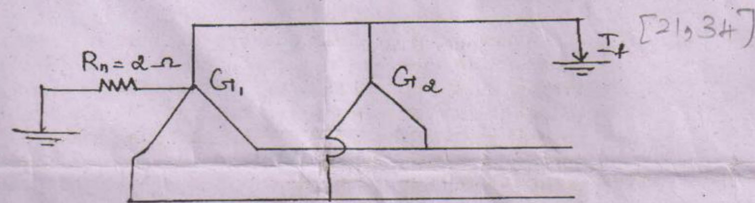


Fig.14.b.

15. (a) (i) Discuss the methods by which transient stability can be improved. [10, 21] (6)

(ii) Find the critical clearing angle of the system shown in Fig. 15.a., for a 3 phase fault at the point 'F'. The generator is delivering 1.0 pu. power under prefault conditions. [17, 30] (10)

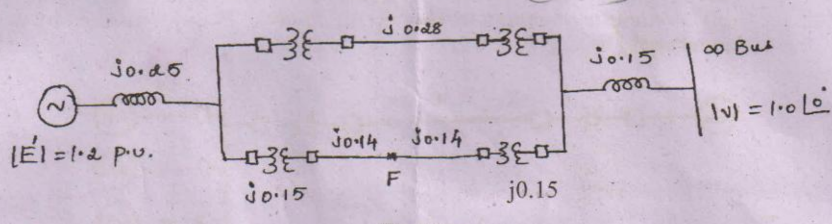


Fig.15.a.

Or

(b) Derive the swing equation of a single machine connected to an infinite bus system and explain the steps of solution by Runge -Kutta method. (16)

[2, 13] [13, 26]

Reg. No. : 4 2 1 6 1 5 1 0 5 3 0 7

Question Paper Code : 50485

B.E./B.Tech. DEGREE EXAMINATION, NOVEMBER/DECEMBER 2017

Fifth Semester

Electrical and Electronics Engineering

EE 6501 – POWER SYSTEM ANALYSIS

(Regulations 2013)

Time : Three Hours Maximum : 100 Marl

Answer ALL questions

PART – A (10×2=20 Mark

1. Define per unit value of an electrical quantity and write the equation for base impedance for a three phase power system.

2. Write the equation for per unit impedance if change of base occurs.

3. What is the need for load flow analysis ?

4. Mention the various types of buses in power system with specified quantities for each bus.

5. State and explain symmetrical fault.

6. What is bolted fault or solid fault ?

7. What are the features of zero sequence current ?

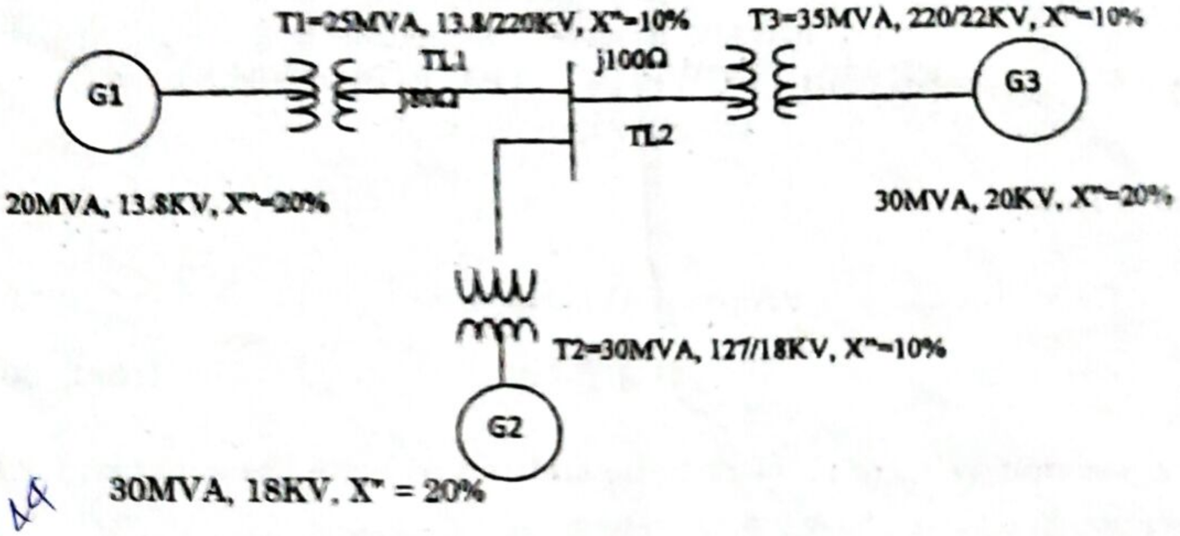
8. Write down the equation to determine symmetrical components currents from unbalanced currents.

9. State equal area criterion.

10. Define transient stability of a power system.

PART – B (5×13=65 Marks)

11. a) The single line diagram of an unloaded power system is shown in figure 11(a) along with components data determine the new per unit values and draw the reactance diagram. Assume 50 MVA and 13.8 KV as new base on generator 1. (13)



B 44

(OR)

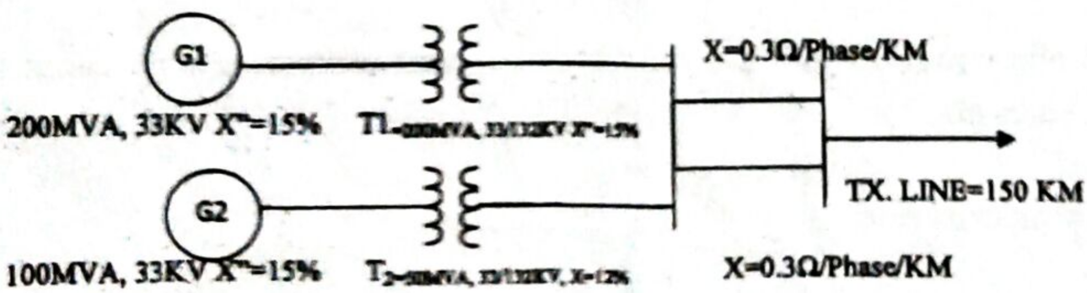
b) Describe the Z_{Bus} building algorithm in details by using a three bus system. (13)

12. a) With a neat flow chart, algorithm and explain the computational procedure for load flow solution using Gauss-Seidal Methods. (13)

(OR)

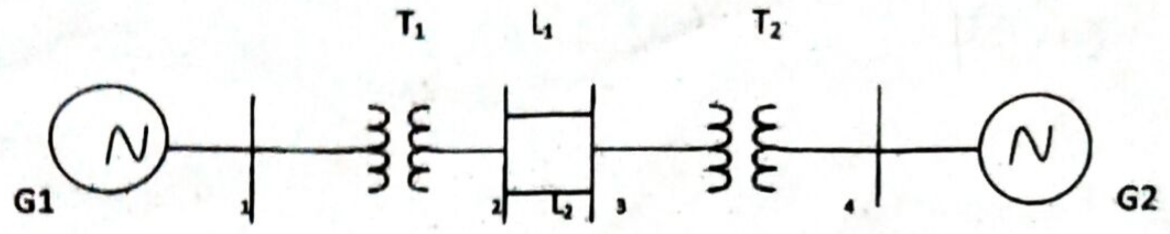
b) Draw the detailed flow chart and explain he algorithm of Newton-Raphson method when the system contains all types of buses. (13)

13. a) A generating stations feeding 132 KV system is shown in Fig. 13(a). Determine the total fault current, fault level and fault current supplied by each alternator for a 3 phase solid fault at the receiving end bus. The length of the transmission line is 150 KM long. (13)



(OR)

b) A symmetrical fault occurs at bus 4 for the system shown in fig. 13(b). Determine the fault current using Z_{bus} building algorithm. **(13)**



G1, G2 : 100 MVA, 20 KV, X" = 15% Transformers T1, T2 : $X_{Leakage}$ = 9%

L1, L2 : X" = 10%

14. a) i) What are the assumption to be made in short circuit studies ? **(4)**

ii) Deduce and draw the sequence network for LLG fault at the terminal of unloaded generator. **(9)**

(OR)

b) Derive the expression for fault current in line fault on unloaded generator. Draw an equivalent network showing the interconnection of networks to simulate line to ground fault. **(13)**

15. a) i) A generator is operating at 50 Hz, delivers 1.0 p.u. power to an infinite bus through a transmission circuit in which resistance is ignored. A fault takes place reducing the maximum power transferred to 0.5 p.u. Before the fault, the power was 2.0 p.u. and after the clearance of the fault it is 1.5 p.u. by the use of equal area criterion, determine the critical clearing angle. **(8)**

ii) Discuss the methods by which transient stability can be improved. **(5)**

(OR)

b) Write the computational algorithm for obtaining swing curves using modified-Euler method. **(13)**

PART – C **(1×15=15 Marks)**

16. a) i) Distinguish between steady state stability and dynamic stability. **(8)**

ii) Explain the importance of stability analysis in power system. **(7)**

(OR)

b) Explain the term critical clearing angle and critical clearing time in connection with the transient stability of a power system. **(13)**

Reg. No. : 4 2 1 6 1 5 1 0 5 3 1 8

Question Paper Code : 41003

B.E./B.Tech. DEGREE EXAMINATION, APRIL/MAY 2018

Fifth Semester

Electrical and Electronics Engineering

EE 6501 – POWER SYSTEM ANALYSIS

(Regulations 2013)

Time : Three Hours   Maximum : 100 Marks

Answer ALL questions

PART – A   (10×2=20 Marks)

1. Mention the requirements of planning the operation of a power system.
2. What is the need for base values ?
3. What is the need for slack bus in power flow analysis ?
4. Discuss the effect of acceleration factor in the load flow solution algorithm.
5. What is meant by fault calculations ?
6. What are all the assumption to be made to simplify the short circuit study ?
7. What is meant by symmetrical fault ?
8. Explain the concept of sequence impedances and sequence networks.
9. Define stability.
10. What is the significance of sub-transient reactance and transient reactance in short circuit studies ?

PART – B   (5×13=65 Marks)

11. a) i) In the single line diagram shown in figure 1, each three phase generator G is rated at 200 MVA, 13.8 kV and has reactances of 0.85 pu and are generating 1.15 pu. Transformer T_1 is rated at 500 MVA, 13.5 kV/220 kV and has a reactance of 8%. The transmission line has a reactance of 7.8 Ω.

Transformer T_2 has a rating of 400 MVA, 220 kV/33 kV and a reactance of 11%. The load is 250 MVA at a power factor of 0.85 lag. Convert all quantities to a common base of 500 MVA and 220 kV on the line and draw the circuit diagram with values expressed in pu. **(10)**

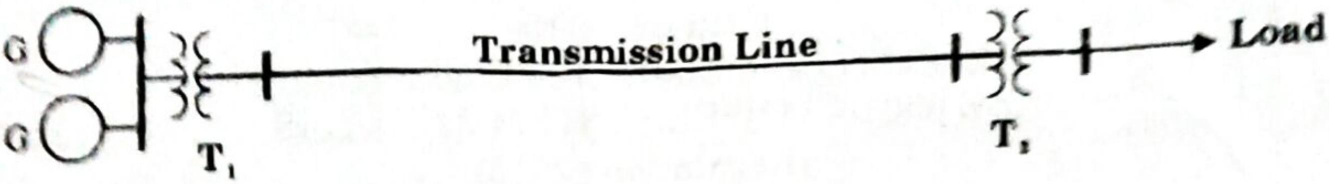


Figure 1

ii) A 200 MVA, 13.8 kV generator has a reactance of 0.85 p.u. and is generating 1.15 pu voltage. Determine the actual values of the line voltage, phase voltage and reactance. **(3)**

(OR)

b) Determine Z-bus for system whose reactance diagram is shown in given figure 2 where the impedance is given in p.u. preserve all the nodes. **(13)**

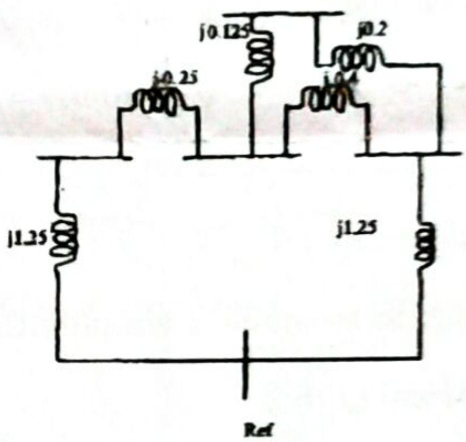


Figure 2

12. a) For the system shown in fig.3, determine the voltages at the end of the first iteration by Gauss-Seidal method. Assume base MVA as 100. **(13)**

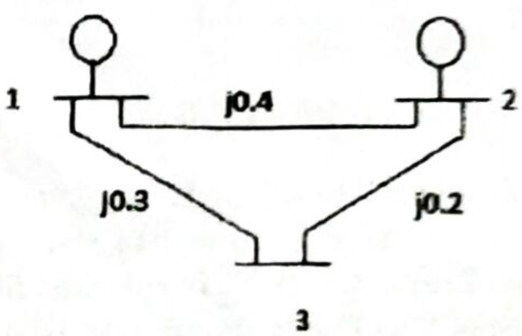


Figure 3

Bus No.	Voltage	Generator		Load		Q_{min}	Q_{max}
		P	Q	P	Q	MVAR	MVAR
1	$1.05 \angle 0°$ p.u.	–	–	–	–	–	–
2	1.02 p.u.	0.3 p.u.	–	–	–	–10	100
3	–	–	–	0.4 p.u.	0.2 p.u.	–	–

(OR)

b) Perform an iteration of Newton-Raphson load flow method and determine the power flow solution for the given system. Take base MVA as 100. **(13)**

Line	Bus From	Bus To	R(p.u.)	X(p.u.)	Half line charging admittance (Yp/2 (p.u.))
1	1	2	0.0839	0.5183	0.0636

Bus	P_L	Q_L
1	90	20
2	30	10

13. a) Figure shows a part of a power system, where the rest of the system at two points of coupling have been represented by their Thevenin's equivalent circuit (or by a voltage source of 1 pu together its fault level which corresponds to the per unit value of the effective Thevenin's impedance). **(13)**

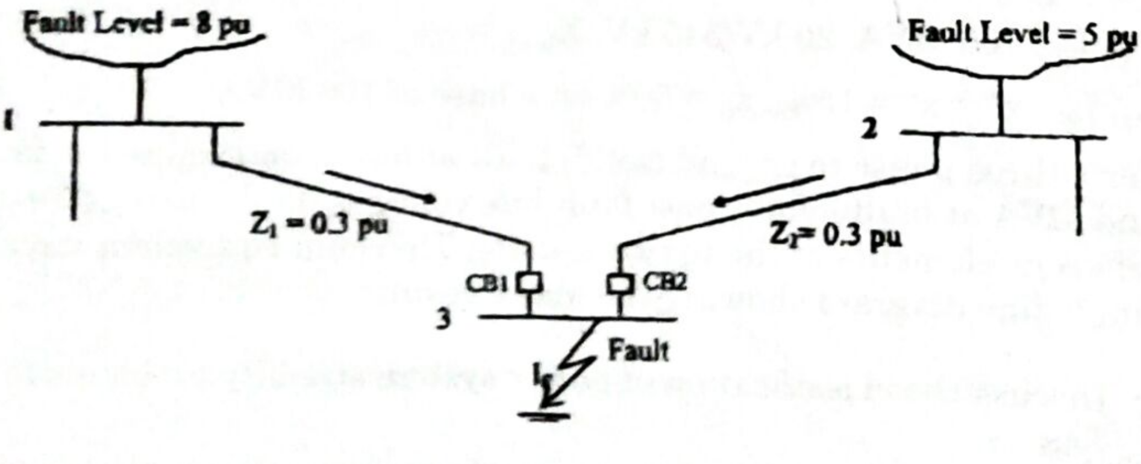


Figure 3

With CB1 and CB2 open, short circuit capacities are

SCC at bus 1 = 8 p.u. gives Zg1 = 1/8 = 0.125 pu

SCC at bus 2 = 5 p.u. gives Zg2 = 1/5 = 0.20 pu

Each of the lines are given to have a per unit impedance of 0.3 pu.

Z1 = Z2 = 0.3 p.u.

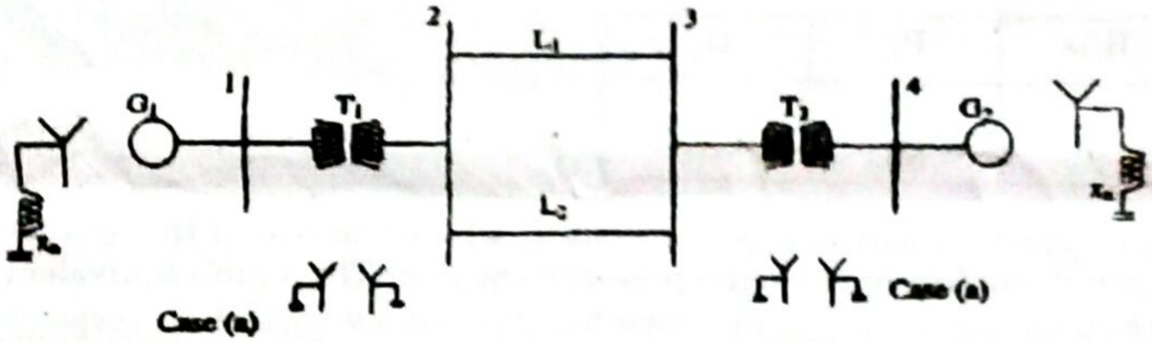
(OR)

b) Explain how the fault current can be determined using Z_{bus} with neat flow chart. (13)

14. a) Brief discuss about the analysis of asymmetrical Faults in the power system with neat circuit diagrams and necessary equations. (13)

(OR)

b) It is proposed to conduct fault analysis on two alternative configurations of the 4-bus system.



G_1, G_2 : 100 MVA, 20 kV, $x^+ = x^- = x_d'' = 20\%$; $x_0 = 4\%$; $x_n = 5\%$.

T_1, T_2 : 100 MVA, 20 kV/345 kV; $X_{leak} = 8\%$

L_1, L_2 : $x^+ = x^- = 15\%$; $x_0 = 50\%$ on a base of 100 MVA

For a three phase to ground (solid) fault at bus 4, determine the fault current and MVA at faulted bus, post fault bus voltages, fault current distribution in different elements of the network using Thevenin equivalent circuit. Draw a single-line diagram showing the above results. (13)

15. a) i) Discuss the classification of power system stability problems in the power system. (6)

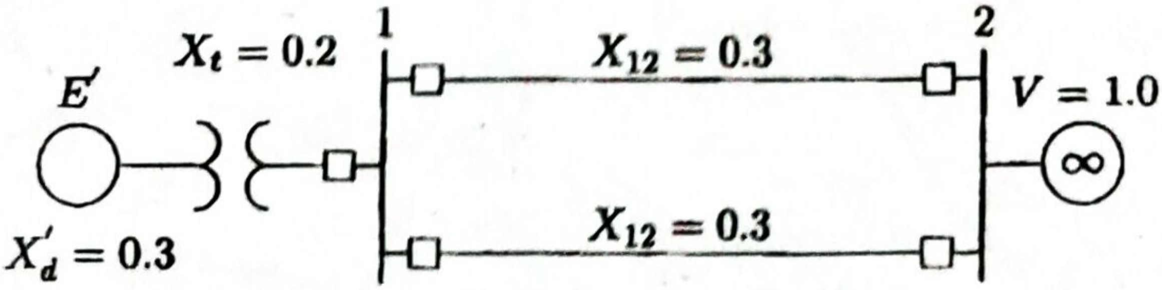
ii) Derive the swing equation of a synchronous machine swinging against an infinite bus. (7)

(OR)

b) A 60 Hz synchronous generator having inertia constant H = 9.94 MJ/MVA and a transient reactance $X_d' = 0.3$ per unit is connected to an infinite bus through a purely reactive circuit as shown in figure. Reactances are marked on the diagram on a common system base. The generator is delivering real power of 0.6 per unit, 0.8 power factor lagging to the infinite bus at a voltage of V = 1 per unit. Assume the per unit damping coefficient is D = 0.138. Consider a small disturbance of $\Delta\delta = 10° = 0.1745$ radian (the breakers open and then quickly close). **(13)**

i) Obtain equations describing the motion of the rotor angle and the generator frequency.

ii) The maximum power input that can be applied without loss of synchronism.



PART – C **(1×15=15 Marks)**

16. Describe the importance of stability analysis of in power system planning and operation. **(15)**
