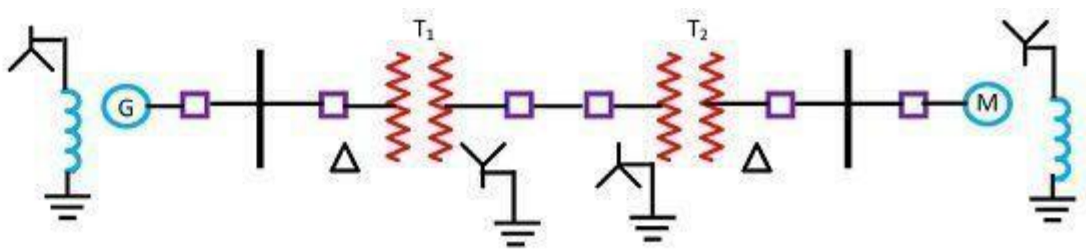
Single Line Diagram of Power System

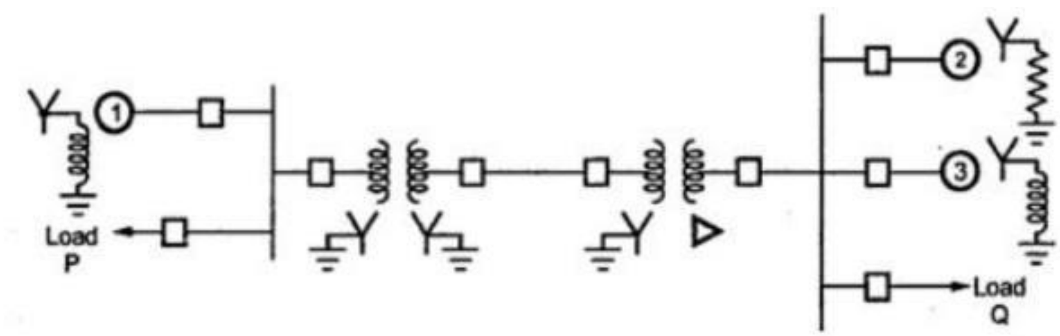
Single line diagram is the representation of a power system using the simple symbol for each component. The single line diagram of a power system is the network which shows the main connections and arrangement of the system components along with their data (such as output rating, voltage, resistance and reactance, etc.).



Single Line Representation of a Typical Power System

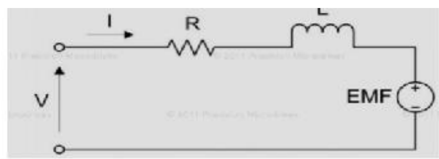
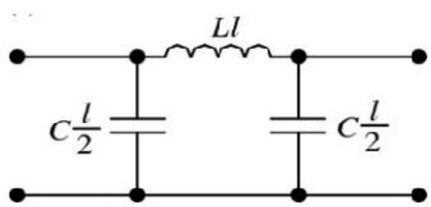
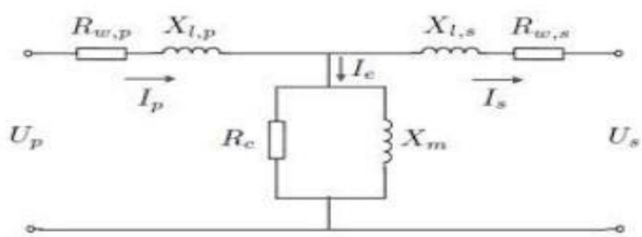
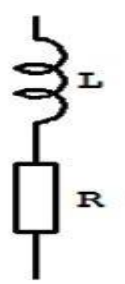
Circuit breakers are represented by rectangular blocks. It is difficult to draw the line diagram of the few components. So for simplification, the impedance diagram is used for representing the power system components.

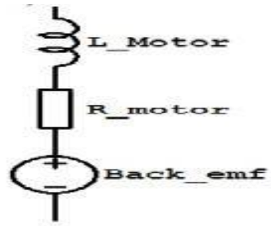
Single Line diagram of an Electrical system



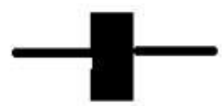
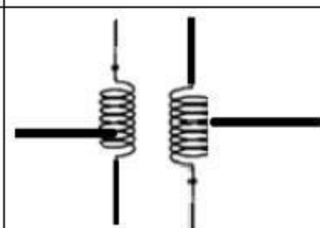
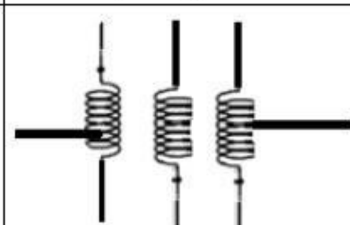
Two generators one grounded through a reactor and one through a resister connected to a bus and through a step up transformer to a transmission lines. Another generator grounded a reactor is connected a bus and through a transformer to the opposite end of the transmission line.A load is connected to each bus. On the diagram information about the loads the ratings of the generators and transformers and reactance of different components of the circuit is often given. It is important to know the location of points where a system is connected to ground to calculate the amount of current flowing when an unsymmetrical fault involving ground occur.

Equivalent circuit for various power system components:

<table>
<tr><th>S.No</th><th>Component</th><th>Equivalent circuit</th></tr>
<tr><td>1</td><td>Generators</td><td>
</td></tr>
<tr><td>2</td><td>Transmission lines</td><td>
</td></tr>
<tr><td>3</td><td>Transformer</td><td>
</td></tr>
<tr><td>4</td><td>Static load</td><td>
</td></tr>
</table>

5	Rotating load (motor)	

REPRESENTATION OF COMPONENTS AND SYMBOL

Sl.no	Components	Symbol
1	Rotating M/c(or) armature	
2	Bus	
3	Two winding power Transfomer	
4	Three winding power Transformer	

FORMATION OF BUS ADMITTANCE MATRIX OF LARGE POWER NETWORK

In a power system, power is injected into a bus from generators, while the loads are tapped from it. There may be some buses with only generators and there may be other only with loads. Some buses have generators and loads while some other may have static capacitors for reactive power compensation. The surplus power at some of the buses is transported through transmission lines to the bus deficient in power.

Single line diagram of a simple 4-bus system with generators and load at an each bus is shown in the figure. Let SGi denote the 3-phase complex generator power flowing into the ith bus and SDi denotes the 3-phase complex power demand at the ith bus. Let SGi and SDi may be represented as

$$S_{Gi} = P_{Gi} + jQ_{Gi}$$

$$S_{Di} = P_{Di} + jQ_{Gi}$$

Net complex power injected into the bus is given as

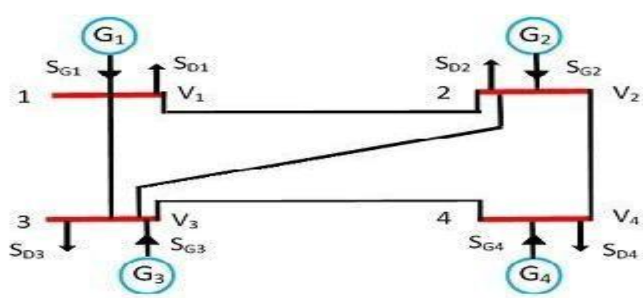
$$S_i = P_i + jQ_i = (P_{Gi} - P_{Di}) + j(Q_{Gi} - Q_{Di})$$

The real and reactive power injected into the ith bus is then.

$$P_i = P_{Gi} - P_{Di}$$

$$Q_i = Q_{Gi} - Q_{Di}$$

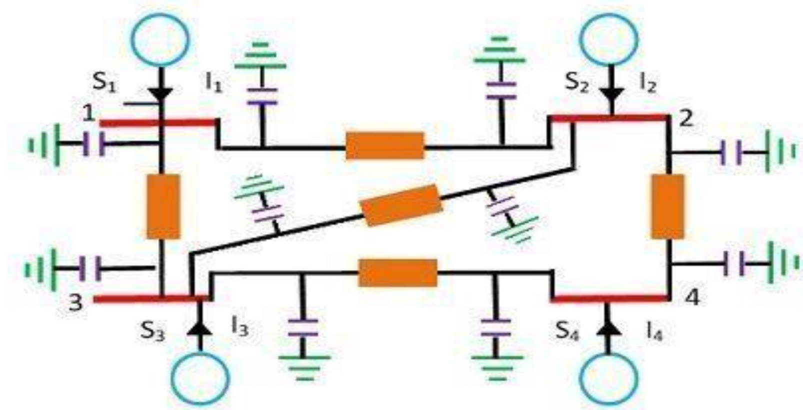
where i = 1, 2, 3, 4,...... n.



One Line Diagram of a 4-Bus System

A network model of the given power system worked out on the above line is shown below in the figure. S1, S2, S3, S4 denote the net 3-phase complex power flowing into the buses and I1, I2, I3, I4 denotes the current flowing into the buses. Each transmission line is represented by a π-circuit.

The equivalent circuit of 4-bus system is shown in the figure below. All the sources of the bus system connected to the common reference at ground potential and the shunt admittance at the busses have been lumped. Besides the ground node, it has four other nodes or buses at which the current from the source is injected into the network. The line admittance between nodes i and k is represented by yik = yki. Further, the mutual admittance between lines is assumed to be zero.



Applications of Kirchhoff's current law to the four nodes give the following equation.

$$I_1 = V_1 y_{10} + (V_1 - V_2) y_{12} + (V_1 - V_2) y_{13}$$

$$I_2 = V_2 y_{20} + (V_2 - V_1) y_{12} + (V_2 - V_3) y_{23} + (V_2 - V_4) y_{24}$$

$$I_2 = V_3 y_{30} + (V_3 - V_1) y_{13} + (V_3 - V_2) y_{23} + (V_3 - V_4) y_{34}$$

$$I_4 = V_4 y_{40} + (V_4 - V_2) y_{24} + (V_4 - V_3) y_{34}$$

The above equation can be rearranged and written in matrix form as below.

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix} = \begin{bmatrix} y_{10}+y_{12}+y_{13} & -y_{12} & -y_{13} & 0 \\ -y_{12} & y_{20}+y_{12}+y_{23}+y_{24} & -y_{23} & -y_{24} \\ -y_{13} & -y_{23} & y_{30}+y_{13}+y_{23}+y_{34} & -y_{34} \\ 0 & -y_{24} & -y_{3} & y_{40}+y_{24}+y_{34} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix}$$

The self-admittance terms of the matrix are given as

$$y_{11} = y_{10} + y_{12} + y_{13}$$

$$y_{22} = y_{20} + y_{12} + y_{23} + y_{24}$$

$$y_{33} = y_{30} + y_{13} + y_{23} + y_{34}$$

$$y_{44} = y_{40} + y_{24} + y_{34}$$

The mutual admittances of the matrix are given as

$$y_{12} = y_{21} = -y_{12} \qquad y_{23} = y_{32} = -y_{23}$$

$$y_{13} = y_{31} = -y_{13} \qquad y_{24} = y_{42} = -y_{24}$$

$$y_{14} = y_{41} = -y_{14} = 0 \qquad y_{34} = y_{43} = -y_{34}$$

Matrix is written in terms of self-bus admittance Yi and mutual bus admittance Yik as follows.

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix} = \begin{bmatrix} y_{11} & y_{12} & y_{13} & y_{44} \\ y_{21} & y_{22} & y_{23} & y_{24} \\ y_{31} & y_{32} & y_{33} & y_{34} \\ y_{41} & y_{42} & -y_{43} & y_{44} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix}$$

Y_{ii} is known as self-admittance (or driving point admittance) of the i_{th} node and is equal to the sum of the admittance connected to the i_{th} node. Each off-diagonal term Y_{ik} is known as mutual admittance (or transfer admittance) between i_{th} and k_{th} node and is equal to the negative of the sum of all the admittances connected directly between i_{th} and k_{th} node

The equation can be written in compact form as

$$[I_{bus}] = [Y_{bus}][V]$$

Where I is the current node matrix, V is the node voltage matrix and [Ybus] is the bus admittance matrix. General equation for n-bus network based on Kirchoff's' current law and admittance form is

$$[I_{bus}] = [Y_{bus}] * [V]$$

Where [I] is the n-bus matrix, [V] is the n-bus voltage matrix and, [Ybus] is called bus admittance matrix and is written as

$$I = Y_{bus}V$$

$$Y_{bus} = \begin{bmatrix} Y_{11} & Y_{12} & - & Y_{1n} \\ Y_{21} & Y_{22} & - & Y_{2n} \\ - & - & - & - \\ Y_{n1} & Y_{n2} & - & y_{nn} \end{bmatrix}$$

it is called the bus admittance matrix and V and I are the n-element node voltage matrix and current node matrix respectively.

NEED FOR SYSTEM PLANNING AND OPERATIONAL STUDIES AND POWER SCENARIO IN INDIA

INTRODUCTION

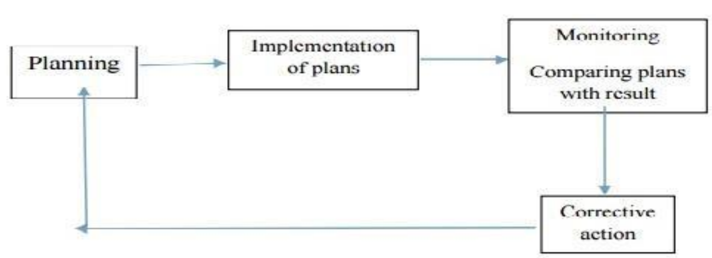
Every power system has three major components

- Generation: source of power, ideally with a specified voltage and frequency
- Load: consumes power; ideally with a constant resistive value
- Transmission System: transmits power; ideally as a perfect conductor

The power system is a network which consists generation, distribution and transmission system. It uses the form of energy (like coal and diesel) and converts it into electrical energy. The power system includes the devices connected to the system like the synchronous generator, motor, transformer, circuit breaker, conductor, etc. The power plant, transformer, transmission line, substations, distribution line, and distribution transformer are the six main components of the power system. The power plant generates the power which is step-up or step-down through the transformer for transmission. The transmission line transfers the power to the various substations. Through substations, the power is transferred to the distribution transformer which step-down the power to the appropriate value which is suitable for the consumers.

Needs for system analysis in planning and operation of power system

- Planning and operation of power system - Operational planning covers the whole period ranging from the incremental stage of system development.
- The system operation engineers at various points like area, space, regional & national load dispatch of power.
- Power system planning and operational analysis covers the maintenance of generation, transmission and distribution facilities.



Steps:

- Planning of power system
- Implementation of the plans
- Monitoring system
- Compare plans with the results
- If no undesirable deviation occurs, then directly go to planning of system
- If undesirable deviation occurs, then take corrective action and then go to planning Of the system

Planning and operation of power system

Planning and operation of power system the following analysis are very important

a) Load flow analysis

b) Short circuit analysis

c) Transient analysis

Load flow analysis

- Electrical power system operate at Steady state mode
- Basic calculation required to determine the characteristics of this state is called as Load flow
- Power flow studies - To determine the voltage current active and reactive power flows in given power system
- A number of operating condition can be analyzed including contingencies.

That operating conditions are

- Loss of generator
- Loss of a transmission line
- Loss of transformer (or) Load
- Equipment over load (or) unacceptable voltage levels

The result of the power flow analysis is starting point for the stability analysis and power factor improvement. Load flow study is done during the planning of a new system or the extension of an existing one.

Short circuit studies

- To determine the magnitude of the current flowing throughout the power system at various time intervals after fault

- The objective of short circuit analysis - To determine the current and voltages at different location of the system corresponding to different types of faults

Transient stability analysis

- The ability of the power system consisting of two (or) more generators to continue to operate after change occurs on the system is a measure of the stability.

- In power system the stability depends on the power flow pattern generator characteristics system loading level and the line parameters

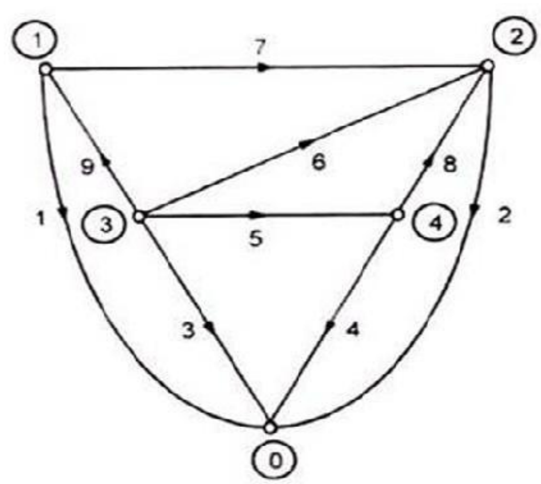
NETWORK GRAPH

In order to describe the geometrical structure of the network, it is sufficient to replace the different power system components (of the corresponding power system network) such as generators, transformers and transmission lines etc. by a single line element irrespective of the characteristics of the power system components.

The geometrical interconnection of these line elements (of the corresponding power system network) is known as a graph (rather linear graph as the graph means always a linear graph). Each source and the shunt admittance across it are taken as a single element. The terminals of the elements are called the nodes.

A graph is connected if, there exists a path between every pair of nodes. A single edge or a single node is a connected graph. If every edge of the graph is assigned a direction, the graph is termed as an oriented graph. The direction is generally, so assigned as to coincide with the assumed positive direction of the current in the element.

Power networks are so structured that out of the m total nodes, one node (normally described by 0) is always at ground potential and the remaining n = (m – 1) nodes are the buses at which the source power is injected. Figure shows the oriented graph of the network given in Fig.



A connected sub-graph containing all the nodes of the original graph but no closed path is called a tree. The tree branches form a sub-set of the elements of the connected graph. The number of branches b required to form a tree is equal to the number of buses in the network (the total number of nodes, including the reference node, is one more than the number of buses), i.e.

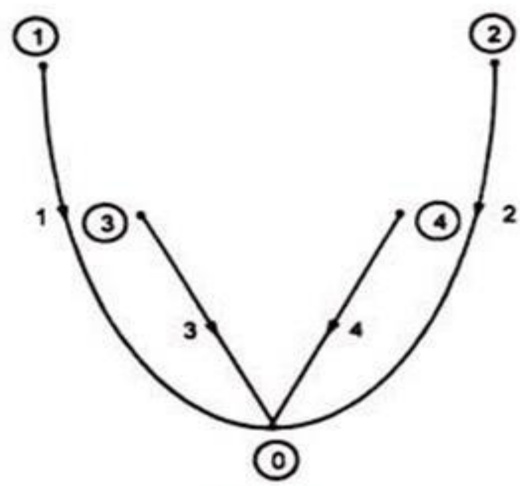
$$b = m - 1 = n \text{ (number of buses)}$$

The elements of the original graph not included in the tree, form a sub-graph which may not necessarily be connected, is known as cotree. The cotree is a complement of a tree. The elements of a cotree are called the links.

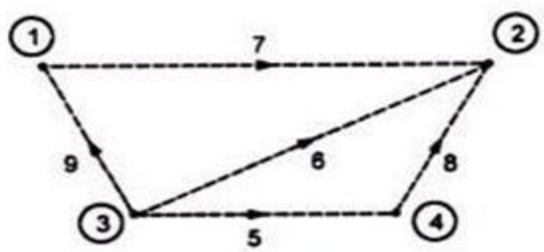
The number of links l of a connected graph with e elements is given as –

$$l = e - b = e - m + 1$$

i.e., number of links equals number of elements less the number of tree branches. A tree and the corresponding cotree of graph shown in Fig. respectively.



(a) Tree



(b) Co-Tree

If a link is added to the tree, the corresponding graph contains one closed path called a loop. Thus a graph has as many loops as the number of links.

The above system has 9 branches. So it has 18 variables (9 branch voltages and 9 branch currents). However, it can be easily seen that all these 18 variables are not independent. The number of independent variables is found from the concept of the tree.

The number of tree branches gives the number of independent voltages. For any system the number of tree branches is equal to the number of buses. The number of links gives the number of independent current variables.

Bus incidence matrix

If "G" is a graph with "n" nodes and "e" elements, then the matrix $\bar{A}$ whose n rows correspond to the "n" nodes (i.e., vertices) and "e" columns correspond to the "e" elements, i.e., edges, is known as an incidence matrix.

The matrix elements are:

aik = 1 if ith element is incident to and directed away from the kth node (bus).

= – 1 if the ith element is incident to but directed towards the kth node

= 0 if the ith element is not incident to the kth node.

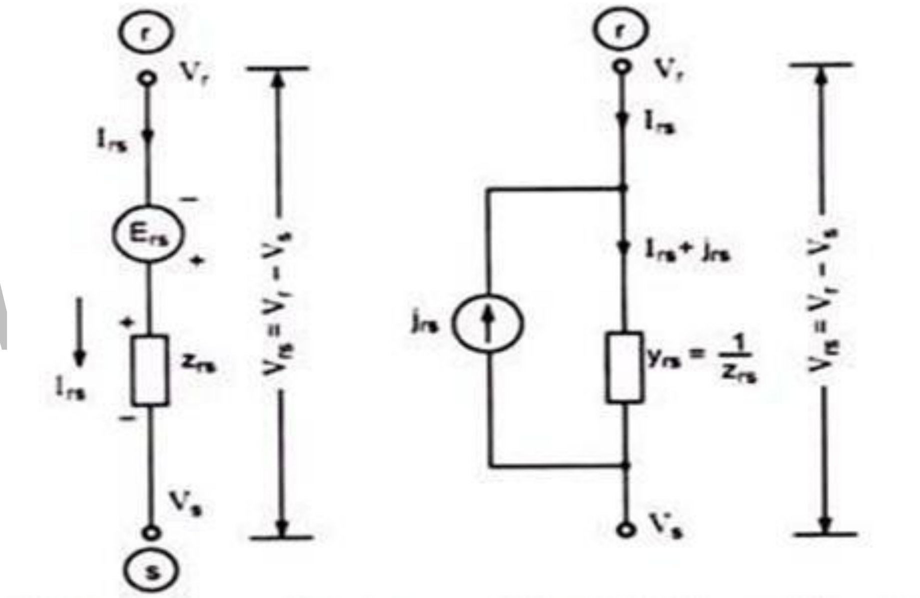
The dimension of this matrix is n x e and its rank is less than n.

Any node of the connected graph can be selected as the reference node and then the variables of the remaining n – 1 nodes which are termed as buses can be measured w.r.t. this assigned reference node.

The matrix "A" obtained from the incidence matrix $\bar{A}$ by deleting the refe row (corresponding to the reference node) is termed as reduced or bus incidence matrix (the number of buses in the connected graph is equal to n – 1 where n is the number of nodes). The order of this matrix is (n – 1) x e and its rows are linearly independent with rank equal to (n – 1).

Primitive Network:

A network is constituted by many branches and each branch consists of active and/or passive elements. Figure show a network branch, containing both active and passive elements in impedance and admittance representation. The impedance is a voltage source Ers in series with and impedance, zrs; while in admittance form there is a current source jrs in parallel with an admittance yrs. The element current is Irs and element voltage, Vrs= Vr – Vs where Vr and Vs are the voltages of the element nodes r and s, respectively.



The noteworthy point is that for steady state ac performance, all element variables (Vrs, Vr, Vs, Irs, Jrs) are phasors and element parameters zrs and yrs are complex numbers.

The performance equation for impedance representation, depicted in Fig. can be written as

$$V_{rs} + E_{rs} = z_{rs} I_{rs}$$

and for admittance representation depicted in Fig

$$I_{rs} + J_{rs} = y_{rs} V_{rs}$$

The two representations shown in Figs. 6.7(a) and 6.7(b) are equivalent wherein the parallel source current in admittance form is related to the series voltage in impedance form by

$$J_{rs} = -y_{rs} E_{rs}$$
$$y_{rs} = 1/Z_{rs}$$

A set of unconnected elements is known as primitive network. The performance equations in admittance (or impedance) form can be written for all branches. The set of these equations in impedance form is

$$V + E = ZI$$

and in admittance form $I + J = YV$

where V and E are branch voltage and source voltage matrices, I and J are branch current and source current matrices, Z is primitive impedance matrix (i.e., a matrix whose elements are branch self-impedances) and Y is primitive admittance matrix (i.e., matrix whose elements are branch self-admittances). These are related as Z = 1/Y. If there is no coupling between elements, Z and Y are diagonal matrices.

Bus admittance matrix from primitive parameters

Formulation of Y_{bus} and Z_{bus}:

Substituting Equation into Equation we have

$$I + J = Y A V_{bus}$$

Pre multiplying Equation A^T (i.e., transpose of the bus incidence matrix) we have

$$A^T I + A^T J = A^T Y A V_{bus}$$

Each component of the n-dimensional vector $A^T I$ is the algebraic sum of the element currents leaving the nodes 1, 2, 3… n.

Therefore, as per Kirchhoff's' current law –

$$A^T I = 0$$

Similarly, each component of vector $A^T J$ can be recognized as the algebraic sum of all source currents injected into nodes 1, 2, … n. These components are therefore the bus currents.

Hence we can write –

$$A^T J = J_{bus}$$

Equation (6.23) is then simplified to

$$J_{bus} = A^T Y A V_{bus}$$

Comparing above Equation we have

$$Y_{bus} = A^T Y A$$

Above Equation suggests the formulation of Y_{bus}. Since matrix A is singular, $A^T YA$ is a singular transformation of Y. The bus incidence matrix can be obtained through a computer programme. Standard matrix multiplication and matrix transpose sub-routines can be employed to compute Y_{bus} using Equation Zbus is the inverse of Y_{bus}.

P.U. IMPEDANCE DIAGRAM FOR THE POWER SYSTEM

Impedance diagram:

The impedance diagram on single-phase basis for use under balanced conditions can be easily drawn from the SLD. The following assumptions are made in obtaining the impedance diagrams.

Assumptions:

1. The single phase transformer equivalents are shown as ideals with impedance on appropriate side (LV/HV),

2. The magnetizing reactance of transformers are negligible,

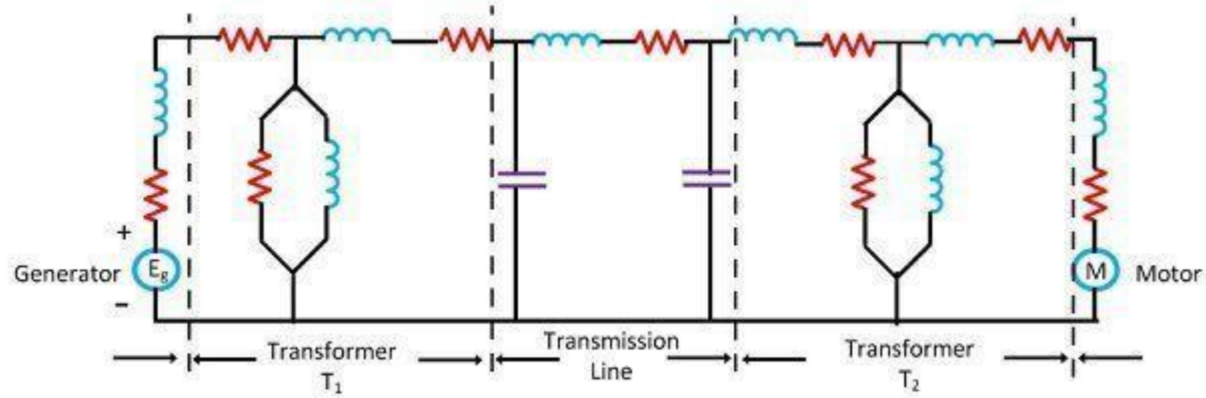
3. The generators are represented as constant voltage sources with series resistance or reactance,

4. The transmission lines are approximated by their equivalent -Models,

5. The loads are assumed to be passive and are represented by a series branch of Resistance or reactance

6. Since the balanced conditions are assumed, the neutral grounding impedance do not appear in the impedance diagram.

In impedance diagram, each component is represented by its equivalent circuit, e.g., the synchronous generator at the generating station by a voltage source in series with the resistance and reactance, the transformer by a nominal ∏-equivalent circuit. The load is assumed to be passive and is represented by a resistive and inductive reactance in the series. Neutral earthing impedance does not appear in the diagram as the balanced condition is assumed.



Impedance Diagram For The Power System

The diagram shown above is the balanced 3-phase diagram. It is also called positive sequence diagram. Three separate diagrams are also used for representing the positive, negative and zero sequence networks. The three separate impedance diagrams are used in the short circuit for the studies of unsymmetrical fault. The impedance diagram can further be simplified by making certain assumptions and reduced to simplified reactance. Reactance diagram is drawn by neglecting the effective resistance of generator armature, transformer winding resistance, transmission line resistance line charging and the magnetizing circuit of transformers.

PU Impedance / Reactance Diagram

For a given power system with all its data with regard to the generators, transformers, transmission lines, loads, etc., it is possible to obtain the corresponding impedance or reactance diagram. If the parametric values are shown in pu on the properly selected base values of the system, then the diagram is referred as the per unit impedance or reactance diagram. In forming a pu diagram, the following are the procedural steps involved:

1. Obtain the one line diagram based on the given data

2. Choose a common base MVA for the system

3. Choose a base KV in any one section (Sections formed by transformers)

4. Find the base KV of all the sections present

5. Find pu values of all the parameters: R,X, Z, E, etc.

6. Draw the pu impedance/ reactance diagram.

REACTANCE DIAGRAM FOR THE POWER SYSTEM

Reactance Diagram

With some more additional and simplifying assumptions, the impedance diagram can be simplified further to obtain the corresponding reactance diagram. The following are the assumptions made.

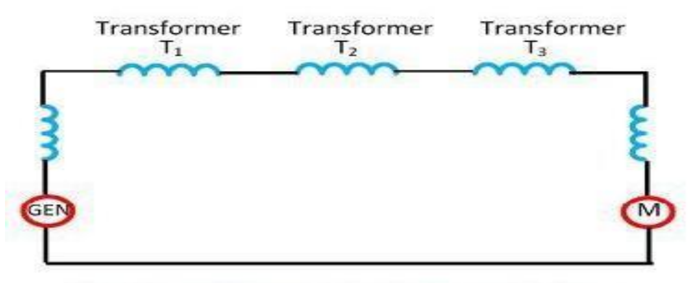
(i). The resistance is often omitted during the fault analysis. This causes a very negligible error since, resistances are negligible

(ii). Loads are Omitted

(iii). Transmission line capacitances are ineffective &

(iv). Magnetizing currents of transformers are neglected.

The reactance diagram gives an accurate result for many power system studies, such as short-circuit studies, etc. The winding resistance, including the line resistance, is quite small in comparison with leakage reactance and shunt path which includes line charging and transformer magnetising circuit provide a very high parallel impedance with fault.



Reactance Diagram For Power System

It is considered that if the resistance is less than one-third of the reactance, and resistance is ignored, then the error introduced will be not more than 5%. If the resistance and reactance ignored errors up to 12% may be introduced. The errors mean their calculation gives a higher value than the actual value.

PER UNIT QUANTITIES

Definition: The per-unit value of any quantity is defined as the ratio of actual value in any unit to the base or reference value in the same unit. Any quantity is converted into per unit quantity by dividing the numeral value by the chosen base value of the same dimension. The per-unit value is dimensionless.

$$\text{Per Unit Value} = \frac{Actual\ value\ in\ nay\ unit}{BAse\ or\ Reference\ value\ in\ the\ same\ unit}$$

The base values can be selected arbitrarily. It is usual to assume the base values as given below

- Base voltage = rated voltage of the machine
- Base current = rated current of the machine
- Base impedance = base voltage /base current
- Base power = base voltage x base current

Firstly, the value of base power and the base voltage are selected, and their choice automatically fixes the other base values. As

Per Unit KV = Actual value/Base value

$$= \frac{KV_{actual}}{KV_B}$$

Base Current I_B = Base KVA/Base KV

$$= \frac{KVA_B}{KV_B}$$

Per unit current Ipu = Actual value of current /Base current

Putting the value of base current from the equation IB in equation Ipu we get

$$\text{Per unit current } I_{pu} = \frac{Actual\ value\ of\ current}{KVA_B/KV_B}$$

$$\text{Per unit current } I_{pu} = \frac{Actual\ value\ of\ current\ X\ KV_B}{KVA_B}$$

Base Impedance $Z_B = \frac{Base\ KV X1000}{Base\ Current}$

Putting the value of base **current equa**tion in the equation Z_B we get

Base Impedance $Z_B = \frac{KV_B\ X1000}{KVA_B/KV_B}$

Base Impedance $Z_B = \frac{(KV_B)^2\ X1000}{KVA_B}$

Base Power = KVA_B

Now,

$$Z_{pu} = \frac{Actual\ Impedance}{Base\ Impedance}$$

Putting the value of base impedance from the equation in the above equation we will get the value of impedance per unit

$$Z_{pu} = \frac{Actual\ Impedance\ XKVA_B}{(KV_B)^2\ X1000}$$

Advantages of Per Unit System

There are mainly two advantages of using the Per Unit System.

- The parameters of the rotating electrical machines and the transformer lie roughly in the same range of numerical values, irrespective of their ratings if expressed in a per-unit system of ratings.
- It relieves the analyst of the need to refer circuit quantities to one or the other side of the transformer, making the calculations easy.

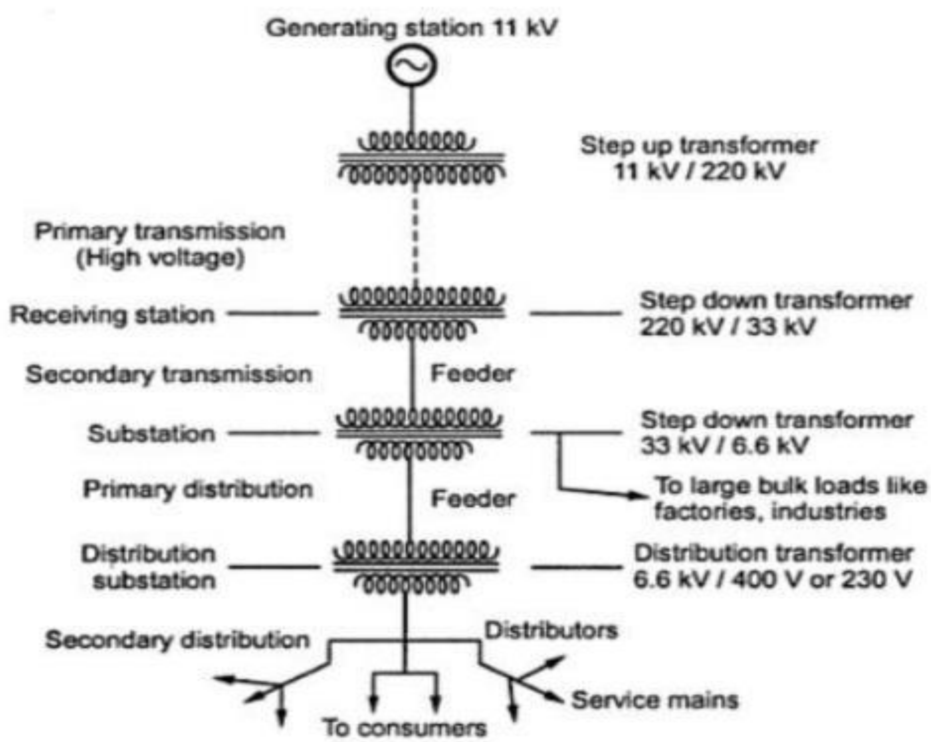
POWER SYSTEM COMPONENTS

BASIC COMPONENTS OF A POWER SYSTEM

Components of power system

- Generators - Convert mechanical energy in to electrical energy
- Transformers - Transfer Power or energy from one circuit to another circuit without change in frequency
- Transmission Lines - Transfer power from one place another place
- Control Equipment: Used for protection purpose

Structure of Power system



The power system is the complex enterprise that may be subdivided into the following sub-systems. The subsystems of the power system are explained below in details

Generating Substation

In generating station the fuel (coal, water, nuclear energy, etc.) is converted into electrical energy. The electrical power is generated in the range of 11kV to 25kV, which is step-up for long distance transmission. The power plant of the generating substation is mainly classified into three types, i.e., thermal power plant, hydropower plant and nuclear power plant. The generator and the transformer are the main components of the generating station. The generator converts the mechanical energy into electrical energy. The mechanical energy comes from the burning of coal, gas and nuclear fuel, gas turbines, or occasionally the internal combustion engine. The transformer transfers the power with very high efficiency from one level to another. The power transfer from the secondary is approximately equal to the primary except for losses in the transformer. The step-up transformer will reduce losses in the line which makes the transmission of power over long distances.

Transmission Substation

The transmission substation carries the overhead lines which transfer the generated electrical energy from generation to the distribution substations. It only supplies the large bulk of power to bulk power substations or very big consumers. The transmission lines mainly perform the two functions

1. It transports the energy from generating stations to bulk receiving stations.
2. It interconnects the two or more generating stations. The neighboring substations are also interconnected through the transmission lines.

The transmission voltage is operating at more than 66kv and is standardized at 69kv, 115KV, 138KV, 161KV, 230KV, 345KV, 500KV, and 765KV, line-to-line. The transmission line above 230KV is usually referred to as extra high voltage (EHV). The high voltage line is terminated in substations which are called high voltage substations, receiving substations or primary substations. In high voltage substation, the voltage is step-down to a suitable value for the next part of flow toward the load. The very large industrial consumers may be served directly to the transmission system.

Sub-transmission Substation

The portion of the transmission system that connects the high voltage substations through the step-down transformer to the distribution substations is called the sub-transmission system. The sub-transmission voltage level ranges from 90 to 138KV. The sub-transmission system directly serves some large industries. The capacitor and reactor are located in the substations for maintaining the transmission line voltage. The operation of the sub-transmission system is similar to that of a distribution system. Its differ from a distribution system in the following manner.

1. A sub-transmission system has a higher voltage level than a distribution system.
2. It supplies only bigger loads.
3. It supplies only a few substations as compared to a distribution system which supplies some loads.

Distribution Substation

The component of an electrical power system connecting all the consumers in an area to the bulk power sources is called a distribution system. The bulk power stations are connected to the generating substations by transmission lines. They feed some substations which are usually situated at convenient points near the load centres. The substations distribute the power to the domestic, commercial and relatively small consumers. The consumers require large blocks of power which are usually supplied at sub-transmission or even transmission system.

Problem:1

1. The single line diagram of an unloaded power system is shown in Fig 1. The generator transformer ratings are as follows.

G1=20 MVA, 11 kV, X''=25%

G2=30 MVA, 18 kV, X''=25%

G3=30 MVA, 20 kV, X''=21%

T1=25 MVA, 220/13.8 kV (Δ/Y), X=15%

T2=3 single phase units each rated 10 MVA, 127/18 kV(Y/Δ), X=15%

T3=15 MVA, 220/20 kV(Y/Δ), X=15%

Draw the reactance diagram using a base of 50 MVA and 11 kV on the generator1.

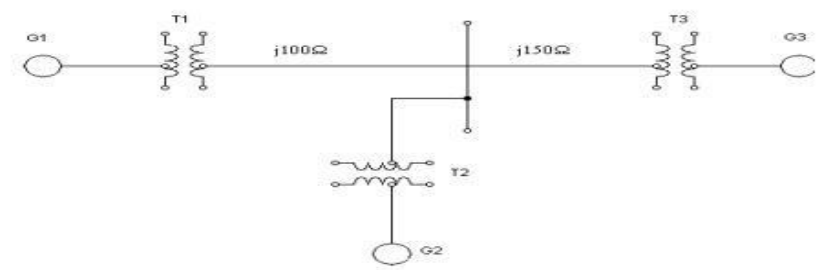


Fig 1

SOLUTION:

Base megavoltampere,MVAb,new=50 MVA

Base kilovolt kVb,new=11 kV (generator side)

FORMULA

Reactance of Generator G

kVb,old=11 kV kVb,new=11 kV

MVAb,old=20 MVA MVAb,new=50 MVA

Xp.u,old=0.25p.u

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

$$= 0.25 \times \left(\frac{11}{11}\right)^2 \times \left(\frac{50}{20}\right) = j0.625 p.u$$

Reactance of Transformer T1

kVb,old=11 kV kVb,new=11 kV

MVAb,old=25 MVA MVAb,new=50 MVA

Xp.u,old=0.15p.u

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

$$= 0.15 \times \left(\frac{11}{11}\right)^2 \times \left(\frac{50}{25}\right) = j0.3 \ p.u$$

Reactance of Transmission Line

It is connected to the HT side of the Transformer T1

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

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

$$\text{Actual Impedance } X_{actual} = 100 ohm$$

$$\text{Base impedance } X_{base} = \frac{(kV_{b,new})^2}{MVA_{b,new}} = \frac{220^2}{50} = 968 \ ohm$$

$$\text{p.u reactance of } 100\ \Omega \text{ transmission line} = \frac{\text{Actual Reactance ,ohm}}{\text{Base Reactance ,ohm}} = \frac{100}{968} = j0.103 \ p.u$$

$$\text{p.u reactance of } 150\ \Omega \text{ transmission line} = \frac{\text{Actual Reactance ,ohm}}{\text{Base Reactance ,ohm}} = \frac{150}{968} = j0.154 \ p.u$$

Reactance of Transformer T2

kVb,old=127*√3 kV=220 kV   kVb,new=220 kV

MVAb,old=10*3=30 MVA   MVAb,new=50 MVA

Xp.u,old=0.15p.u

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

$$= 0.15 \times \left(\frac{220}{220}\right)^2 \times \left(\frac{50}{30}\right) = j0.25\ p.u$$

Reactance of Generator G2

It is connected to the LT side of the Transformer T2

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

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

kVb,old=18 kV   kVb,new=18 kV

MVAb,old=30 MVA   MVAb,new=50 MVA

Xp.u,old=0.25 p.u

$$The\ new\ p.u.\ reactance\ of\ Generator\ G2 = X_{pu,old} \times \left(\frac{kV_{b,old}}{kV_{b,new}}\right)^2 \times \left(\frac{MVA_{b,new}}{MVA_{b,old}}\right)$$

$$= 0.25 \times \left(\frac{18}{18}\right)^2 \times \left(\frac{50}{30}\right) = j0.4167\ p.u$$

Reactance of Transformer T3

kVb,old=20 kV   kVb,new=20 kV

MVAb,old=20 MVA   MVAb,new=50 MVA

Xp.u,old=0.15p.u

$$The\ new\ p.u.\ reactance\ of\ Transformer\ T3 = X_{pu,old} \times \left(\frac{kV_{b,old}}{kV_{b,new}}\right)^2 \times \left(\frac{MVA_{b,new}}{MVA_{b,old}}\right)$$

$$= 0.15 \times \left(\frac{20}{20}\right)^2 \times \left(\frac{50}{30}\right) = j0.25\ p.u$$

Reactance of Generator G3

It is connected to the LT side of the Transformer T3

$$Base\ kV\ on\ LT\ side\ of\ transformer\ T\ 3 = Base\ kV\ on\ HT\ side \times \frac{LT\ voltage\ rating}{HT\ voltage\ rating}$$

$$= 220 \times \frac{20}{220} = 20\ kV$$

kVb,old=20 kV kVb,new=20 kV

MVAb,old=30 MVA MVAb,new=50 MVA

Xp.u,old=0.21 p.u

$$The\ new\ p.u.\ reactance\ of\ Generator\ G\ 3 = X_{pu,old} \times \left(\frac{kV_{b,old}}{kV_{b,new}}\right)^2 \times \left(\frac{MVA_{b,new}}{MVA_{b,old}}\right)$$

$$= 0.21 \times \left(\frac{20}{20}\right)^2 \times \left(\frac{50}{30}\right) = j0.35\ p.u$$

Problem: 2

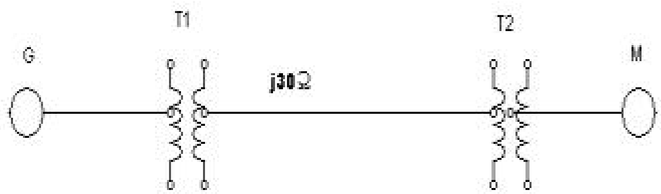
Draw the reactance diagram for the power system shown in fig. Use a base of 50MVA 230 kV in 30 Ω line. The ratings of the generator, motor and transformers are

Generator = 20 MVA, 20 kV, X=20%

Motor = 35 MVA, 13.2 kV, X=25%

T1 = 25 MVA, 18/230 kV (Y/Y), X=10%

T2 = 45 MVA, 230/13.8 kV (Y/Δ), X=15%



Solution

Base megavoltampere,MVAb,new=50 MVA

Base kilovolt kVb,new=230 kV (Transmission line side)

FORMULA

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

Reactance of Generator G

It is connected to the LT side of the T1 transformer

$$\text{Base kV on LT side of transformer T 1} = \text{Base kV on HT side} \times \frac{\text{LT voltage rating}}{\text{HT voltage rating}}$$

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

kVb,old=20 kV kVb,new=18 kV

MVAb,old=20 MVA MVAb,new=50 MVA

Xp.u,old=0.2p.u

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

$$= 0.2 \times \left(\frac{20}{18}\right)^2 \times \left(\frac{50}{20}\right) = j0.617\ p.u$$

Reactance of Transformer T1

kVb,old=18 kV kVb,new=18 kV

MVAb,old=25 MVA MVAb,new=50 MVA

Xp.u,old=0.1p.u

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

$$= 0.1 \times \left(\frac{18}{18}\right)^2 \times \left(\frac{50}{25}\right) = j0.2\ p.u$$

Reactance of Transmission Line

It is connected to the HT side of the Transformer T1

Actual Impedance X actual= j30 ohm

$$\text{Base impedance } X_{base} = \frac{(kV_{b,new})^2}{MVA_{b,new}} = \frac{230^2}{50} = 1058\ ohm$$

$$\text{p.u reactance of } j30\ \Omega \text{ transmission line} = \frac{\text{Actual Reactance ,ohm}}{\text{Base Reactance ,ohm}} = \frac{j30}{1058} = j0.028\ p.u$$

Reactance of Transformer T2

kVb,old=230 kV kVb,new=230 kV

MVAb,old=45 MVA MVAb,new=50 MVA

Xp.u,old=0.15p.u

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

$$= 0.15 \times \left(\frac{230}{230}\right)^2 \times \left(\frac{50}{45}\right) = j0.166\ p.u$$

Reactance of Motor M2

It is connected to the LT side of the Transformer T2

$$\text{Base kV on LT side of transformer } T\,2 = \text{Base kV on HT side} \times \frac{\text{LT voltage rating}}{\text{HT voltage rating}}$$

$$= 230 \times \frac{13.8}{230} = 13.8\ kV$$

kVb,old=13.2 kV   kVb,new=13.8 kV

MVAb,old=35 MVA   MVAb,new=50 MVA

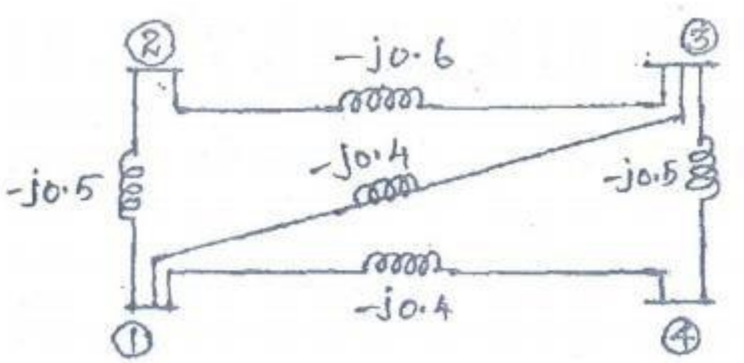
Xp.u,old=0.25 p.u

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

$$= 0.25 \times \left(\frac{13.2}{13.8}\right)^2 \times \left(\frac{50}{35}\right) = j0.326 \ p.u$$

Bus admittance matrix

Problem:1



Solution:

$$Y_{BUS} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} & Y_{14} \\ Y_{21} & Y_{22} & Y_{23} & Y_{24} \\ Y_{31} & Y_{32} & Y_{33} & Y_{34} \\ Y_{41} & Y_{42} & Y_{43} & Y_{44} \end{bmatrix}$$

$Y11 = y12 + y13 + y14 = -j0.5 - j0.4 - j0.4 = -j1.3$

$Y22 = y12 + y23 = -j0.5 - j0.6 = -j1.1$

$Y33 = y32 + y31 + y34 = -j0.6 - j0.4 - j0.5 = -j1.5$

$Y44 = y41 + y43 = -j0.4 - j0.5 = -j0.9$

$Y12 = \ y12 = j0.5 \ Y13 = -y13 = j0.4$

$Y14 = \ y14 = j0.4 \ Y21 = Y12 = j0.5$

$Y23 = \ y23 = j0.6$

$Y24 = -y24 = 0$

$Y31 = Y13 = j0.4$

$Y32 = Y23 = j0.6$

$Y34 = -y34 = j0.5$

$Y41 = Y14 = j0.4$

$Y42 = Y24 = 0$

$Y43 = Y34 = j0.5$

$$Y_{BUS} = \begin{bmatrix} -j1.3 & j0.5 & j0.4 & j0.4 \\ j0.5 & -j1.1 & j0.6 & 0 \\ j0.4 & j0.6 & -j1.5 & j0.5 \\ j0.4 & 0 & j0.5 & -j0.9 \end{bmatrix}$$

Elements of new bus admittance matrix after eliminating 4th row and 4th column

N=4, j=1,2,3 k=1,2,3

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

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

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

$$Y_{21,new} = Y_{12,new} = j0.5$$

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

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

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

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

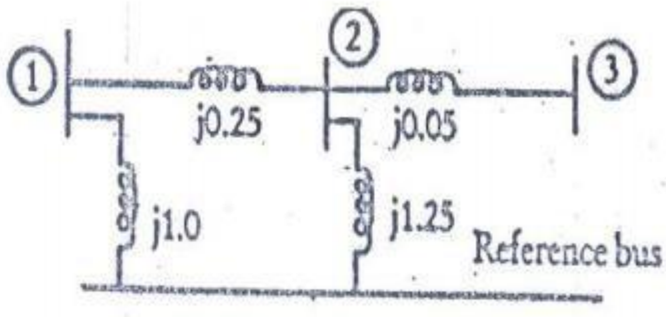
$$Y_{33,new} = Y_{33} - \frac{Y_{34}Y_{43}}{Y_{44}} = -j1.5 - \frac{(j0.5)(j0.5)}{-j0.9} = -j1.22$$

Reduced admittance matrix after eliminating 4 th row and 4th column

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

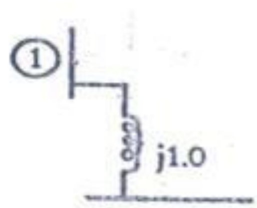
Problem:2

Find the bus impedance matrix for the system whose reactance diagram is shown in fig 3. All the impedances are in p,u.

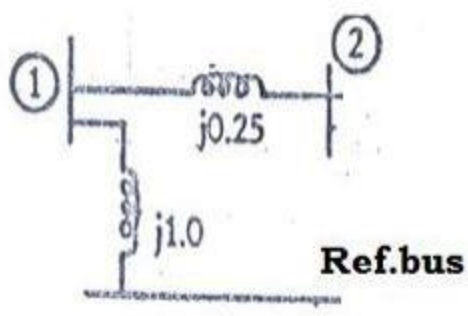


Solution:

Step 1: connect bus 1 to ref bus through impedance j1.0



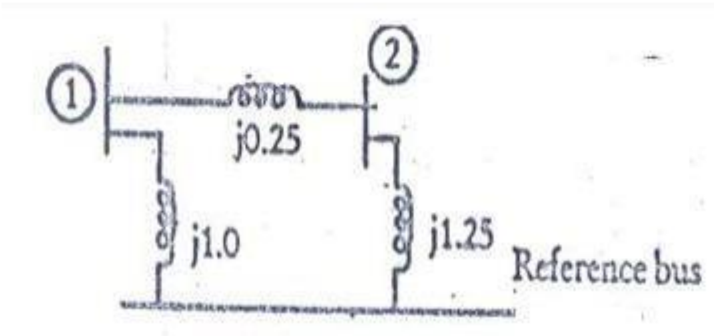
Step 2: connect bus 2 to the bus 1 through impedance j0.25



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

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

Step 3: connect bus 2 to ref bus through impedance j1.25



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

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

Number of buses is only 2. But matrix size is 3*3. The matrix size is reduced by eliminating 3rd row and 3rd column

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

Where n=2 j=1,2 k=1,2

n=2 j=1 k=1

$$Z_{11,ack} = Z_{11} - \frac{Z_{13}Z_{31}}{Z_{33}}$$

$$Z_{11,ack} = j1.0 - \frac{j1.0 * j1.0}{j2.5} = j0.6$$

n=2 j=1 k=2

$$Z_{12,ack} = Z_{12} - \frac{Z_{13}Z_{32}}{Z_{33}}$$

$$Z_{12,ack} = j1.0 - \frac{j1.0 * j1.25}{j2.5} = j0.5$$

n=2 j=2 k=1

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

n=2 j=2 k=2

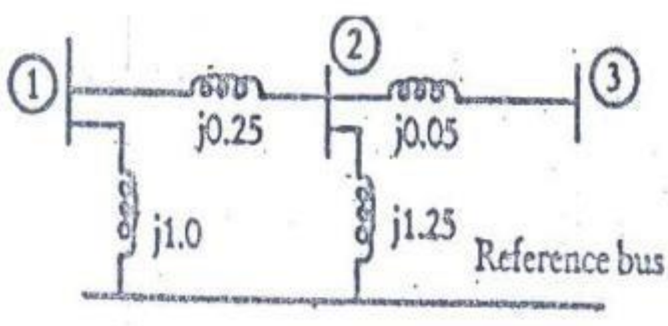
$$Z_{22,ack} = Z_{22} - \frac{Z_{23}Z_{32}}{Z_{33}}$$

$$Z_{22,ack} = j1.25 - \frac{j1.25 * j1.25}{j2.5} = j0.625$$

The reduced matrix

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

Step 4: connect bus 3 to bus 2 through impedance j0.05



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