Power System Analysis1_BEE601

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MODULE - 1

REPRESENTATION OF POWER SYSTEM COMPONENTS

Contents

Introduction

A typical power system consists of a 3-phase grid to which all generating stations feeds energy and from which all substations taps energy

A grid is either a 3-phase single circuit or 3-phase two circuit transmission line

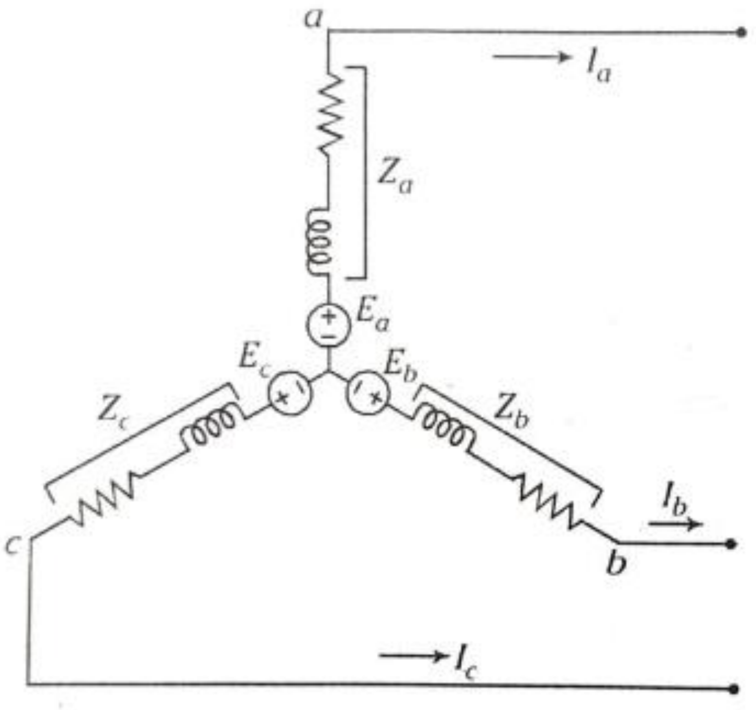
From the substations electrical energy is transmitted to distribution transformers and from the distribution transformer, the energy is fed to various loads.

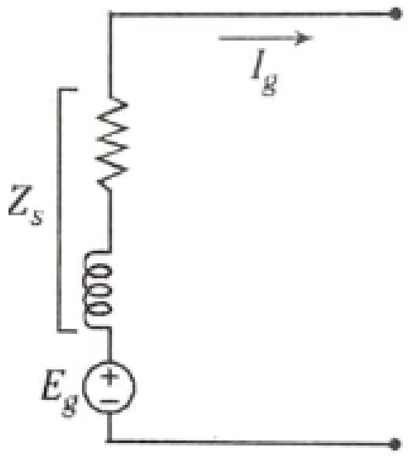
The components of power system are Generating stations (Alternators), Power transformers, Transmission lines, Substations (Substation transformers), Distribution transformers and Loads

The various types of loads are Synchronous motors, Induction motors, Heating coils, Lights, etc.

Single-phase Representation of Balanced Three Phase Networks

Equivalent Circuit of a Synchronous Machine(Non-Salient Type)

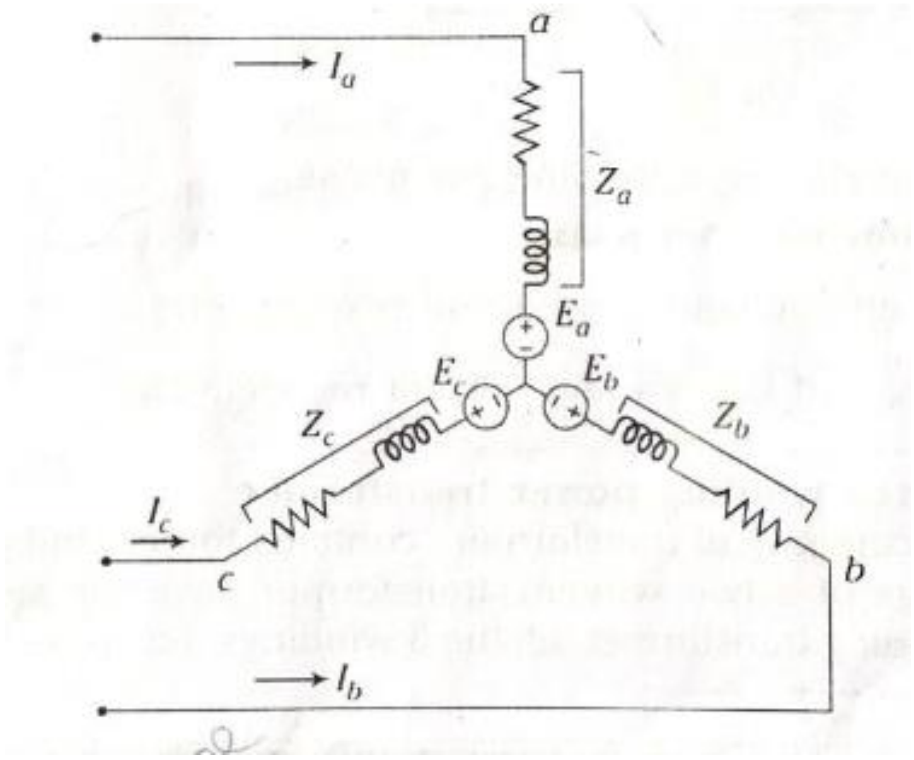


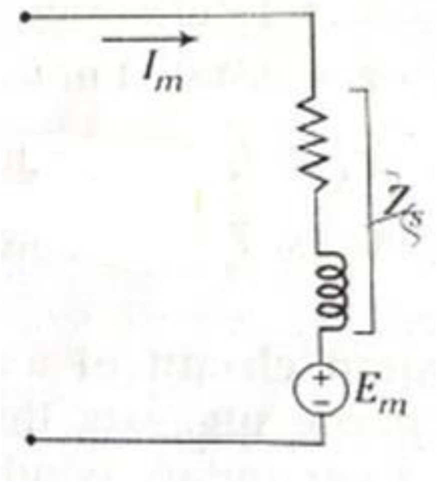


$E_a=E_b=E_c=E_g$

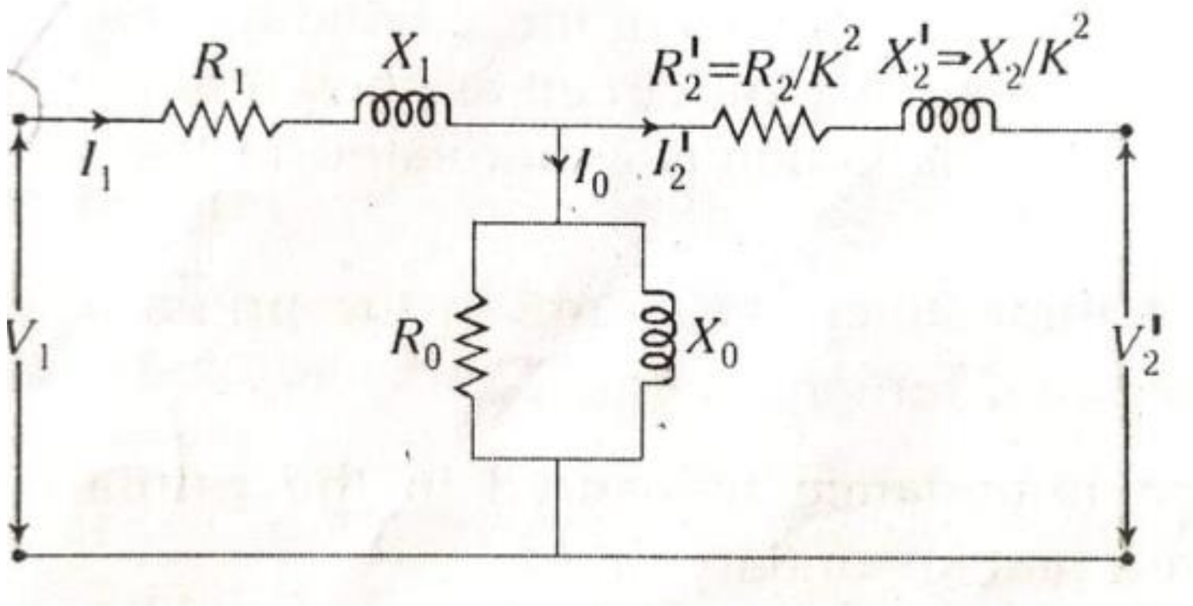
$Z_a=Z_b=Z_c=Z_s$

Equivalent Circuit of a Synchronous Machine(Non-Salient Type)

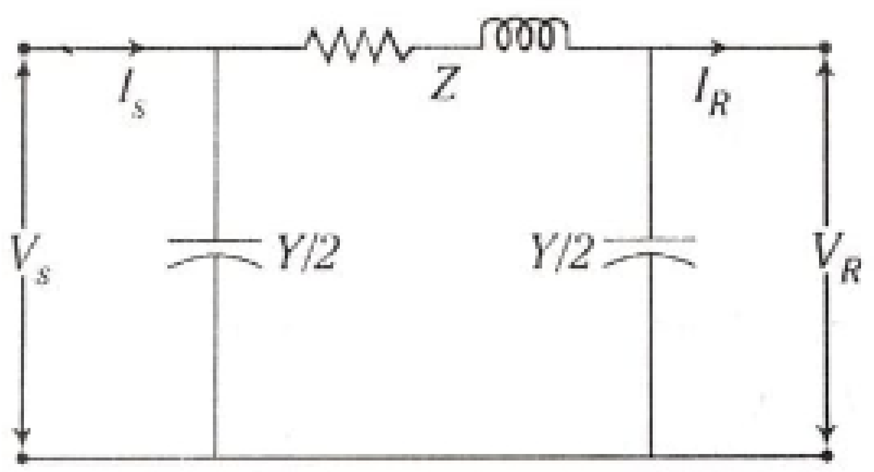




Equivalent Circuit of a two winding power transformer



Equivalent Circuit of Transmission Line



Nominal Pai Circuit with 160KM above

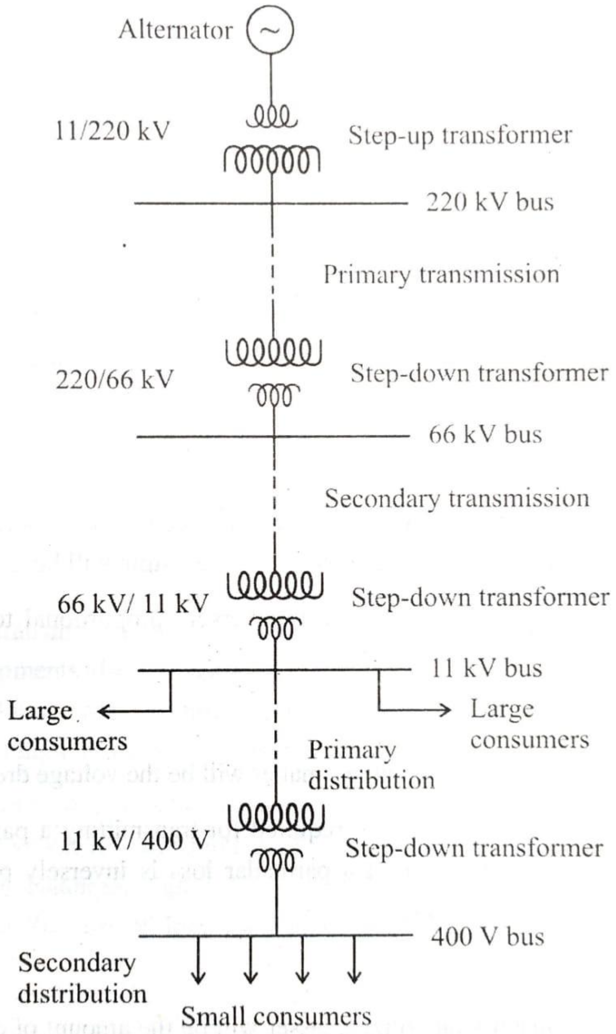
Z= Total Series Impedance of the line per phase

Y= Total Shunt Admittance per phase

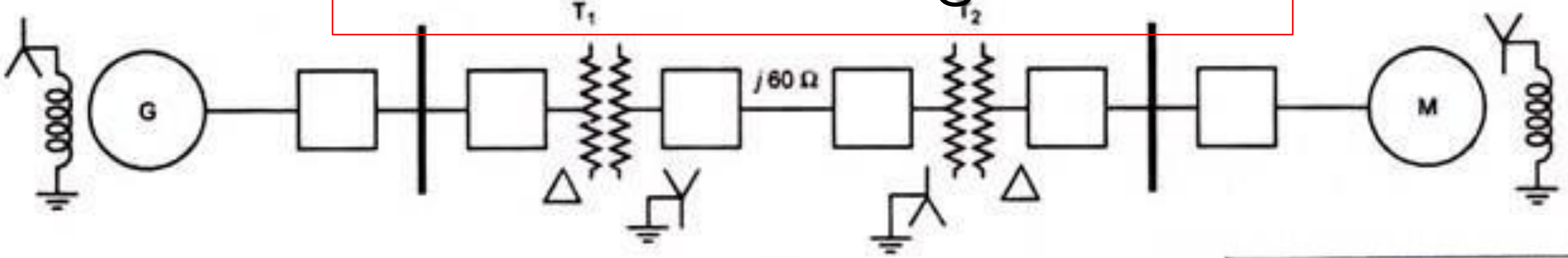
Vs and Is =Sending End Voltage and Current

VR and IR = Receiving End Voltage and Current

One Line Diagram



One Line Diagram



Generator	:	40 MVA, 11 kV, X" = 20 %
Motor	:	30 MVA, 11 kV, X" = 30 %
Transformer T_1	:	40 MVA, 11/220 kV, X = 15 %
Transformer T_2	:	40 MVA, 220/11 kV, X = 15 %

Fig. 2.7. ***Single Line Representation of a Typical Power Sys***

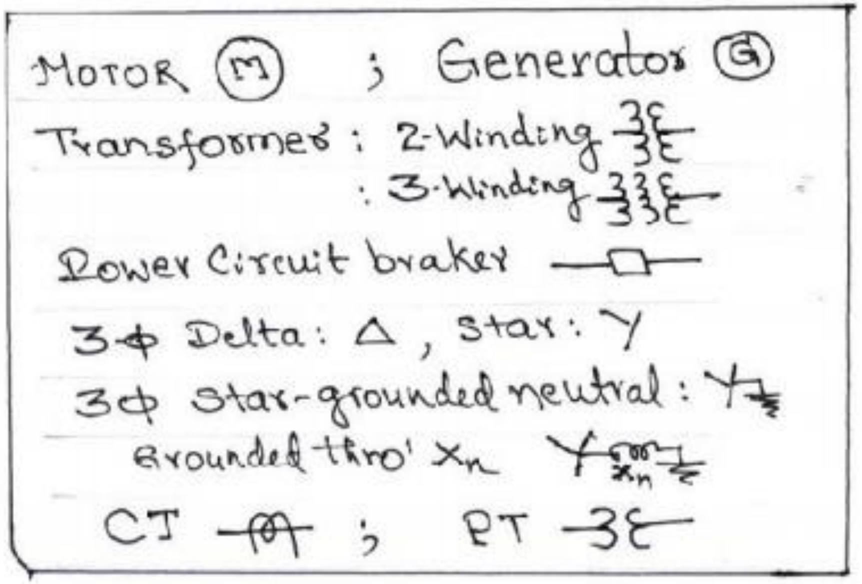
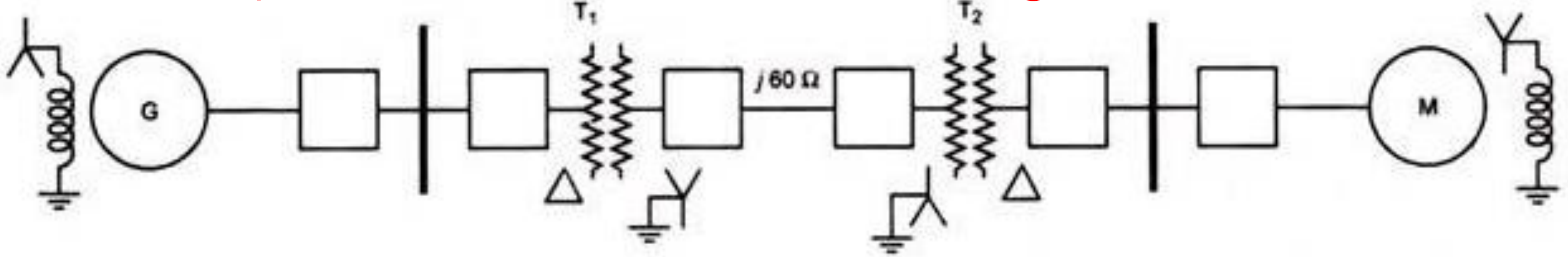
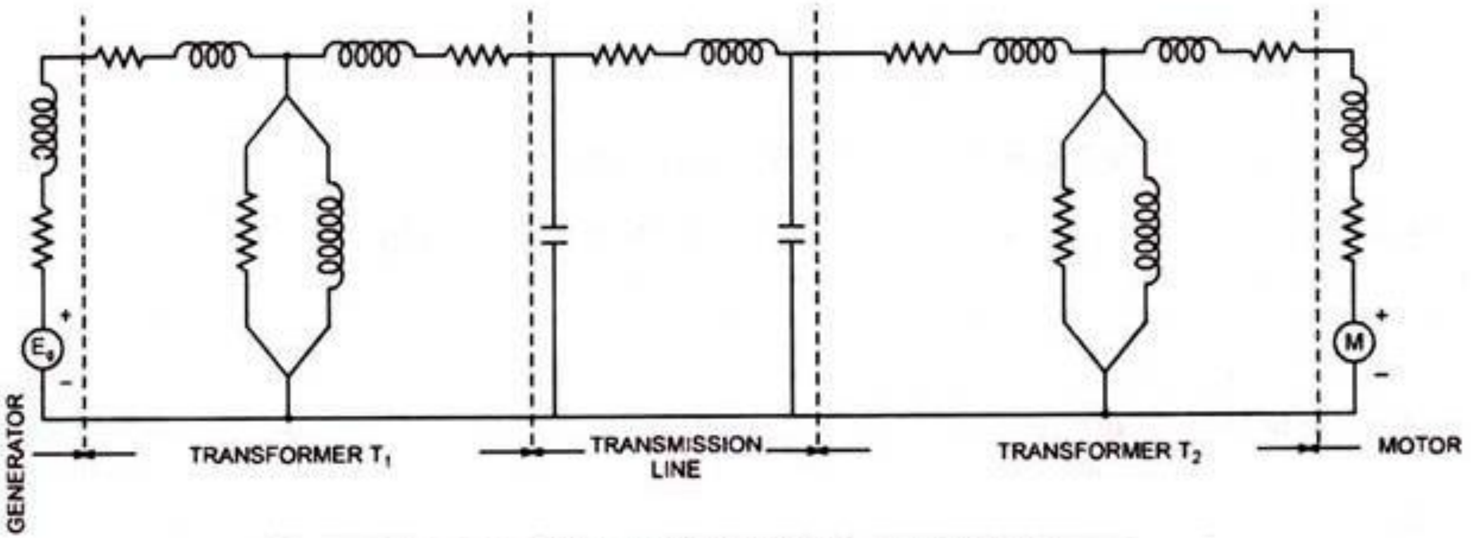


Figure 1. TABLE OF SYMBOLS FOR USE ON SLDS

Impedance or Reactance Diagram

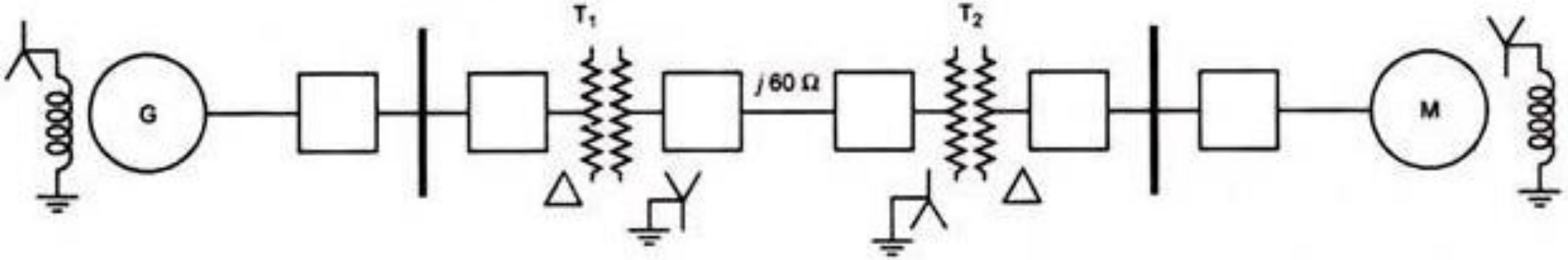


Impedance Diagram

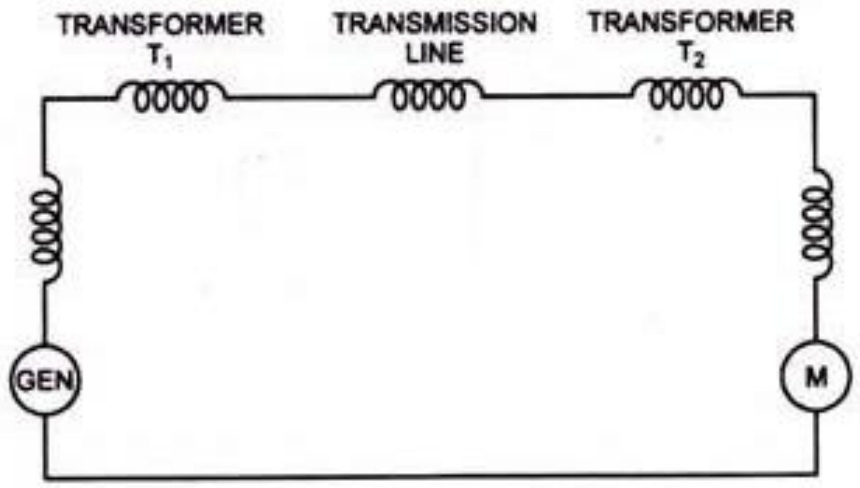


Impedance Diagram For The Power System Shown

1.The generators are represented as constant voltage sources with series resistance or reactance
2.The single phase transformer equivalents are shown as ideals with impedances on appropriate side (LV/HV)
3.The transmission lines are approximated by their equivalent π-Models
4.The loads are assumed to be passive and are represented by a series branch of resistance or reactance
5.Since the balanced conditions are assumed, the neutral grounding impedances do not appear in the impedance diagram



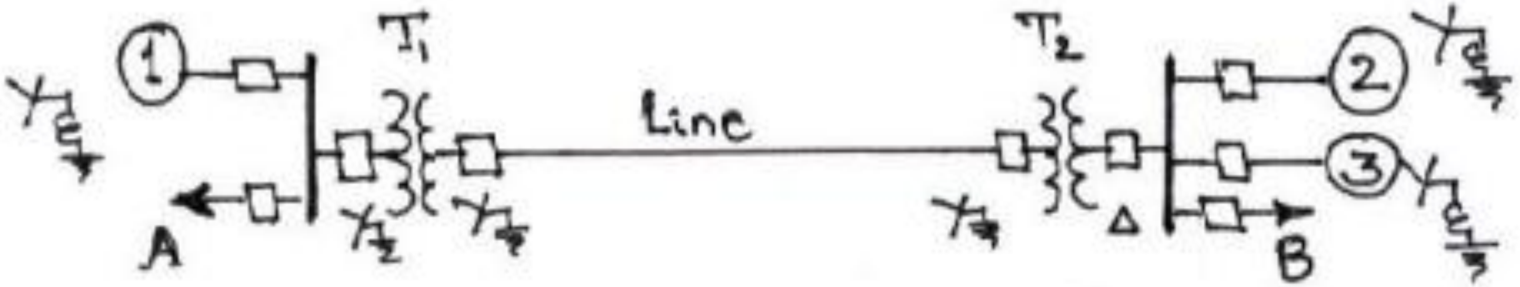
Reactance Diagram

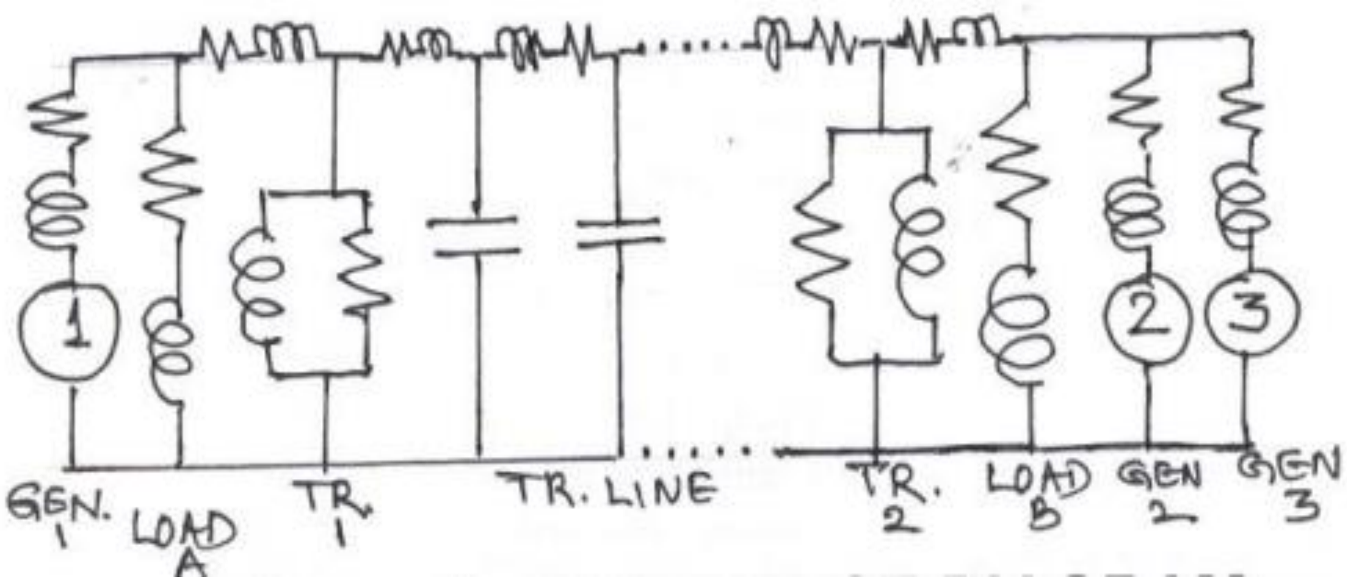


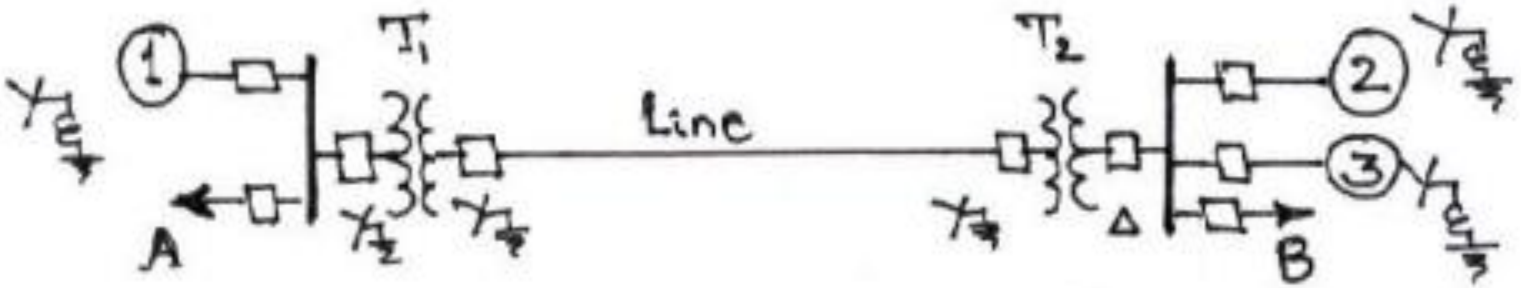
Reactance Diagram For Power System Shown in Fig

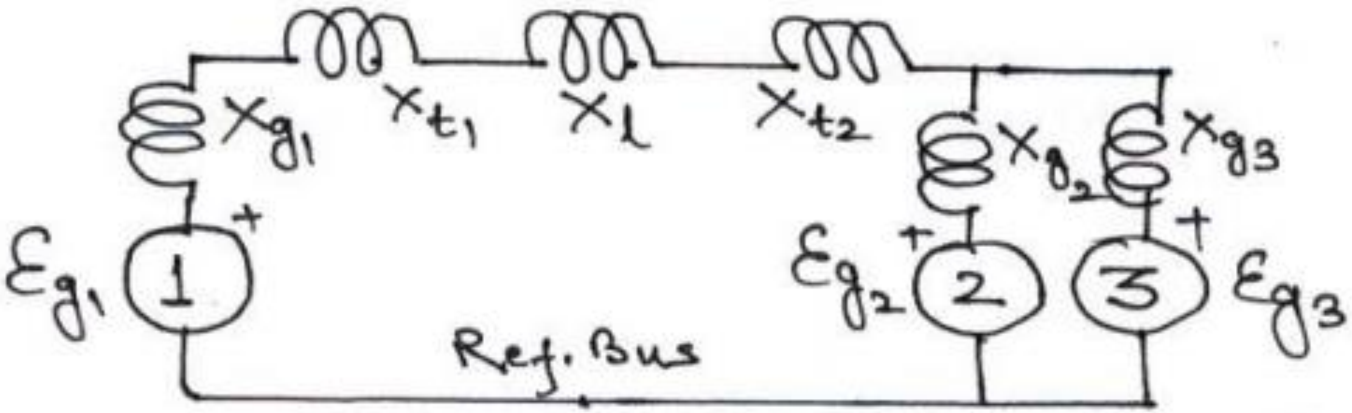
1. The resistance is often omitted during the fault analysis. This causes a very negligible error since, resistances are negligible
2. Loads are Omitted
3. Transmission line capacitances are ineffective & Magnetizing currents of transformers are neglected

Example-1






T_1
T_2
Line
A
B
1
2
3


X_{g_1}
X_{t_1}
X_l
X_{t_2}
X_{g_2}
X_{g_3}
E_{g_1}
E_{g_2}
E_{g_3}
Ref. Bus

Per Unit System

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.

$$\text{Per Unit Value} = \frac{\text{Actual value in any unit}}{\text{Base or reference value in the same unit}}$$

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

As

$$\text{Per Unit KV} = \frac{\text{Actual KV}}{\text{Base KV}} = \frac{KV_{actual}}{KV_B}$$

$$\text{Base current } I_B = \frac{\text{Base KVA}}{\text{Base KV}} = \frac{KVA_B}{KV_B} \ldots\ldots\ldots\ldots (1)$$

$$\text{Per unit current } I_{pu} = \frac{\text{Actual value of current}}{\text{Base current}} \ldots\ldots\ldots (2)$$

Putting the value of base current from the equation (1) in equation (2) we get

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

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

$$\text{Base impedance } Z_B = \frac{\text{Base KV x 1000}}{\text{Base current}} \ldots\ldots\ldots (3)$$

Putting the value of base current from the equation (1) in the equation (3) we get

$$\text{Base impedence } Z_B = \frac{KV_B \text{ x } 1000}{KVA_B / KV_B}$$

$$\text{Base impedence } Z_B = \frac{(KV_B)^2 \text{ x } 1000}{KVA_B} \ldots\ldots\ldots.(4)$$

$$\text{Base Power} = KVA_B$$

$$Z_{pu} = \frac{\text{Actual Impedence}}{\text{Base impedence}} \ldots\ldots\ldots.(5)$$

Putting the value of base impedance from the equation (4) in the equation (5) we will get the value of impedance per unit

$$Z_{pu} = \frac{\text{Actual Impedence x } KVA_B}{(KV_B)^2 \text{ x } 1000}$$

Per Unit (P.U) system

The per unit value of any quantity is defined as:

$$\text{Per Unit (P.U)} = \frac{\text{the actual value of the quantity in any unit}}{\text{the base or reference value in the same unit}}$$

- If we choose, 50A as the base current, then a current of 30 A is equal to 30/50 = 0.6 in per unit, a current of 80A is equal to 80/50= 1.6 in per unit.
- It is usual to express voltage, current, volt-amperes and impedance of an electrical system in per unit quantities.

Per Unit system applied to single phase circuits

Let,
Base volt-amperes = $(VA)_B$

Base voltage = V_B

Then Base current $I_B = \dfrac{(VA)_B}{V_B}$

Base impedance $Z_B = \dfrac{V_B}{I_B}$

$= \dfrac{V_B^2}{(VA)_B}$ Ω

If the actual impedance is Z Ω, it's per unit value is given by

$$Z\,p.u = \frac{Z}{Z_B}$$

$$= \frac{Z\,(\Omega) \times (VA)_B}{V_B^2}$$

For a power system, practical choices of base value are:
Base volt amperes = $(MVA)_B$
Base voltage = $(kV)_B$
Hence,

Per unit system extended to three phase circuits

Three phase base mega volt amperes =(MVA)B

Line to line base kilovolts = (kV)B

Assuming star connection (or equivalent star can always be found),

$$\text{Base current } I_B = \frac{((MVA)_B / 3)}{((kV)_B / \sqrt{3})}$$

$$I_B = \frac{1000 \times (MVA)_B}{\sqrt{3} \times (kV)_B}$$

$$\text{Base impedance } Z_B = \frac{1000 \times (kV)_B}{(\sqrt{3} \times I_B)}$$

$$= \frac{1000 \times (kV)_B}{\left(\sqrt{3} \times \frac{1000 \times (MVA)_B}{\sqrt{3} \times (kV)_B}\right)}$$

$$= \frac{(kV)_B^2}{(MVA)_B}\ \Omega$$

If the actual impedance is Z Ω, its per unit impedance is given by,

$$Z_{p.u} = \frac{Z(\Omega)}{Z_B} = \frac{Z(\Omega)}{\frac{(kV)_B^2}{(MVA)_B}}$$

$$Z_{p.u} = \frac{Z(\Omega) \times (MVA)_B}{(kV)_B^{\ 2}}$$

Change of Base Quantities

Let $(kV)_{B,\ old}$ and $(MVA)_{B,\ old}$ represent old base values

$(kV)_{B,\ new}$ and $(MVA)_{B,\ new}$ represent new base values.

$Z_{p.u.\ old}$ = p.u impedance of a circuit element on old base

$$= \frac{Z(\Omega)\times(MVA)_{B,\ old}}{(kV)^2_{B,\ old}} \quad \text{---------------(1)}$$

$Z_{p.u.\ new}$ = p.u impedance of a circuit element on new base

$$= \frac{Z(\Omega)\times(MVA)_{B,\ new}}{(kV)^2_{B,\ new}} \quad \text{---------------(2)}$$

Dividing equation (2)by equation (1) and rearranging, we get

$$Z_{p.u.\ new} = Z_{p.u.\ old} \times \frac{(MVA)_{B,\ new}}{(MVA)_{B,\ old}} \times \frac{(kV)^2_{B,\ old}}{(kV)^2_{B,\ new}}$$

The primary and secondary sides of a single phase 1 MVA, 4kV / 2kV transformer have a leakage reactance of 2 Ω each. Find the p.u reactance of the transformer referred to the primary and secondary side.

Base values:

$(MVA)_B = 1$ MVA

Primary base voltage $(KV_1)_B = 4$kV

Secondary base voltage $(kV_2)_B = 2$kV

Also, it is given that $X_1 = X_2 = 2\ \Omega$.

Primary side:

The total impedances as referred to the primary side $X_{01} = X_1 + X_2'$

where,

$$X_2' = X_2 \left(\frac{KV1}{KV2}\right)^2 = 2 \text{ X } \left(\frac{4}{2}\right)^2 = 8\ \Omega$$

Therefore $X_{01} = 2+8 = 10\ \Omega$

$$(X_{01})_{p.u} = X_{01}(\Omega) \times \frac{(MVA)_B}{(kV1)^2}$$

$= 10 \text{ X } (1 / 4)^2 = 0.625$p.u...............................(a)

Secondary side:

The total impedance as referred to the secondary side is $X_{02} = X_2 + X_1'$

$$X_1' = X_1 \times \left(\frac{KV2}{KV1}\right)^2 = 2\ (2 / 4)2 = 0.5\ \Omega$$

Therefore $X_{02} = 2+0.5 = 2.5\ \Omega$

$$(X_{02})_{p.u} = X_{02}(\Omega) \times \frac{(MVA)_B}{(kV2)^2}$$

$= 2.5\ (1 / 2)^2 = 0.625$p.u...............................(b)

From eq. a and b, it can be observed that p.u reactance of the transformer referred to primary side and secondary side is the same, though their ohmic values are different.

show that the per unit impedance of a transformer is the same irrespective of the side on which it is calculated.

Let,

(MVA)B= rated MVA of the transformer.

(kV1)B= base voltage in the primary side.

(kV2)B= base voltage in the secondary side.

Also, let Zeq1 be the impedance of the transformer referred to primary side and Zeq2 the impedance as referred to the secondary.

We have,

$$(Z_{eq1})_{p.u} = Z_{eq1}(\Omega) \times \frac{(MVA)_B}{(kV_1)_B^{\,2}} \quad \text{.................................a)}$$

And

$$(Z_{eq2})_{p.u} = Z_{eq2}(\Omega) \times \frac{(MVA)_B}{(kV_2)^2_B} \quad \text{.................................b)}$$

Where,

$$Z_{eq2}(\Omega) = Z_{eq1}(\Omega) \times \frac{(kV_2)_B^{\,2}}{(kV_1)_B^{\,2}} \quad \text{.................................c)}$$

Substituting eq. c) in eq. b), we get,

$$(Z_{eq2})_{p.u} = Z_{eq1}(\Omega) \times \frac{(kV_2)_B^{\,2}}{(kV_1)_B^{\,2}} \times \frac{(MVA)_B}{(kV_2)_B^{\,2}}$$

$$= Z_{eq1}(\Omega) \times \frac{(MVA)_B}{(kV_1)_B^{\,2}}$$

$$(Z_{eq2})_{p.u} = (Z_{eq1})_{p.u}$$

Thus, it is proved that the per unit impedance of a transformer is the same whether computed from primary or secondary side.

Three generators are rated as follows:

Generator 1 : 100 MVA, 33kV, reactance 10%.

Generator 2: 150MVA, 32kV, reactance 8%.

Generator 3: 110MVA, 30kV, reactance 12%.

Determine the reactance of the generator corresponding to base values of 200MVA, 35kV.

Here, the reactances of the generators are specified on the basis of their own rated MVA and kV. We consider this as old values. Therefore,

$$(X_{g1})_{p.u.\ old} = 10\% = 0.1\text{p.u on 100MVA, 33kV old bases}$$

$$(X_{g2})_{p.u.\ old} = 8\% = 0.08\text{p.u on 150MVA, 32kV old bases}$$

$$(X_{g3})_{p.u.\ old} = 12\% = 0.12\text{ p.u on 110MVA, 30kV old bases}$$

The new base values are 200MVA, 35kV. (Given) hence using the formula

$$X_{p.u.\ new} = X_{p.u.\ old} \times \frac{(MVA)_{B,\ new} \times (kV)^2_{B,\ old}}{(MVA)_{B,\ old} \times (kV)^2_{B,\ new}}$$

$$(X_{g1})_{p.u.\ new} = 0.1 \times \frac{200}{100} \times \left(\frac{(33)}{(35)}\right)^2 = 0.1777\text{ p.u}$$

$$(X_{g2})_{p.u.\ new} = 0.08 \times \frac{200}{150} \times \left(\frac{(32)}{(35)}\right)^2 = 0.08916\text{ p.u}$$

$$(X_{g3})_{p.u.\ new} = 0.12 \times \frac{200}{110} \times \left(\frac{(30)}{(35)}\right)^2 = 0.1603\text{ p.u}$$

Advantages of per unit computations

1) Manufacturers usually specify the impedance of an apparatus in per unit or percent value on the base of the name plate rating of the apparatus.

2) The per unit impedance of the same type of machines, may be of different ratings, lie within a narrow range. However, the ohmic values differ materially for machines of different ratings. Hence, if the per unit impedance of a generator is not known, then it can be chosen from a set of tabulated values.

3) The per unit impedance of transformer is the same referred to either side of it.

4) The method of connection of transformers (Y-Y, Y- Δ etc) do not effect the per unit value

5) The greatest advantage of using per unit values is that it makes the calculations relatively easier.

Procedure to form per unit reactance diagram from one-line diagram.

1) Choose a base kilo volt ampere (kVA)B or mega volt ampere (MVA)B.
2) Select a base kilovolt (kV)B for one section of power system. In case of three phase power system, the (kV)B is a line value.

$$(KV)_B \text{ on HT Section} = (KV)_B \text{ on LT Section} \times \frac{\text{HT voltage rating}}{\text{LT voltage rating}}$$

$$(KV)_B \text{ on LT Section} = (KV)_B \text{ on HT Section} \times \frac{\text{LT voltage rating}}{\text{HT voltage rating}}$$

3) The impedance of the components of power system are expressed either in ohms or in p.u which is calculated using the component rating as the base values. In reactance diagram, the resistance are neglected and reactance's of all components are expressed on a common base. Hence, starting from one end of power system the reactance's of each component should be converted to p.u reactance's on the selected new base.

$$X_{p.u} = \frac{X(\Omega) \times (MVA)_{B,new}}{(kV)_{B}^{2}{}_{,new}}$$

$$X_{p.u.\,new} = X_{p.u.\,old} \times \frac{(MVA)_{B,\,new}}{(MVA)_{B,\,old}} \times \frac{(kV)^2_{B,\,old}}{(kV)^2_{B,\,new}}$$

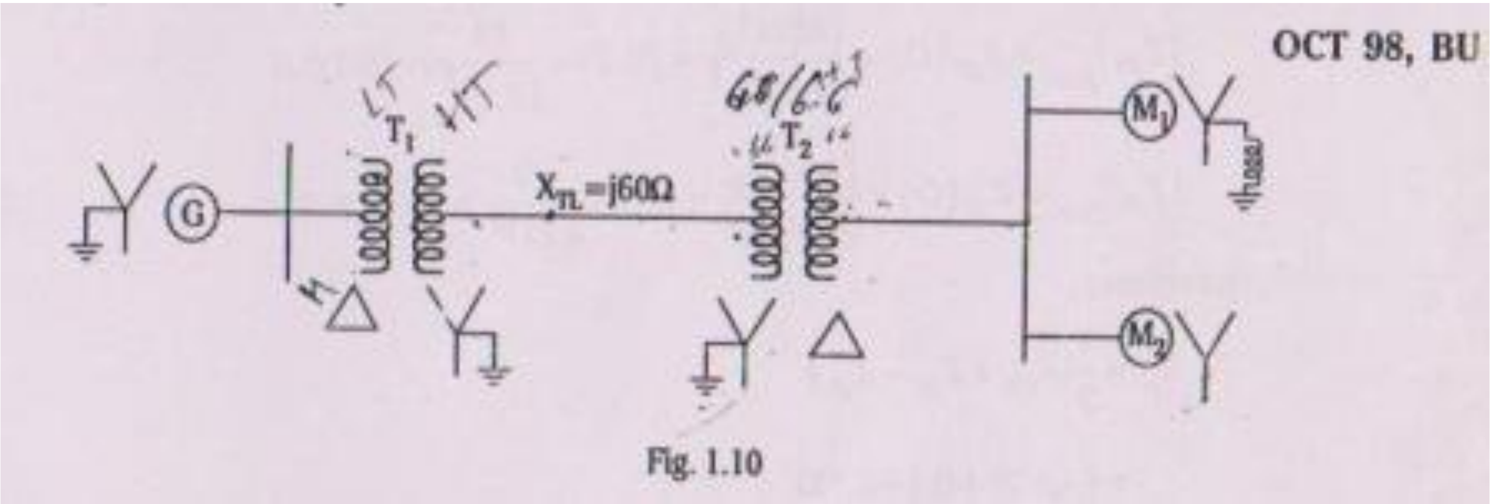
Draw the reactance diagram of the system shown in fig. 1.10. the ratings of the components are

G: 15MVA, 6.6kV, X" = 12%

T1= 20 MVA, 6.6/66 kV, X=8%

T2= 20 MVA, 66/6.6 kV, X=8%

M1 & M2: 5MVA, 6.6kV, X"=20%



base mega volt amperes, (MVA)B = 15MVA

base kilovolt on the generator G, (kV)B = 6.6kV

Base kV on transmission line $= 6.6 \times \left(\frac{66}{6.6}\right) = 66$ kV

Base kV on the motors M1 & M2 $= 66 \times \left(\frac{6.6}{66}\right) = 6.6$ kV

Reactance of generator G:

$$X_{g,\,new} = X_{g,\,old} \times \frac{(MVA)_{B,\,new}}{(MVA)_{B,\,old}} \times \frac{(kV)^2_{B,\,old}}{(kV)^2_{B,\,new}}$$

$$= j0.12 \times \frac{15}{15} \times \left(\frac{6.6}{6.6}\right)^2$$

$$= j\,0.12 \text{ p.u}$$

Reactance of transformer T1: (calculated primary side)

$$X_{T1,\,new} = X_{T1,\,old} \times \frac{(MVA)_{B,\,new}}{(MVA)_{B,\,old}} \times \frac{(kV)^2_{B,\,old}}{(kV)^2_{B,\,new}}$$

$$= j0.08 \times \frac{15}{20} \times \left(\frac{66}{66}\right)^2$$

$$= j\,0.06 \text{ p.u}$$

Reactance of transformer T1: (calculated secondary side)

$$X_{T1,\,new} = X_{T1,\,old} \times \frac{(MVA)_{B,\,new}}{(MVA)_{B,\,old}} \times \frac{(kV)^2_{B,\,old}}{(kV)^2_{B,\,new}}$$

$$= j0.08 \times \frac{15}{20} \times \left(\frac{66}{66}\right)^2$$

$$= j\,0.06 \text{ p.u}$$

Reactance of 60 Ω transmission line TL:

$$X_{TL} = \frac{X(\Omega) \times (MVA)_B}{(kV)_B^2}$$

$$= j60 \times \frac{15}{(66)2}$$

$$= j0.207 \text{p.u}$$

Reactance of transformer T2: (calculated primary side)

$$X_{T2,\ new} = X_{T2,\ old} \times \frac{(MVA)_{B,\ new}}{(MVA)_{B,\ old}} \times \frac{(kV)^2_{B,\ old}}{(kV)^2_{B,\ new}}$$

$$= j0.08 \times \frac{15}{20} \times \left(\frac{66}{66}\right)^2$$

$$= j\,0.06 \text{ p.u}$$

Reactance of transformer T2: (calculated secondary side)

$$X_{T2,\ new} = X_{T2,\ old} \times \frac{(MVA)_{B,\ new}}{(MVA)_{B,\ old}} \times \frac{(kV)^2_{B,\ old}}{(kV)^2_{B,\ new}}$$

$$= j0.08 \times \frac{15}{20} \times \left(\frac{6.6}{6.6}\right)^2$$

$$= j\,0.06 \text{ p.u}$$

Reactance of motor M1:

$$X_{M1,\ new} = X_{M1,\ old} \times \frac{(MVA)_{B,\ new}}{(MVA)_{B,\ old}} \times \frac{(kV)^2_{B,\ old}}{(kV)^2_{B,\ new}}$$

$$= j0.2 \times \frac{15}{5} \times \left(\frac{6.6}{6.6}\right)^2$$

$$= j\,0.6 \text{ p.u}$$

Reactance of motor M2:

$$X_{M2,\ new} = X_{M2,\ old} \times \frac{(MVA)_{B,\ new}}{(MVA)_{B,\ old}} \times \frac{(kV)^2_{B,\ old}}{(kV)^2_{B,\ new}}$$

$$= j0.2 \times \frac{15}{5} \times \left(\frac{6.6}{6.6}\right)^2$$

$$= j\,0.6 \text{ p.u}$$

As ratings for motor M1 & M2 are same,

XM1, new =XM2, new=j 0.6 p.u

The reactance diagram is as shown in fig

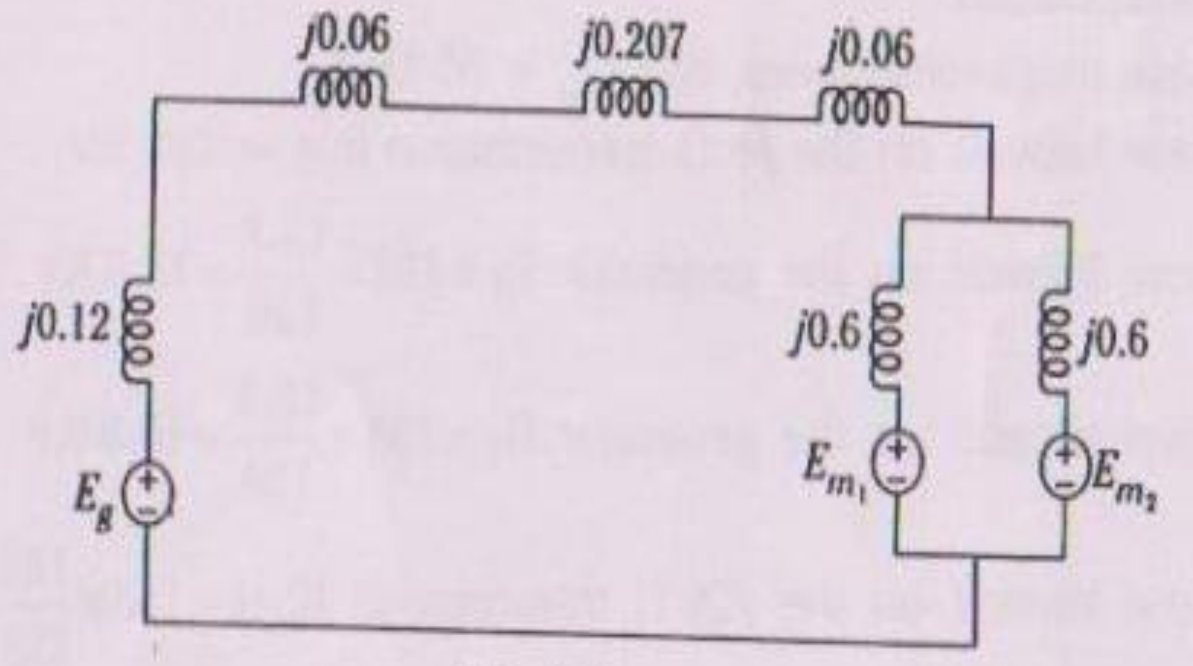


Fig. 1.11

Obtain the impedance diagram of the electrical power system shown in fig. 1.12. Mark all impedance values in per unit on a base of 50MVA, 138kV in the 40 ohm line. The machine ratings are:

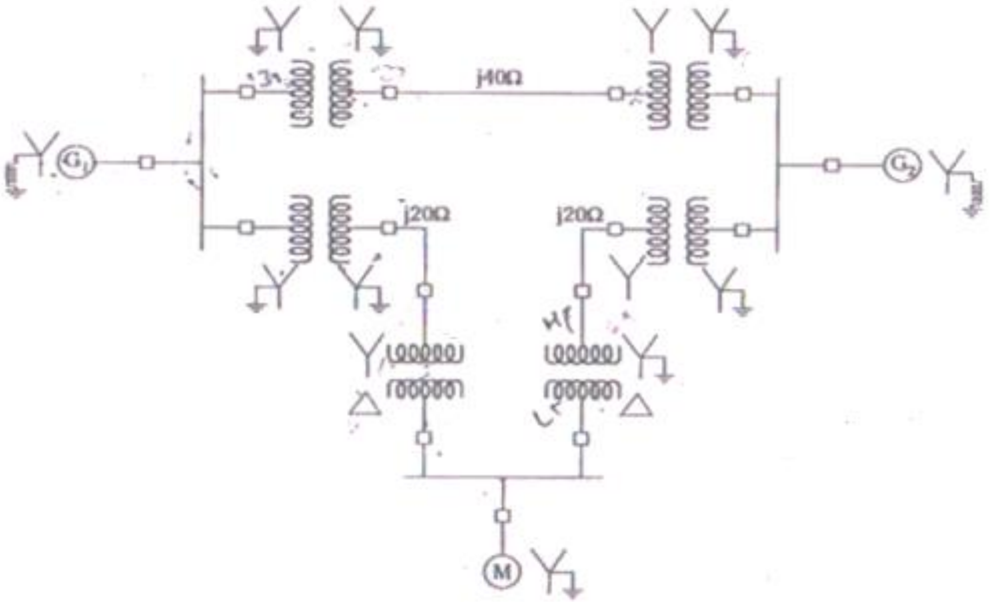
G1: 20MVA, 13.2kV, X”=15%

G2: 20MVA, 13.2kV, X”=15%

M: 30MVA, 6.9kV, X”=20%

Three phase Y-Y transformers: 20MVA, 13.8/138kV, X=10%

Three phase Y- Δ transformers: 15MVA, 6.9/138kV, X=10%



Base MVA= 50 MVA

Base kV on the j40 Ω transmission line = 138 KV

We calculate,

$$(KV)_B \text{ on LT Section} = (KV)_B \text{ on HT Section X } \frac{\text{LT voltage rating}}{\text{HT voltage rating}}$$

$$\text{Base kV on the generator section G1} = 138 \times \frac{13.8}{138} = 13.8 \text{ KV}$$

$$\text{Base kV on the generator section G2} = 138 \times \frac{13.8}{138} = 13.8 \text{ KV}$$

$$(KV)_B \text{ on HT Section} = (KV)_B \text{ on LT Section X } \frac{\text{HT voltage rating}}{\text{LT voltage rating}}$$

$$\text{Base kV on the j20 Ω transmission lines} = 13.8 \times \frac{138}{13.8} = 138 \text{ KV}$$

$$\text{Base kV on the motor section M} = 138 \times \frac{6.9}{138} = 6.9 \text{ KV}$$

Reactance of generators G1 & G2:

$$X_{G1,\ new} = X_{G2,\ new} = X_{G1,\ old} \times \frac{(MVA)_{B,\ new}}{(MVA)_{B,\ old}} \times \frac{(kV)^2_{B,\ old}}{(kV)^2_{B,\ new}}$$

$$= j0.15 \times \frac{15}{20} \times \left(\frac{13.8}{13.8}\right)^2$$

$$= j\,0.343 \text{ p.u}$$

Reactance of Y-Y connected transformers : (calculated considering primary winding old and new base kV values) The Y-Y connected transformers are all identical. Hence their p.u reactances are same.

$$X_{TR1,\ new} = X_{TR1,\ old} \times \frac{(MVA)_{B,\ new}}{(MVA)_{B,\ old}} \times \frac{(kV)^2_{B,\ old}}{(kV)^2_{B,\ new}}$$

$$= j0.1 \times \frac{50}{20} \times \left(\frac{13.8}{13.8}\right)^2$$

$$= j\,0.25 \text{ p.u}$$

Reactance of j20 Ω transmission lines : both the sections of the j20 ohm transmission lines have same values of reactances and same base values. Hence their p.u reactances will be the same.

$$X_{TL1} = \frac{X(\Omega) \times (MVA)_B}{(kV)_B^2}$$

$$= j20 \times \frac{50}{(138)^2} = j0.053\,p.u$$

Reactance of Y- Δ connected transformers :(calculated considering primary winding old and new base kV values) Since the Y- Δ connected transformers are all identical. Hence their p.u reactances are the same.

$$X_{TR1,\,new} = X_{TR1,\,old} \times \frac{(MVA)_{B,\,new}}{(MVA)_{B,\,old}} \times \frac{(kV)^2_{B,\,old}}{(kV)^2_{B,\,new}}$$

$$= j0.1 \times \frac{50}{15} \times \left(\frac{138}{138}\right)^2$$

$$= j\,0.33\,p.u$$

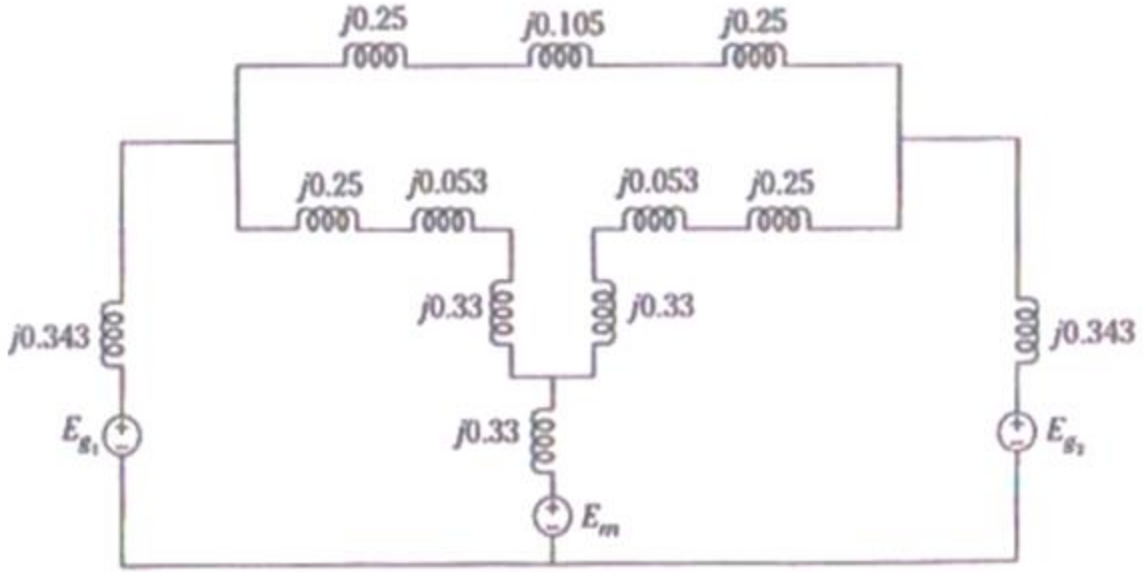
Reactance of motor M: This motor is connected on to the secondary windings of the Y- Δ transformers (i.e Low Voltage side or Low tension side)

$$X_{M1,\ new} = X_{M1,\ old} \times \frac{(MVA)_{B,\ new}}{(MVA)_{B,\ old}} \times \frac{(kV)^2_{B,\ old}}{(kV)^2_{B,\ new}}$$

$$= j0.2 \times \frac{50}{30} \times \left(\frac{6.9}{6.9}\right)^2$$

$$= j\,0.33 \text{ p.u}$$

The impedance (reactance) diagram of the system is as in fig



The one-line diagram of an unloaded generator is shown in the fig 1.14 Draw the p.u impedance diagram. Choose a base of 50MVA, 13.8kV in the circuit of generator G1.

The generators and transformers are rated as follows:

G_1: 20MVA, 13.8kV, X"=0.2 p.u

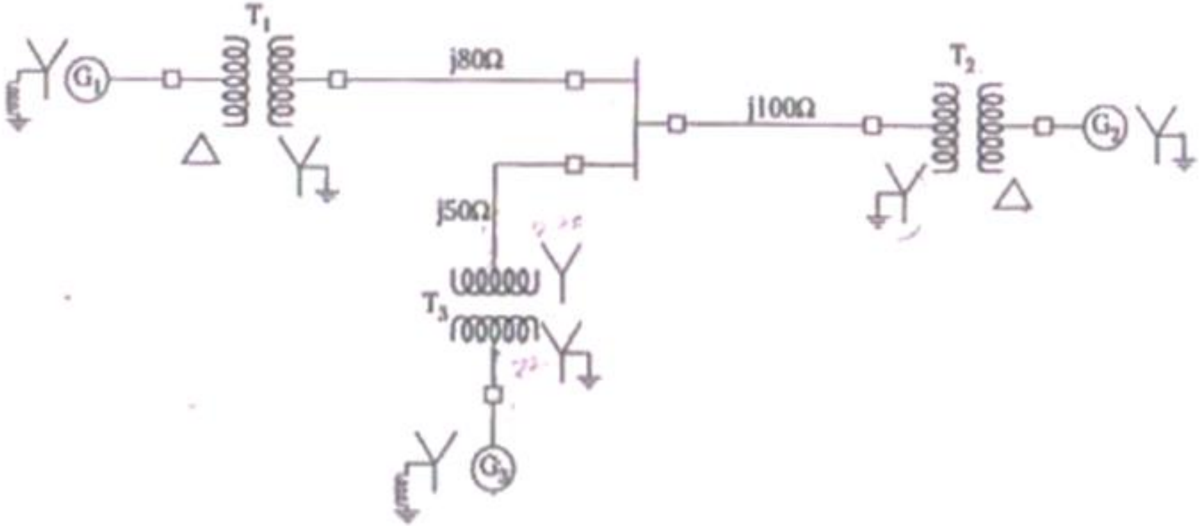
G_2: 30MVA, 18kV, X"=0.2 p.u

G_3: 30MVA, 20kV, X"=0.2 p.u

T1: 25MVA, Y220 kV/13.8 kV Δ , X=10%

T2: Three single phase units each rated 10MVA, 127/18kV, X=10%

T3=35MVA, 220kV Y/22kV Y, X=10%



Base values:

Base MVA=50 MVA

Base kV on the generator G1=13.8 KV

Base kV on the j80 ohm transmission line= 13.8 × 220 / 13.8 = 220 KV

Base kV on the j50 ohm transmission line=220 KV

Base kV on the j100 ohm transmission line=220 KV

(as all the transmission lines are connected to the same bus, so base kV on them is the same)

Base kV on the generator G3= 220 × 22 / 220 = 22

The transformer T2 is a three phase bank formed using three single phase transformers with a voltage rating of 127/18kV. In this, the HT side is star connected and LT side is delta connected.

Voltage ratio of line voltage of 3-phase transformer bank T2= $\sqrt{3} \times \frac{127}{18}$

$= \frac{220KV}{18KV}$

(as primary winding is star connected $V_{line}=\sqrt{3}\, V_{ph}$, and secondary is Δ, $V_{line}=V_{ph}$)

Base kV on the generator G2= $220 \times \frac{18}{220} = 18$

Reactance of generator G1:

$$X_{G1,\,new} = X_{G1,\,old} \times \frac{(MVA)_{B,\,new}}{(MVA)_{B,\,old}} \times \frac{(kV)_{B}^{2},_{old}}{(kV)_{B}^{2},_{new}}$$

$$= j0.2 \times (50 / 20) \times (13.8^2 / 13.8^2)$$

$$= j\,0.5 \text{ p.u}$$

Reactance of transformer T1: (calculated primary side)

$$X_{T1,\,new} = X_{T1,\,old} \times \frac{(MVA)_{B,\,new}}{(MVA)_{B,\,old}} \times \frac{(kV)_{B}^{2},_{old}}{(kV)_{B}^{2},_{new}}$$

$$= j0.1 \times (50 / 25) \times (13.8^2 / 13.8^2)$$

$$= j\,0.2 \text{ p.u}$$

Reactance of transmission lines: j80 ohm line,

$$X_{TL1} = \frac{X_{TL1}(\Omega) \times (MVA)_B}{(kV)_B^2}$$

$$= j80 \times 50 / 220^2 = j0.083\text{p.u}$$

j100 ohm line,

$$X_{TL2} = \frac{X_{TL2}(\Omega) \times (MVA)_B}{(kV)_B^2}$$

$$= j100 \times 50 / 220^2 = j0.1033\text{p.u}$$

j50 ohm line,

$$X_{TL3} = \frac{X_{TL3}(\Omega) \times (MVA)_B}{(kV)_B^2}$$

$$= j50 \times 50 / 220^2 = j0.0516\text{p.u}$$

Reactance of transformer T2: (calculated secondary side)

This is a bank of three single phase transformers, hence, base MVA old

$= 10 \times 3 = 30$ MVA

$$X_{T2,\ new} = X_{T2,\ old} \times \frac{(MVA)_{B,\ new}}{(MVA)_{B,\ old}} \times \frac{(kV)_{B,\ old}^2}{(kV)_{B,\ new}^2}$$

$= j0.1 \times (50 / 30) \times (220^2 / 220^2)$

$= j\,0.1667$ p.u

Reactance of generator G2: this is connected to the LT side of T2,

$$X_{G2,\ new} = X_{G2,\ old} \times \frac{(MVA)_{B,\ new}}{(MVA)_{B,\ old}} \times \frac{(kV)_{B,\ old}^2}{(kV)_{B,\ new}^2}$$

$= j0.2 \times (50 / 20) \times (18^2 / 18^2)$

$= j\,0.333$ p.u

Reactance of transformer T3: (calculated secondary side of it)

$$X_{T3,\ new} = X_{T3,\ old} \times \frac{(MVA)_{B,\ new}}{(MVA)_{B,\ old}} \times \frac{(kV)_{B,\ old}^2}{(kV)_{B,\ new}^2}$$

$= j0.1 \times (50 / 30) \times (22^2 / 22^2)$

$= j\,0.143$ p.u

Reactance of generator G3:

$$X_{G3,\ new} = X_{G3,\ old} \times \frac{(MVA)_{B,\ new}}{(MVA)_{B,\ old}} \times \frac{(kV)_{B,\ old}^2}{(kV)_{B,\ new}^2}$$

$= j0.2 \times (50 / 30) \times (20^2 / 22^2)$

$= j\,0.275$ p.u

The reactance diagram is as constructed in fig.1.15

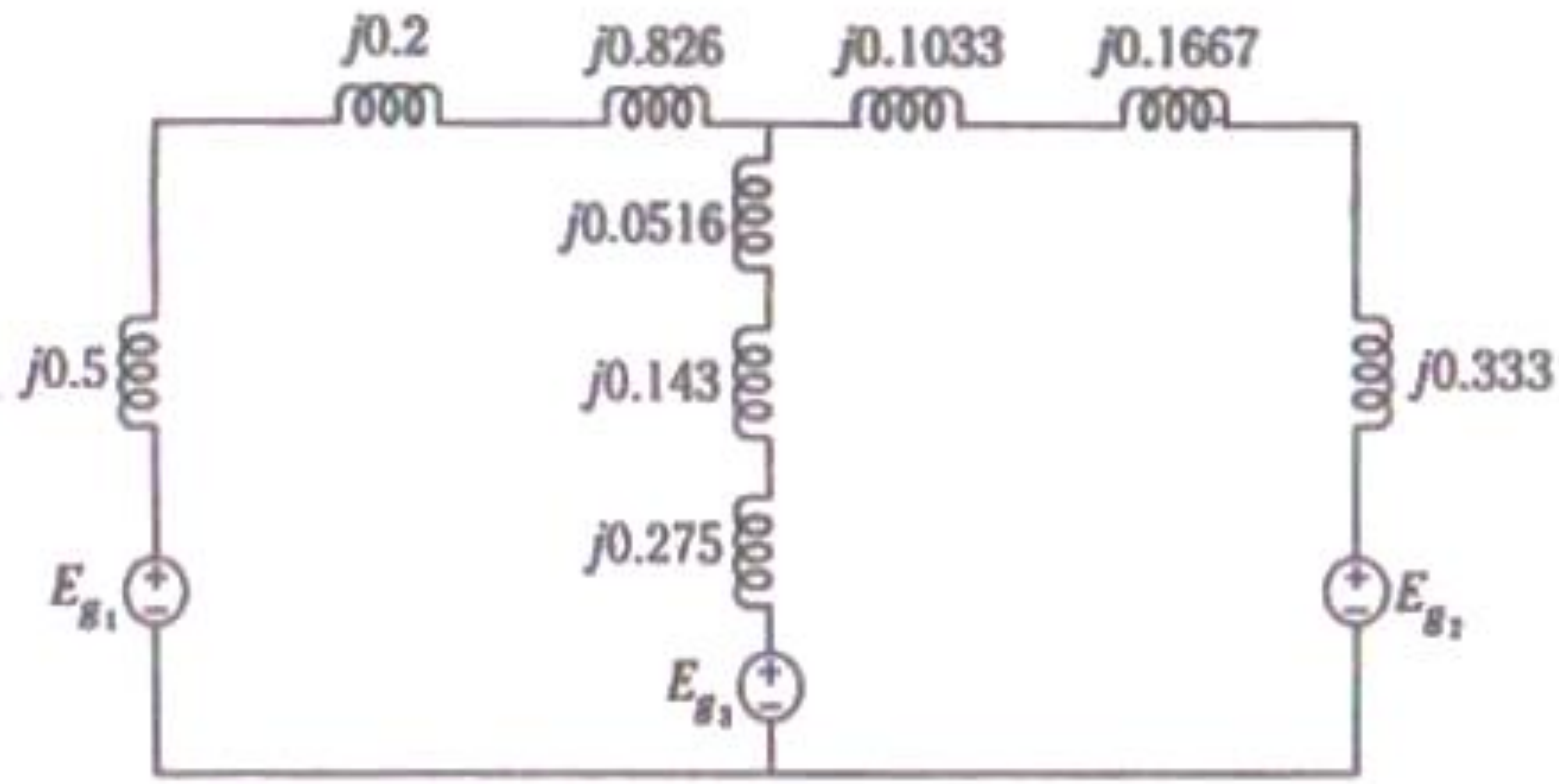


Fig. 1.15

Fig 1.16 shows the schematic diagram of a radial transmission system. The ratings and reactance's of the various components are shown therein. A load of 60MW at 0.9p.f lagging is tapped from the 66kV substation which is to be maintained at 60kV. Calculated the terminal voltage of the machine. Represent the transmission line and transformer by series reactance's only.

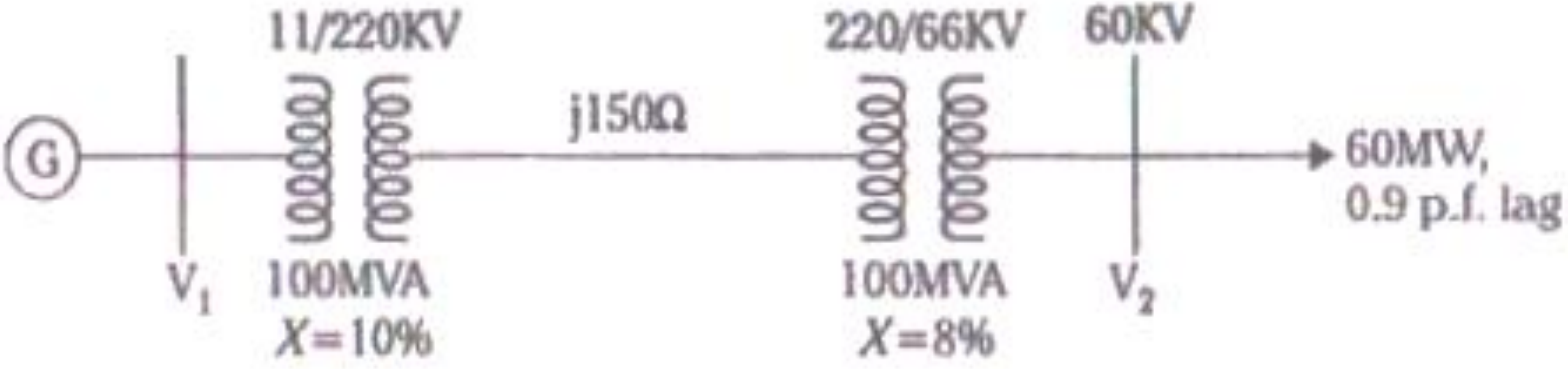


Fig. 1.16

Choose the base MVA throughout the system be 100MVA

Base kV in the transmission line j150 ohm = 220KV

Base kV on the load= 220 × 66 / 220 = 66 KV

Base kV on the generator side = 220 × 11 / 220 = 11 KV

Reactance on 11/220kV transformers: (calculated secondary side of it)

$$X_{T1,\,new} = X_{T1,\,old} \times \frac{(MVA)_{B,\,new}}{(MVA)_{B,\,old}} \times \frac{(kV)_{B}^{2},_{old}}{(kV)_{B}^{2},_{new}}$$

$$= j0.1 \times (100 / 100) \times (220^2 / 220^2)$$

$$= j\,0.1 \text{ p.u}$$

Reactance of j150 ohm transmission line:

$$X_{TL} = \frac{X_{TL}(\Omega) \times (MVA)_B}{(kV)_B^2}$$

$$= j150 \times 100 / 220^2$$

$$= j0.31 \text{p.u}$$

Reactance on 220/66kV transformers:(calculated primary side of it)

$$X_{T1,\,new} = X_{T1,\,old} \times \frac{(MVA)_{B,\,new}}{(MVA)_{B,\,old}} \times \frac{(kV)_{B}^{2},_{old}}{(kV)_{B}^{2},_{new}}$$

$$= j0.08 \times (100 / 100) \times (220^2 / 220^2)$$

$$= j\,0.08 \text{ p.u}$$

The reactance diagram of the system is as shown in fig1.17

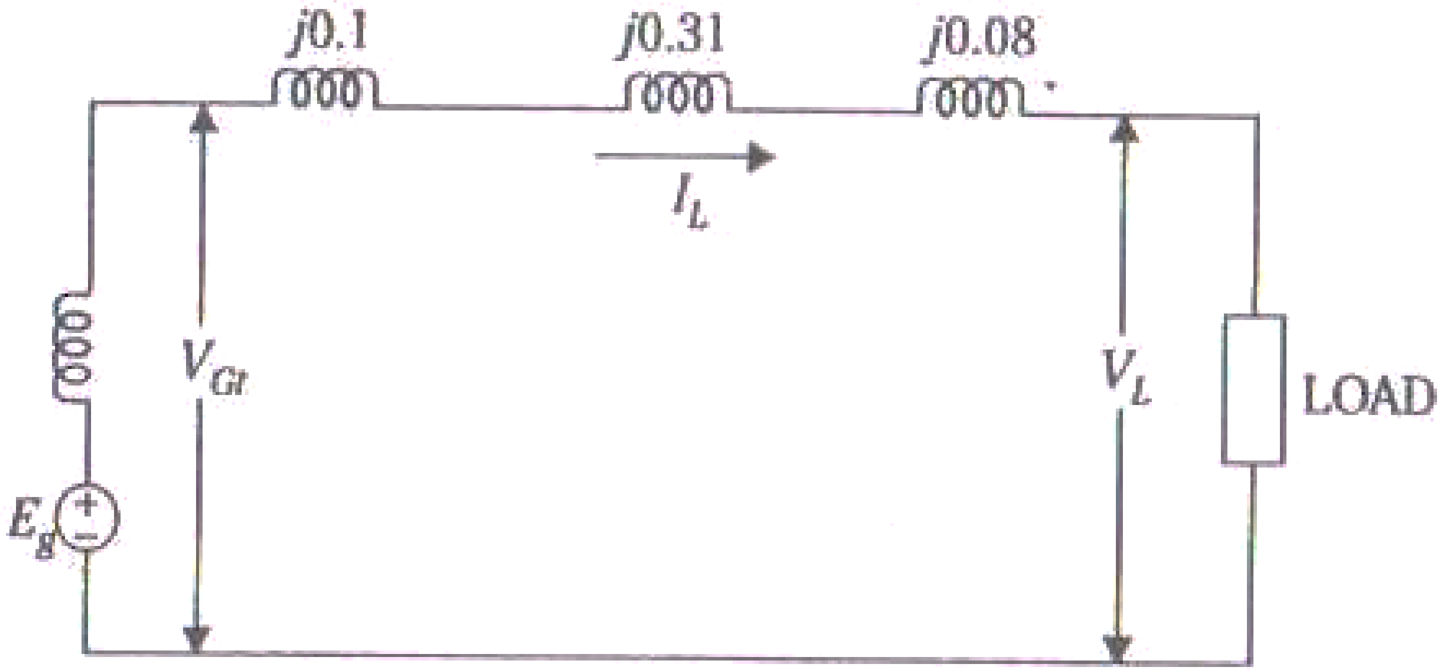


Fig. 1.17

Terminal voltage of the machine:

Let V_{Gt}=terminal voltage of the machine

V_L=load voltage

I_L=load current

V_L=60kV= 60kV/66kV = 0.909p.u

$$I_L = \frac{P}{(\sqrt{3} \times V_L \cos\varphi)} \angle -\cos^{-1}\varphi$$

$$I_L = \frac{(60\times10^6)}{(\sqrt{3} \times 60\times10^3 \times 0.9)} \angle -\cos^{-1} 0.9$$

$$I_L = 641.5 \angle -25.48° \text{ A}$$

The value of IL should be in p.u. Hence, determine the base current IB

$$I_B = \frac{(1000 \times (MVA)_B)}{(\sqrt{3} \times (kV)_B)}$$

$$= \frac{(1000 \times 100)}{(\sqrt{3} \times 66)}$$

$$= 874.77 \text{ A}$$

Therefore, I_L in p.u $= I_L/I_B = \frac{641.5 \angle -25.48°}{874.77}$

$$= 0.733 \angle -25.48° \text{ p.u}$$

From fig 1.17 it can be observed that,

$$(V_{Gt})p.u = (V_L)p.u + I_L\,(X_{T1}+X_{TL}+X_{T2})$$

$$=0.909+0.733\angle{-25.48^\circ}(j0.1+j0.31+j0.08)$$

$$=0.909+0.359\angle 64.16^\circ$$

$$=0.909+0.156+j0.323$$

$$=1.065+j0.323$$

$$=1.112\angle 16.87^\circ\ p.u$$

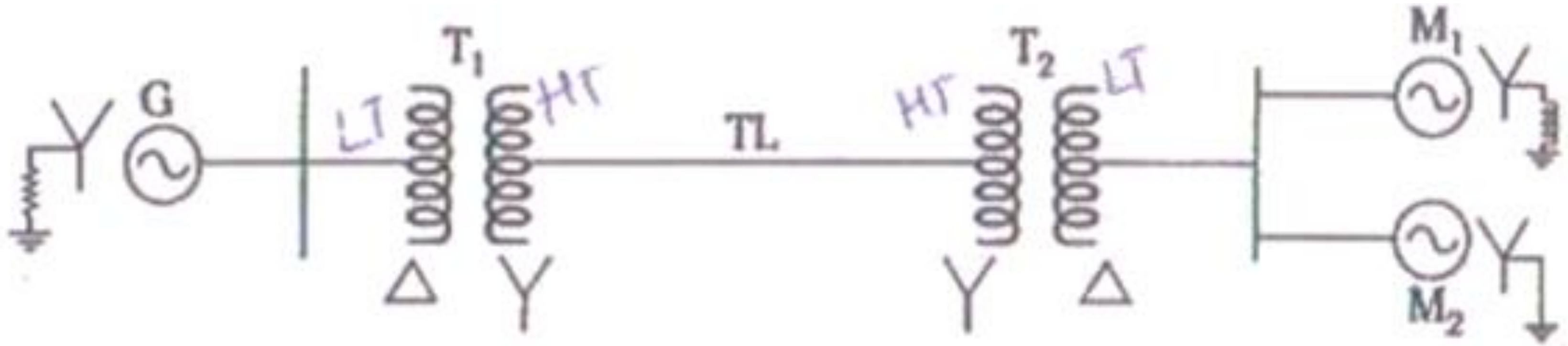
V_{Gt} in kilovolts $=(V_{Gt})p.u \times$ base kV on the generator

$$=1.112\times 11$$

$$=12.232kV$$

$$|V_{Gt}|=12.232kV$$

A 300MVA, 20kV, 3φ generator has a reactance of 20%. The generator supplies two motors M1 and M2 over a transmission line of 64km as shown in one line diagram.



The ratings of the components are as follows:

T1: 350 MVA, 230KV-Y/20KV-Δ, X=10%

TL: L=64Km, XTL= j0.5Ω/Km.

T2: Composed of three single phase transformers each rated 127/13.2 KV, 100 MVA with leakage reactance of 10%.

M1: 200 MVA, 13.2 KV, X"= 20%

M2: 100 MVA, 13.2 KV, X"= 20%

Select the generator ratings as the base & draw the reactance diagram with all reactance's marked in p.u. If the motors M1 & M2 have inputs of 120 MW & 60 MW at 13.2KV and operate at upf, find the voltage at the terminals of the generator.

Base values:

Given that to choose base MVA=300

Base kV on the generator =20

Base kV on the transmission line = 20 × 230 / 20 = 230

Base kV on the motors= 230 × 13.2 / (127√3) =13.8

Reactance of generator G:

$$X_{G,\,new} = X_{G,\,old} \times \frac{(MVA)_{B,\,new}}{(MVA)_{B,\,old}} \times \frac{(kV)_{B}^{2}{}_{,\,old}}{(kV)_{B}^{2}{}_{,\,new}}$$

$= j0.2 \times (300 / 300) \times (20^2 / 20^2)$

$= j\ 0.2$ p.u

Reactance of transformer T_1: (calculated considering secondary side of it)

$$X_{T1,\,new} = X_{T1,\,old} \times \frac{(MVA)_{B,\,new}}{(MVA)_{B,\,old}} \times \frac{(kV)_{B}^{2}{}_{,\,old}}{(kV)_{B}^{2}{}_{,\,new}}$$

$= j0.1 \times (300 / 350) \times (230^2 / 230^2)$

$= j\ 0.085$ p.u

Reactance of transformer T_2: (calculated considering primary side)

$$X_{T2,\,new} = X_{T2,\,old} \times \frac{(MVA)_{B,\,new}}{(MVA)_{B,\,old}} \times \frac{(kV)_{B}^{2}{}_{,\,old}}{(kV)_{B}^{2}{}_{,\,new}}$$

$= j0.1 \times (300 / 300) \times ((127\sqrt{3})^2 / 230^2)$

$= j\ 0.09$ p.u

Reactance of transmission line TL:

$$X_{TL,\,new} = \frac{X_{TL}(\Omega) \times (MVA)_B}{(kV)_B^2}$$

$= (j0.5 \times 64)\ 300 / 220^2$

$= j0.181$ p.u

Reactance of generator M_1:

$$X_{M1,\,new} = X_{M1,\,old} \times \frac{(MVA)_{B,\,new} \times (kV)_{B}^{2}{}_{,\,old}}{(MVA)_{B,\,old} \times (kV)_{B}^{2}{}_{,\,new}}$$

$= j0.2 \times (300 / 200) \times (13.2^2 / 13.8^2)$

$= j\,0.274$ p.u

Reactance of generator M_2:

$$X_{M2,\,new} = X_{M2,\,old} \times \frac{(MVA)_{B,\,new} \times (kV)_{B}^{2}{}_{,\,old}}{(MVA)_{B,\,old} \times (kV)_{B}^{2}{}_{,\,new}}$$

$= j0.2 \times (300 / 100) \times (13.2^2 / 13.8^2)$

$= j\,0.549$ p.u

Let,

VMt=terminal voltage at the motor ends.

VGt=terminal voltage of the generator.

The total electrical power that flows into the motors is,

P=120+60=180MW at 13.2kV, upf.

Therefore,

the current drawn by the motors,

Im= (180 × 106) / (√3 ×13.2× 103×1)=7873 A

it is required to express the current in p.u. Hence,

the base current IB=(1000×300) / (√3 ×13.8)

=12551A

I_m in p.u $= I_m/I_B = 7873/12551 = 0.627\angle 0°$ p.u

V_{mt} in p.u $= 13.2\angle 0°/13.8 = 0.96\angle 0°$ p.u,

$(V_{Gt})_{p.u} = (V_{Mt})_{p.u} + I_m\,(X_{T1}+X_{TL}+X_{T2})$

$= 0.96\angle 0° + 0.627(j0.085+j0.181+j0.09)$

$= 0.96\angle 0° + j0.223$

$= 0.986\angle 13.07°$

$|V_{Gt}| = |V_{Gt} \text{ in p.u}| \times 20\text{kV} = 0.986\times 20 = 19.72\text{kV}.$

The three parts of a single phase electric system are designated as A, B, C and are connected to each other through transformers. The transformers are rated as follows:

A-B: 10MVA, 13.8-138KV, leakage reactance 10%

B-C: 10MVA, 69-138KV, leakage reactance 8%

If the base in circuit B is chosen as 10MVA, 138KV, find the P.U. impedance of the 300 ohms resistive lead in circuit C referred to circuit C, B and A. Draw the impedance diagram of the system. Determine the voltage regulation if the voltage at the load is 66KV with the assumption that the voltage input to circuit remains constant.

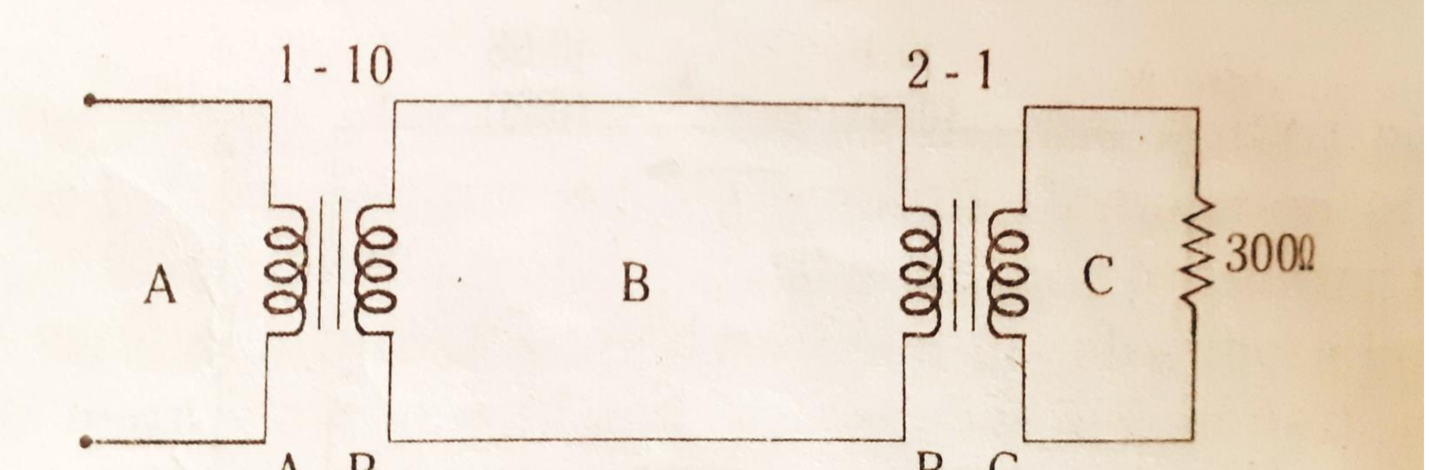


Fig. 1.22

Base power for the entire system, $(MVA)_B = 10MVA$
Base voltage on circuit B=138KV
Base voltage on Circuit A= 138 X (13.8/138)= 13.8KV
Base voltage on circuit C= 138 X (69/138) =69KV

P.U impedance of load connected in C= $300 \times ((MVA)_B /(KV)_B{}^2)$

$= 300 \times (10/(69)^2)$

$= 0.63$ pu

Load impedance as referred to circuit B

B= $300 \times ((138)^2/(69)^2)$

$= 1200$ ohms

Load impedance in pu as referred to B

B= $1200 \times (10/(138)^2)$

$= 0.63$ pu

Load impedance as referred to circuit C

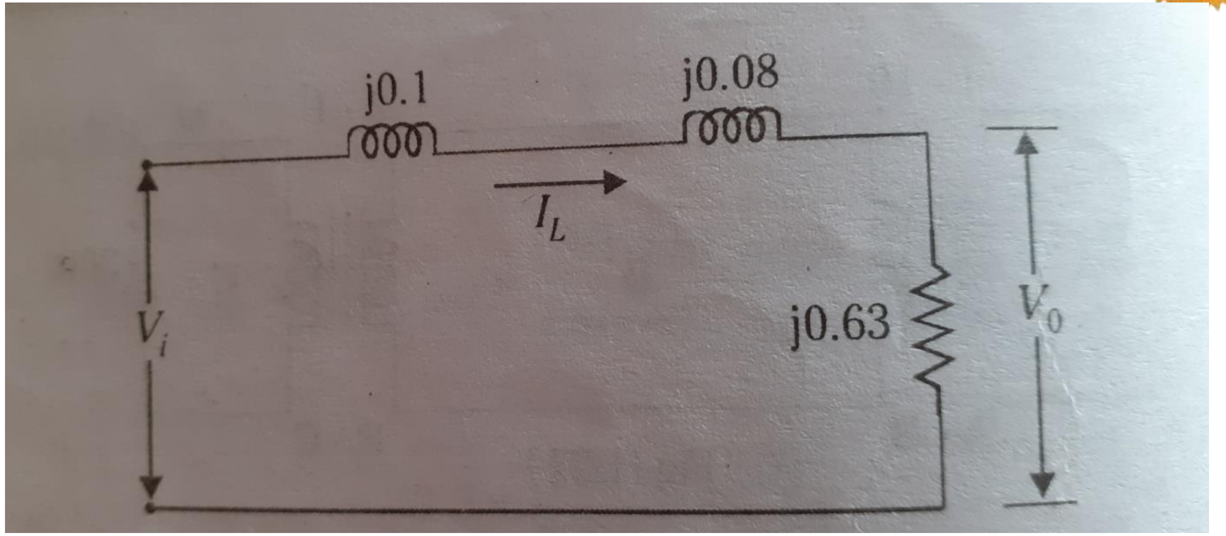
C= $1200 \times ((13.8)^2/(138)^2)$

$= 12$ ohms

Load impedance in pu as referred to C

B= $12 \times (10/(13.8)^2)$

$= 0.63$ pu



Voltage at the load, V_0 =66KV/69KV=0.957pu

Load current, I_L =0.957/0.63=1.52pu

Voltage at input, Vi= I_L (j0.1+j0.08)+ V_0

= (1.52) (j0.1+j0.08)+0.957

= j0.2736+0.957

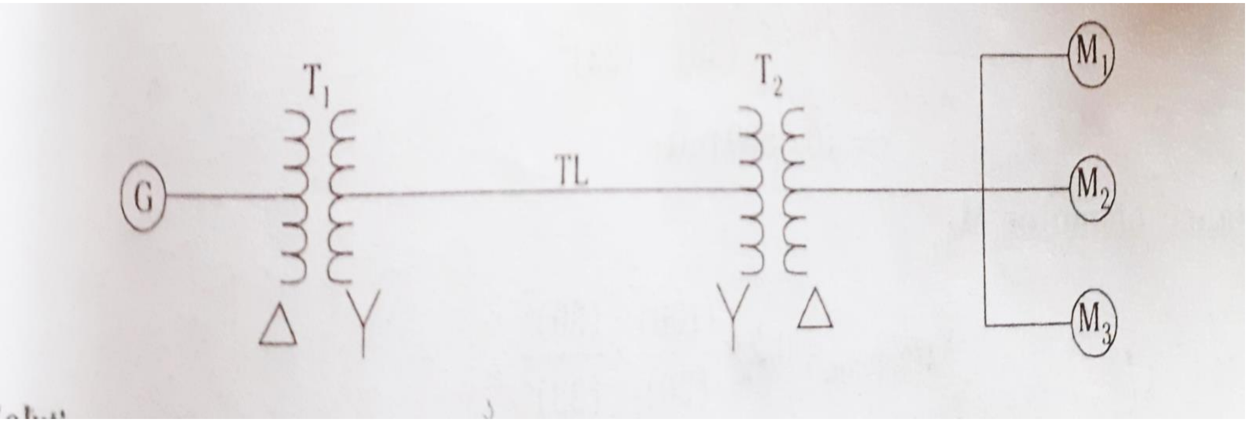
= 0.995<15.95^0

$$\text{Percentage regulation} = \frac{|V_i| - |V_0|}{|V_0|} \times 100$$

$$= ((0.995 - 0.957)/0.957) \times 100$$

$$= 3.97\%$$

100MVA, 33KV, 3 phase generator has a sub transient reactance of 15%. The generator is connected to the motors through a transmission line and transformers as shown in fig. The motors have rated output of 30MVA, 20MVA,and 50MVA at 30KV with 20% sub transient reactance each. The three phase transformers are rated 100MVA, 32KV delta/ 100KV star with leakage reactance of 8% the line has a reactance of 50 ohms. Selecting the generator rating as the base in generator circuit, draw the pu reactance diagram



THANK YOU