1.5 THE PER UNIT SYSTEM

In a large interconnected power system with various voltage levels and various capacity equipments it has been found quite convenient to work with per unit (p.u.) system of quantities for analysis purposes rather than in absolute values of quantities. Sometimes per cent values are used instead of p.u. but it is always convenient to use p.u. values. The p.u. value of any quantity is defined as

$$\frac{\text{The actual value of the quantity (in any unit)}}{\text{The base or reference value in the same unit}}$$

In electrical engineering the three basic quantities are voltage, current and impedance. If we choose any two of them as the base or reference quantity, the third one automatically will have a base or reference value depending upon the other two *e.g.*, if V and I are the base voltage and current in a system, the base impedance of the system is fixed and is given by

$$Z = \frac{V}{I}$$

The ratings of the equipments in a power system are given in terms of operating voltage and the capacity in kVA. Therefore, it is found convenient and useful to select voltage and kVA as the base quantities. Let V_b be the base voltage and kVA_b be the base kilovoltamperes, then

$$V_{\text{p.u.}} = \frac{V_{\text{actual}}}{V_b}$$

The base current $= \dfrac{kVA_b \times 1000}{V_b}$

$\therefore$ p.u. current $= \dfrac{\text{Actual current}}{\text{Base current}} = \dfrac{\text{Actual current}}{kVA_b \times 1000} \times V_b$

Base impedance $= \dfrac{\text{Base voltage}}{\text{Base current}}$

$$= \frac{V_b^2}{kVA_b \times 1000}$$

$\therefore$ p.u. impedance $= \dfrac{\text{Actual impedance}}{\text{Base impedance}}$

$$= \frac{Z \,.\, kVA_b \times 1000}{V_b^2} = \frac{Z \,.\, MVA_b}{(kV_b)^2}$$

This means that the p.u. impedance is directly proportional to the base kVA and inversely proportional to square of base voltage. Normally the p.u. impedance of various equipments corresponding to its own rating voltage and kVA are given and since we choose one common base kVA and voltage for the whole system, therefore, it is desired to find out the p.u. impedance of the various equipments corresponding to the common base voltage and kVA. If the individual quantities are $Z_{\text{p.u. old}}$, kVA_{old} and V_{old} and the common base quantities are $Z_{\text{p.u. new}}$, kVA_{new} and V_{new}, then making use of the relation above,

$$Z_{\text{p.u. new}} = Z_{\text{p.u. old}} \cdot \frac{kVA_{\text{new}}}{kVA_{\text{old}}} \cdot \left(\frac{V_{\text{old}}}{V_{\text{new}}}\right)^2 \tag{1.23}$$

This is a very important relation used in power system analysis.

The p.u. impedance of an equipment corresponding to its own rating is given by

$$Z_{\text{p.u.}} = \frac{IZ}{V}$$

where Z is the absolute value of the impedance of the equipment. It is seen that the p.u. representation of the impedance of an equipment is more meaningful than its absolute value *e.g.*, saying that the impedance of a machine is 10 ohms does not give any idea regarding the size of the machine. For a large size machine 10 ohms appears to be quite large, whereas for small machines 10 ohms is very small. Whereas for equipments of the same general type the p.u. volt drops and losses are in the same order regardless of size.

With p.u. system there is less chance of making mistake in phase and line voltages, single phase or three phase quantities. Also the p.u. impedance of the transformer is same whether referred on to primary or secondary side of the transformer which is not the case when considering absolute value of these impedances. This is illustrated below:

Let the impedance of the transformer referred to primary side be Z_p and that on the secondary side be Z_s, then

$$Z_p = Z_s \left(\frac{V_p}{V_s}\right)^2$$

where V_p and V_s are the primary and secondary voltages of the transformer.

Now
$$Z_{p\text{ p.u.}} = \frac{Z_p I_p}{V_p} = Z_s \left(\frac{V_p}{V_s}\right)^2 \cdot \frac{I_p}{V_p}$$

$$= Z_s \cdot \frac{V_p I_p}{V_s^2} = Z_s \cdot \frac{V_s I_s}{V_s^2} = \frac{Z_s I_s}{V_s}$$

$$= Z_{s\text{ p.u.}}$$

From this it is clear that the p.u. impedance of the transformer referred to primary side $Z_{p\text{ p.u.}}$ is equal to the p.u. impedance of the transformer referred to the secondary side $Z_{s\text{ p.u.}}$. This is a great advantage of p.u. system of calculation.

The base values in a system are selected in such a way that the p.u. voltages and currents in system are approximately unity. Sometimes the base *kVA* is chosen equal to the sum of the ratings of the various equipments on the system or equal to the capacity of the largest unit.

The different voltage levels in a power system are due to the presence of transformers. Therefore, the procedure for selecting base voltage is as follows: A voltage corresponding to any part of the system could be taken as a base and the base voltages in other parts of the circuit, separated from the original part by transformers is related through the turns ratio of the transformers. This is very important. Say, if the base voltage on primary side is V_{pb} then on the secondary side of the transformer the base voltage will be $V_{sb} = V_{pb}(N_s/N_p)$, where N_s and N_p are the turns of the transformer on secondary and primary side respectively.

The following example illustrates the procedure for selecting the base quantities in various parts of the system and their effect on the p.u. values of the impedances of the various equipments.

Example 1.1: A 100 MVA, 33 kV 3-phase generator has a subtransient reactance of 15%. The generator is connected to the motors through a transmission line and transformers as shown in Fig. E1.1*a*. The motors have rated inputs of 30 MVA, 20 MVA and 50 MVA at 30 kV with 20% subtransient reactance. The 3-phase transformers are rated at 110 MVA, 32 kV, Δ/110 kV Y with leakage reactance 8%. The line has a reactance of 50 ohms. Selecting the generator rating as the base quantities in the generator circuit, determine the base quantities in other parts of the system and evaluate the corresponding p.u. values.

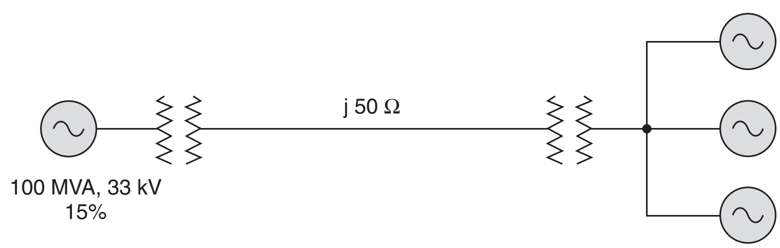


Fig. E1.1*a*

Solution: Assuming base values as 100 MVA and 33 kV in the generator circuit, the p.u. reactance of generator will be 15%. The base value of voltage in the line will be

$$33 \times \frac{110}{32} = 113.43 \text{ kV}$$

In the motor circuit,

$$113.43 \times \frac{32}{110} = 33 \text{ kV}$$

The reactance of the transformer given is 8% corresponding to 110 MVA, 32 kV. Therefore, corresponding to 100 MVA and 33 kV the p.u. reactance will be (using Eq. 1.23).

$$0.08 \times \frac{100}{110} \times \left(\frac{32}{33}\right)^2 = 0.06838 \text{ p.u.}$$

$$\text{The p.u. impedance of line} = \frac{50 \times 100}{(113.43)^2} = 0.3886 \text{ p.u.}$$

$$\text{The p.u. reactance of motor 1} = 0.2 \times \frac{100}{30} \times \left(\frac{30}{33}\right)^2 = 0.5509 \text{ p.u.}$$

$$\text{motor 2} = 0.2 \times \frac{100}{20} \times \left(\frac{30}{33}\right)^2 = 0.826 \text{ p.u.}$$

$$\text{motor 3} = 0.2 \times \frac{100}{50} \times \left(\frac{30}{33}\right)^2 = 0.3305 \text{ p.u.}$$

The reactance diagram for the system is shown in Fig. E1.1*b*.

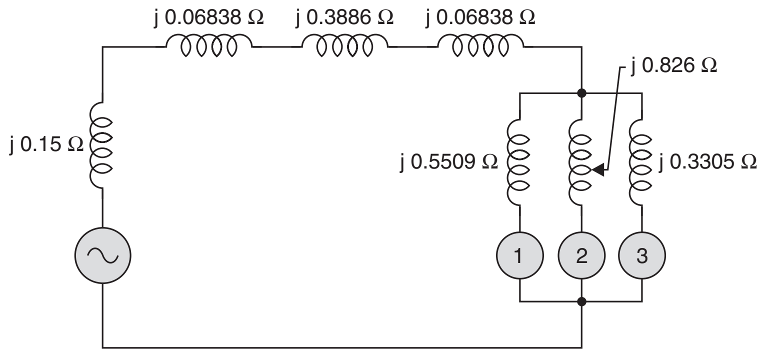


Fig. E1.1*b* Reactance diagram for Example 1.1.

PROBLEMS

1.1. Two generators rated at 10 MVA, 13.2 kV and 15 MVA, 13.2 kV are connected in parallel to a busbar. They feed supply to two motors of inputs 8 MVA and 12 MVA respectively. The operating voltage of motors is 12.5 kV. Assuming base quantities as 50 MVA and 13.8 kV draw the reactance diagram. The per cent reactance for generators is 15% and that for motors is 20%.

1.2. Three generators are rated as follows: Generator 1–100 MVA, 33 kV, reactance 10%; Generator 2–150 MVA, 32 kV, reactance 8%; Generator 3–110 MVA, 30 kV, reactance 12%. Determine the reactance of the generator corresponding to base values of 200 MVA, 35 kV.

1.3. A 3-bus system is given in Fig. P1.3. The ratings of the various components are listed below:

Generator 1 = 50 MVA, 13.8 kV, $X'' = 0.15$ p.u.

Generator 2 = 40 MVA, 13.2 kV, $X'' = 0.20$

Generator 3 = 30 MVA, 11 kV, $X'' = 0.25$

Transformer 1 = 45 MVA, 11 kV, Δ/110 kV Y, X = 0.1 p.u.

Transformer 2 = 25 MVA, 12.5 kV, Δ/115 kV Y, X = 0.15 p.u.

Transformer 3 = 40 MVA, 12.5 kV, Δ/115 kV Y, X = 0.1 p.u.

The line impedances are shown in Fig. P1.3. Determine the reactance diagram based on 50 MVA and 13.8 kV as base quantities in Generator 1.

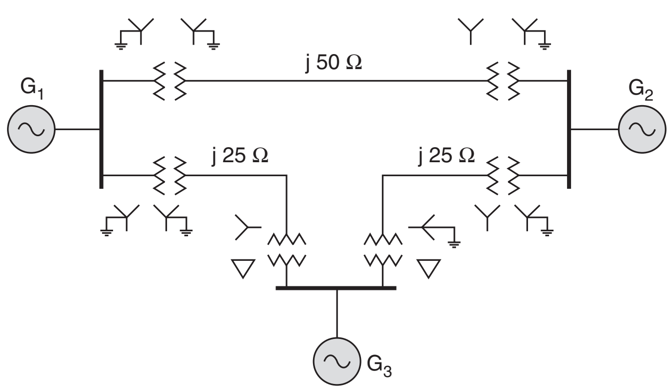


Fig. P1.3

BEE701 POWER SYSTEM ANALYSIS

UNIT I

POWER SYSTEM COMPONENTS

Power system analysis

The evaluation of power system is called as power system analysis

Functions of power system analysis

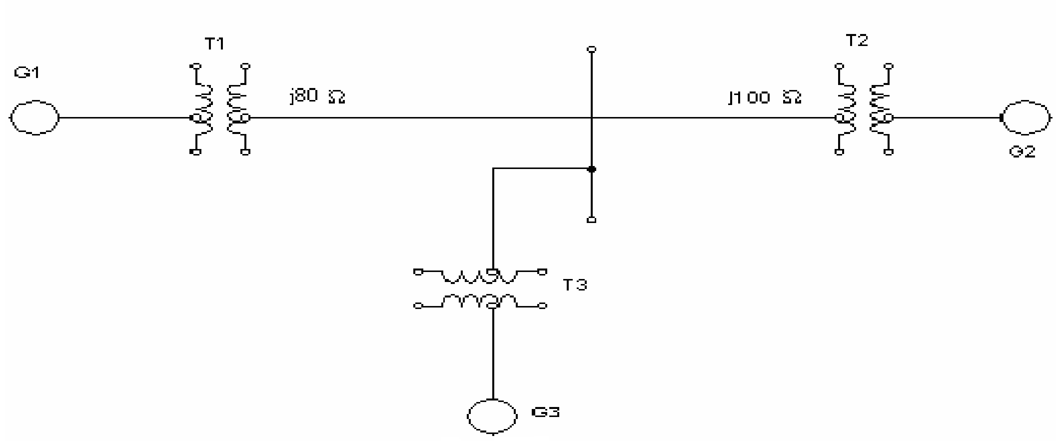
- To monitor the voltage at various buses, real and reactive power flow between buses.
- To design the circuit breakers.
- To plan future expansion of the existing system
- To analyze the system under different fault conditions
- To study the ability of the system for small and large disturbances (Stability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

COMPONENTS OF A POWER SYSTEM

1.Alternator
2.Power transformer
3.Transmission lines
4.Substation transformer
5.Distribution transformer
6.Loads

SINGLE LINE DIAGRAM

A single line diagram is diagrammatic representation of power system in which the components are represented by their symbols and interconnection between them are shown by a straight line9eventhough the system is three phase system0.The ratings and the impedances of the components are also marked on the single line diagram.



Purpose of using single line diagram

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

Per unit value.

The per unit value of any quantity is defined as the ratio of the actual value of the any quantity to the base value of the same quantity as a decimal.

per unit=actual value/base value

Need for base values

The components or various sections of power system may operate at different voltage and power levels. It will be convenient for analysis of power system if the voltage, power, current and impedance rating of components of power system are expressed with reference to a common value called base value.

Advantages of per unit system

i. Per unit data representation yields valuable relative magnitude information.
ii. Circuit analysis of systems containing transformers of various transformation ratios is greatly simplified.
iii. The p.u systems are ideal for the computerized analysis and simulation of complex power system problems.
iv. Manufacturers usually specify the impedance values of equivalent in per unit of the equipments rating. If the any data is not available, it is easier to assume its per unit value than its numerical value.

v. The ohmic values of impedances are refereed to secondary is different from the value as referee to primary. However, if base values are selected properly, the p.u impedance is the same on the two sides of the transformer.
vi. The circuit laws are valid in p.u systems, and the power and voltages equations are simplified since the factors of √3 and 3 are eliminated.

Change the base impedance from one set of base values to another set

Let Z=Actual impedance ,Ω

Zb=Base impedance ,Ω

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

The eqn 1 show that the per unit impedance is directly proportional to base megavoltampere and inversely proportional to the square of the base voltage.

Using Eqn 1 we can derive an expression to convert the p.u impedance expressed in one base value (old base) to another base (new base)

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

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

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

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

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

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

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

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

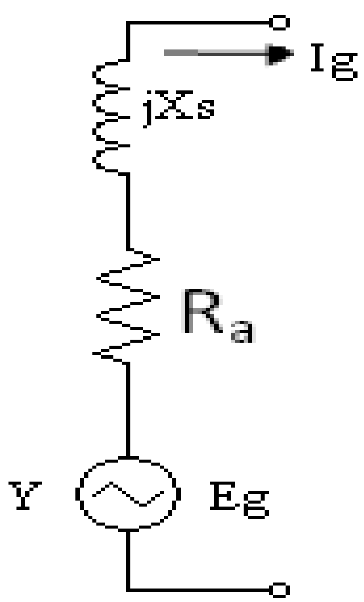
On substituting for Z from eqn 2 in eqn 3 we get

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

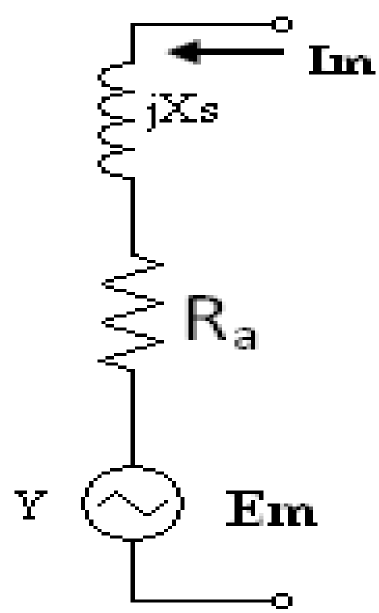
$$Z_{p.u,new} = Z_{pu,old} \times \left(\frac{kV_{b,old}}{kV_{b,new}}\right)^2 \times \left(\frac{MVA_{b,new}}{MVA_{b,old}}\right) \qquad (4)$$

The eqn 4 is used to convert the p.u.impedance expressed on one base value to another base

MODELLING OF GENERATOR AND SYNCHRONOUS MOTOR

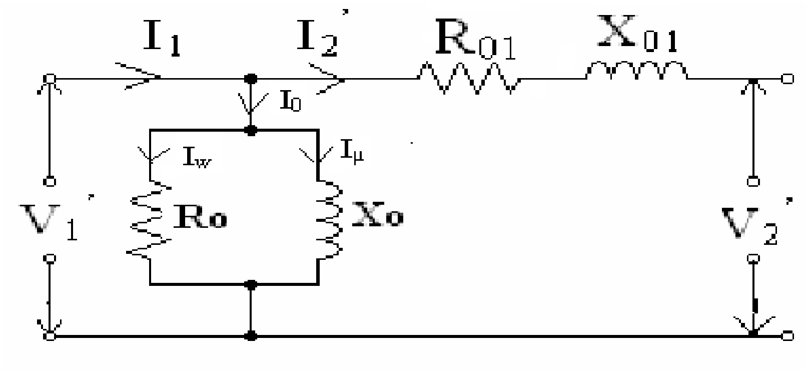


1Φ equivalent circuit of generator



1Φ equivalent circuit of synchronous motor

MODELLING OF TRANSFORMER

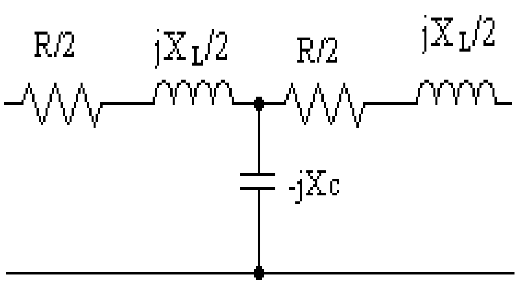


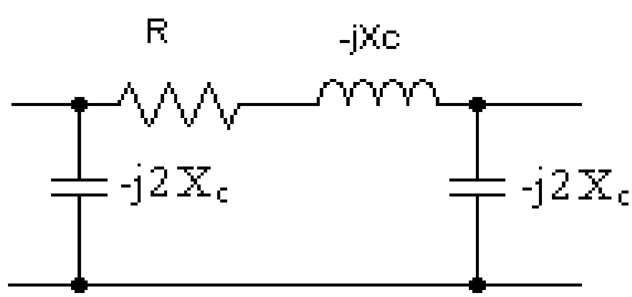
$$K = \frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2}$$

$$R_{01} = R_1 + R_2^{'} = R_1 + \frac{R_2}{K^2}$$ =Equivalent resistance referred to 1°

$$X_{01} = X_1 + X_2^{'} = X_1 + \frac{X_2}{K^2}$$ =Equivalent reactance referred to 1°

MODELLING OF TRANSMISSION LINE

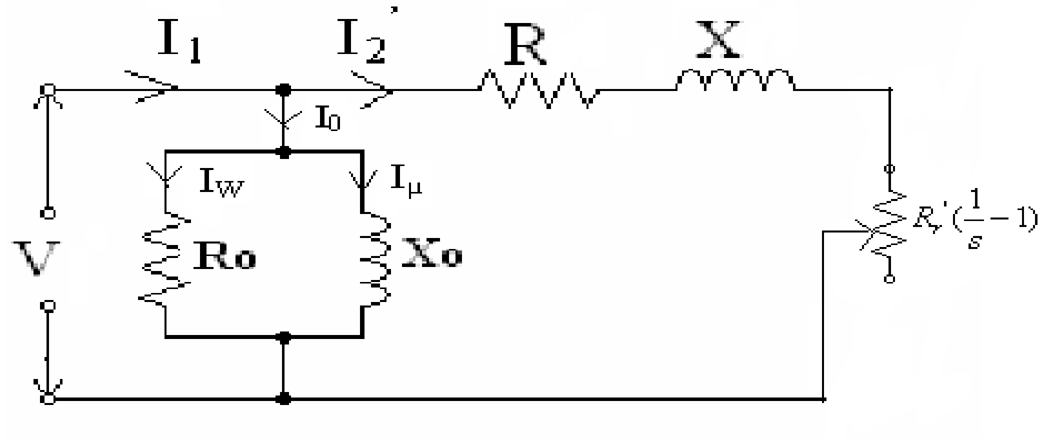




T type

Π type

MODELLING OF INDUCTION MOTOR



$R_r'\left(\frac{1}{s}-1\right)$ =Resistance representing load

$R = R_s + R_r'$ =Equivalent resistance referred to stator

$X = X_s + X_r'$ =Equivalent reactance referred to stator

Impedance diagram & approximations made in impedance diagram

The impedance diagram is the equivalent circuit of power system in which the various components of power system are represented by their approximate or simplified equivalent circuits. The impedance diagram is used for load flow studies.

Approximation:

(i) The neutral reactances are neglected.

(ii) The shunt branches in equivalent circuit of transformers are neglected.

Reactance diagram & approximations made in reactance diagram

The reactance diagram is the simplified equivalent circuit of power system in which the various components of power system are represented by their reactances. The reactance diagram can be obtained from impedance diagram if all the resistive components are neglected. The reactance diagram is used for fault calculations.

Approximation:

(i) The neutral reactances are neglected.

(ii) The shunt branches in equivalent circuit of transformers are neglected.

(iii) The resistances are neglected.

(iv) All static loads are neglected.

(v) The capacitance of transmission lines are neglected.

PROCEDURE TO FORM REACTANCE DIAGRAM FROM SINGLE LINE DIAGRAM

1.Select a base power kVA_b or MVA_b

2.Select a base voltage kV_b

3. The voltage conversion is achieved by means of transformer kV_b on LT section= kV_b on HT section x LT voltage rating/HT voltage rating

4. When specified reactance of a component is in ohms

p.u reactance=actual reactance/base reactance

specified reactance of a component is in p.u

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

EXAMPLE

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.

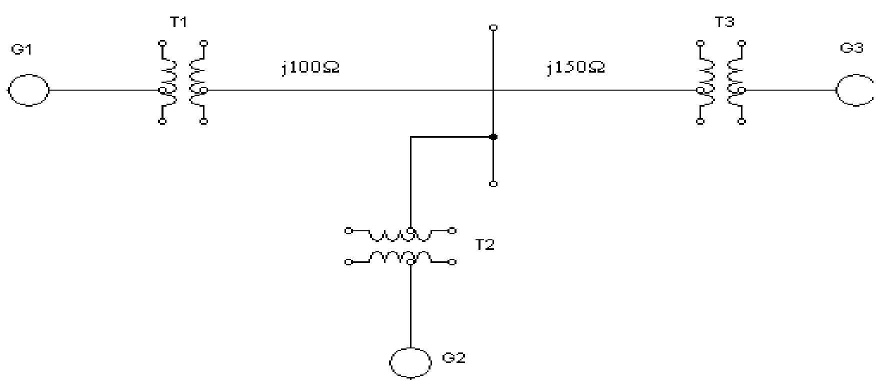


Fig 1

SOLUTION

Base megavoltampere, $MVA_{b,new}$*=50 MVA*

Base kilovolt $kV_{b,new}$*=11 kV (generator side)*

FORMULA

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

$kV_{b,old}$*=11 kV* $kV_{b,new}$*=11 kV*

$MVA_{b,old}$*= 20 MVA* $MVA_{b,new}$*=50 MVA*

$X_{p.u,old}$*=0.25p.u*

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

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

Reactance of Transformer T1

$kV_{b,old}$*=11 kV* $kV_{b,new}$*=11 kV*

$MVA_{b,old}$*= 25 MVA* $MVA_{b,new}$*=50 MVA*

$X_{p.u,old}$*=0.15p.u*

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

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

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

Actual Impedance X_{actual}*= 100ohm*

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

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

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

Reactance of Transformer T2

$kV_{b,old}=127 * \sqrt{3}\ kV\ \ =220\ kV$ $kV_{b,new}=220\ kV$

$MVA_{b,old}= 10 * 3=30\ MVA$ $MVA_{b,new}=50\ MVA$

$X_{p.u,old}=0.15 p.u$

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

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

Reactance of Generator G2

It is connected to the LT side of the Transformer T2

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

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

$kV_{b,old}=18\ kV$ $kV_{b,new}=18\ kV$

$MVA_{b,old}= 30\ MVA$ $MVA_{b,new}=50\ MVA$

$X_{p.u,old}=0.25\ p.u$

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

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

Reactance of Transformer T3

$kV_{b,old}=20\ kV$ $kV_{b,new}=20\ kV$

$MVA_{b,old}= 20\ MVA$ $MVA_{b,new}=50\ MVA$

$X_{p.u,old}$=0.15p.u

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

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

Reactance of Generator G3

It is connected to the LT side of the Transformer T3

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

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

$kV_{b,old}$=20 kV

$kV_{b,new}$=20 kV

$MVA_{b,old}$= 30 MVA

$MVA_{b,new}$=50 MVA

$X_{p.u,old}$=0.21 p.u

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

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

2) Draw the reactance diagram for the power system shown in fig 4 .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%

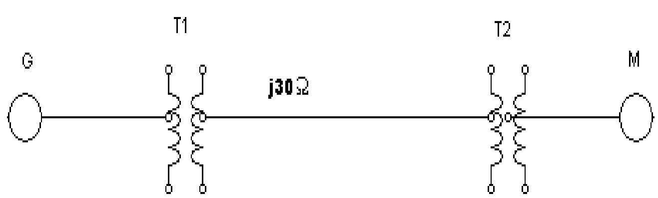


Fig 4

Solution

Base megavoltampere,$MVA_{b,new}$*=50 MVA*

Base kilovolt $kV_{b,new}$*=230 kV (Transmission line side)*

FORMULA

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

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

$kV_{b,old}$*=20 kV* $kV_{b,new}$*=18 kV*

$MVA_{b,old}$*= 20 MVA* $MVA_{b,new}$*=50 MVA*

$X_{p.u,old}$*=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

$kV_{b,old}$*=18 kV* $kV_{b,new}$*=18 kV*

$MVA_{b,old}$*= 25 MVA* $MVA_{b,new}$*=50 MVA*
$X_{p.u,old}$*=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 $X_{actual} = j30\ ohm$

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

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

Reactance of Transformer T2

$kV_{b,old} = 230\ kV$ $\qquad$ $kV_{b,new} = 230\ kV$

$MVA_{b,old} = 45\ MVA$ $\qquad$ $MVA_{b,new} = 50\ MVA$

$X_{p.u,old} = 0.15 p.u$

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

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

Reactance of Motor M2

It is connected to the LT side of the Transformer T2

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

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

$kV_{b,old} = 13.2\ kV$ $\qquad$ $kV_{b,new} = 13.8\ kV$

$MVA_{b,old} = 35\ MVA$ $\qquad$ $MVA_{b,new} = 50\ MVA$

$X_{p.u,old} = 0.25\ p.u$

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

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