Advantages of per unit (p.u) system

1. Calculations are Simplified.
2. The characteristics of machines (generators, transformers, motors etc.) when described in per unit system are Specified by almost the same number, regardless of the rating of the machines. Thus per unit system provides a method of Comparision.
3. For circuits Connected by transformers, per unit system is particularly Suitable. By choosing Suitable base KV's for the circuits the per unit reactance remains the same, referred to either side of the transformer. Therefore, the Various circuits can be Connected in the reactance diagram.

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Per unit System Representation

→ In a power system different power equipment with different voltage and power levels are Connected together through various stepup or step down transformers. However the presence of Various voltage and power levels Causes problem in finding out the Currents (or Voltages) at different points in the network. To alleviate this problem, all the power system quantities are Converted into a uniform normalized platform. This is called the per unit system.

→ In a per unit system each system variable or quantity is normalized with respect to its own base value. The units of these normalized values are per unit (abbreviated as P.u).

The base quantities choosen are :

- VA base (S_{base}) : This is the three phase apparent power (VA) base that is Common to the entire circuit
- Voltage base (V_{base}) : This is the line-to-line base Voltage. This quantity is not uniform for the entire circuit but gets changed by the turns ratio of the transformer.

⇒ **Per unit** : The per unit value of any quantity is defined as the ratio of the actual value of the quantity in any unit to the base or reference value in the same unit.

$$\text{P.u of any Quantity} = \frac{\text{Actual Value of quantity in any unit}}{\text{Base Value or reference Value in the same unit}}$$

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Comparision between per unit and Absolute System :-

Per unit	Absolute system
1) No. of equation is only one	1) No. of equations = No. of voltage levels
2) operating time is very less for calculations	2) operating time is more for calculations.
3) No need of transformer transformation ratio.	3) Required transformation ratio.
4) Computer memory required is very less	4) Memory required is more.
5) Calculated all the parameters simultaneously	5) Calculated step by step.

Determination of Base Impedances :

Voltage, Current, volt-amperes and impedances are so related that selection of base values for any two of them determines the base values of the remaining two. For Example for a single phase circuit we have the following relations

$$S_b = V_b I_b \quad \text{— (1)}$$

$$Z_b = \frac{V_b}{I_b} \quad \text{— (2)}$$

Where, S_b, V_b, I_b and Z_b represent base power, base voltage, base current, base Impedance expressed in Volt-amp, volts, amperes and ohms respectively.

Thus from eqns (1) & (2), if any two of the four Quantities are specified, the remaining two may be determined without any problem.

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Let KVA_b and KV_b be the base KVA and base KV, then

$$\text{P.u KV} = \frac{\text{Actual KV}}{\text{Base KV}} = \frac{KV_{actual}}{KV_{base}} \quad \text{— (3)}$$

$$\text{Base Current}, \; I_b = \frac{\text{Base KVA}}{\text{Base KV}} = \frac{KVA_{base}}{KV_{base}} \text{ amperes} \quad \text{— (4)}$$

$$\text{P.u current}, \; I_{p.u} = \frac{\text{Actual Current}}{\text{Base Current}}$$

$$I_{p.u} = \frac{\text{Actual current}}{\left(\frac{KVA_{base}}{KV_{base}}\right)}$$

$$I_{p.u} = \frac{\text{Actual current}}{KVA_{base}} \times KV_{base} \quad \text{— (5)}$$

$$\text{Base Impedance}, \; Z_B = \frac{\text{Base KV} \times 1000}{\text{Base Current}}$$

$$= \frac{KV_{base}}{\left(\frac{KVA_{base}}{KV_{base}}\right)} \times 1000.$$

$$= KV_b \times \frac{KV_b}{KVA_b} \times 1000.$$

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$$Z_b = \frac{(KV_b)^2 \times 1000}{KVA_b} \text{ ohms.} \quad \text{——— (6).}$$

$$Z_{p.u} = \frac{\text{Actual Impedance}}{\text{Base Impedance}}$$

$$= \frac{\text{Actual Impedance}}{\left(\frac{(KV_b)^2 \times 1000}{KVA_b}\right)}$$

$$Z_{p.u} = \text{Actual Impedance} \times \frac{KVA_b}{(KV_b)^2 \times 1000}$$

→ (7)

Change of Base :

Normally the per unit Impedance of various components corresponding to its own rating voltage and KVA are given and since we choose one common base KVA and base KV for the whole system, therefore, it becomes imperative to determine the per unit Impedance of the various equipments corresponding to the common base KV and base KVA.

If the Individual quantities are $Z_{p.u\,old}$, KVA_{old}, KV_{old} and the common base quantities are $Z_{p.u\,new}$, KVA_{new}, KV_{new}, then making use of equation (7), according to which per unit Impedance is directly proportional to the base KVA and Inversely proportional to the square of the base KV, we have

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$$Z_{p.u.o} = Z_{\Omega} \cdot \frac{(MVA)_{bo}}{(KV)^2_{bo}} \quad \text{———} \quad (8)$$

$$Z_{p.u\,new} = Z_{\Omega} \cdot \frac{(MVA)_{bn}}{(KV)^2_{bn}} \quad \text{———} \quad (9)$$

$$\frac{\text{eqn } (9)}{\text{eqn } (8)} \Rightarrow \frac{Z_{p.u\,new}}{Z_{p.u.old}} = \frac{(MVA)_{bn}}{(MVA)_{bo}} \cdot \frac{(KV)^2_{bo}}{(KV)^2_{bn}}$$

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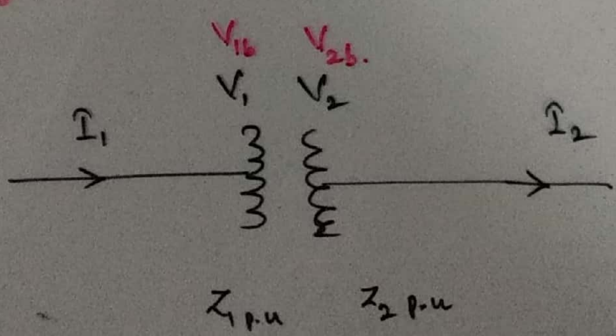
$$Z_{p.u\,new} = Z_{p.u\,old} \cdot \frac{(MVA)_{bn}}{(MVA)_{bo}} \cdot \frac{(KV)^2_{bo}}{(KV)^2_{bn}}$$

↳ valid for R, X, Z.

Transformer :



$$K = \frac{V_2}{V_1} = \frac{I_1}{I_2} = \frac{V_{2b}}{V_{1b}}.$$

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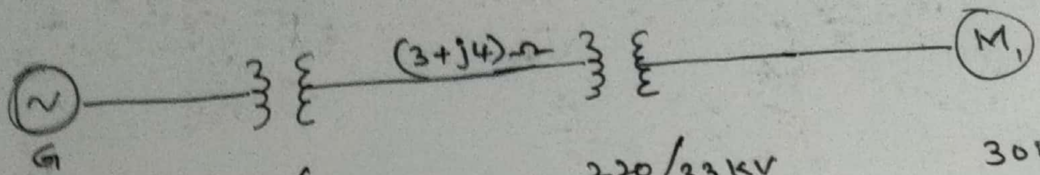
Ex :- find the p.u reactances for given SLD.

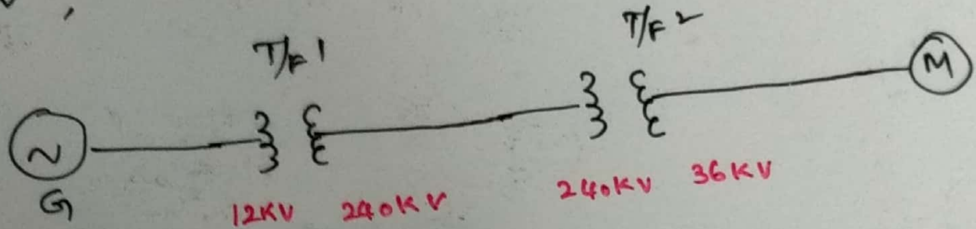


G	T/F 1	T/F 2	M
12KV	11/220KV	220/33KV	30MVA
50MVA	40MVA	30 MVA	30KV
5%	10%	8%	10%

Sol :

Let base values = 50MVA and 12KV.

then,



base,
12KV
50MVA

Gen : $X_{pu_n} = X_{pu_o} \times \frac{(MVA)_n}{(MVA)_o} \times \left(\frac{KV_o}{KV_n}\right)^2$

$X_{p.u} = 0.05 \times \left(\frac{50}{50}\right) \times \left(\frac{12}{12}\right)^2$

$X_{p.u} = 0.05$

T/F 1 :

$X_{p.u} = 0.01 \times \left(\frac{50}{40}\right) \times \left(\frac{11}{12}\right)^2$

(or)

$= 0.01 \times \frac{50}{40} \times \left(\frac{220}{240}\right)^2$

$= 0.01 p.u$

$Z_{p.u\,line} = \frac{Z_\Omega \cdot (MVA)_b}{(KV)_b^2} = \frac{(3+j4) \times 50}{(240)^2}$

$= (2.60 \times 10^{-3} + j3.4 \times 10^{-3})$ p.u

T/F 2 :

$X_{p.u} = 0.08 \times \frac{50}{30} \times \left(\frac{33}{36}\right)^2$

(or)

$= 0.08 \times \frac{50}{30} \times \left(\frac{220}{240}\right)$

$= 0.08$

$X_{p.u\,motor} = 0.10 \times \left(\frac{50}{30}\right) \times \left(\frac{30}{36}\right)^2$

$= 0.$ [illegible] p.u.

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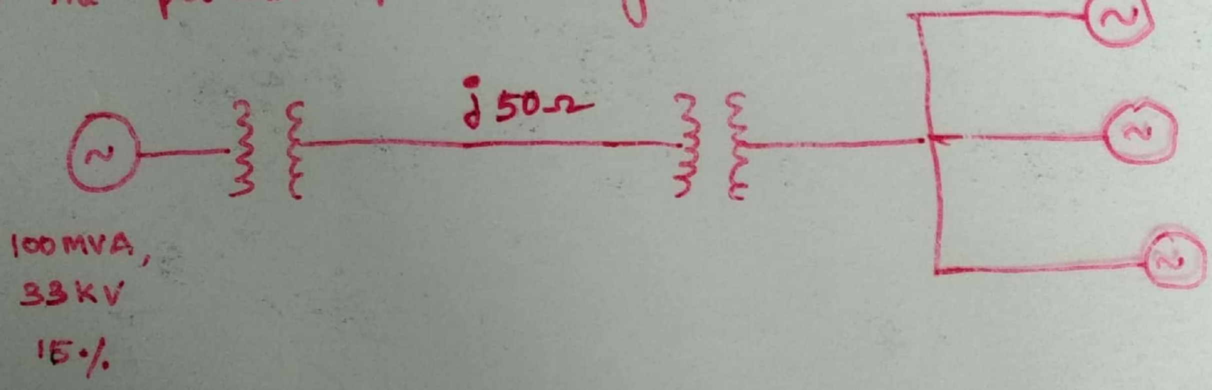
Q: 100MVA, 33KV 3-phase generator has a sub-transient reactance of 16%. The generator is connected to the motors through a transmission line and transformers as shown below. The motor have rated inputs of 20MVA, 30MVA and 40MVA at 30KV with 17% subtransient reactance. The 3-phase transformers are rated at 110MVA, 32KV Δ/110KV Y with leakage reactance 9%. 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. Draw the per unit equivalent diagram.

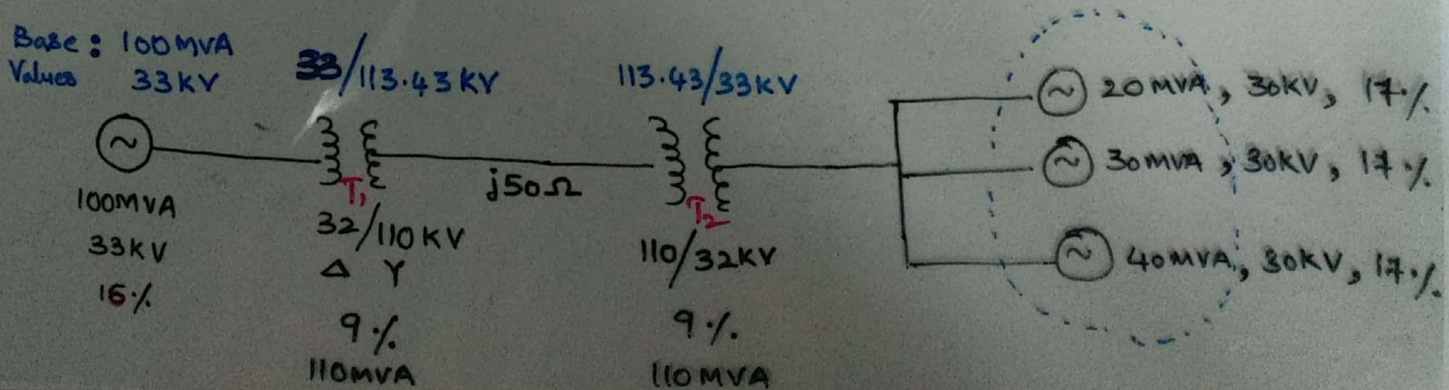


Sol: Taking generator ratings as base values.

i.e, MVA_b = 100MVA

KV_b = 33KV

p.u reactance of generator = j0.16



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The base value of the line,

$$KV_{bL} = 33 \times \frac{110}{32} = 113.4375\ KV$$

The base value of the motor

$$KV_{bM} = 113.4375 \times \frac{32}{110} = 33KV.$$

P.u reactance of T/F 1 :

$$X_{p.u\,n} = X_{p.u\,o} \times \frac{(MVA)_n}{(MVA)_o} \times \left(\frac{KV_o}{KV_n}\right)^2$$

$$\Rightarrow \quad X_{p.u\,T_1} = 0.09 \times \left(\frac{100}{110}\right) \times \left(\frac{110}{113.43}\right)^2$$

$$X_{p.u\,T_1} = 0.0769$$

p.u reactance of T/F 2 :

$$X_{p.u\,T_2} = 0.09 \times \left(\frac{100}{110}\right) \times \left(\frac{32}{33}\right)^2$$

$$X_{p.u\,T_2} = 0.0769$$

p.u react of motor 1 : $X_{p.u\,M_1} = 0.17 \times \left(\frac{100}{20}\right) \times \left(\frac{30}{33}\right)^2$

$$X_{p.u\,M_1} = 0.702$$

P.u reactance of motor 2 : $X_{p.u\,M_2} = 0.17 \times \left(\frac{100}{30}\right) \times \left(\frac{30}{33}\right)^2$

$$X_{p.u\,M_2} = 0.468$$

P.u reactance of motor 3 : $X_{p.u\,M_3} = 0.17 \times \left(\frac{100}{40}\right) \times \left(\frac{30}{33}\right)^2$

$$X_{p.u\,M_3} = 0.351$$

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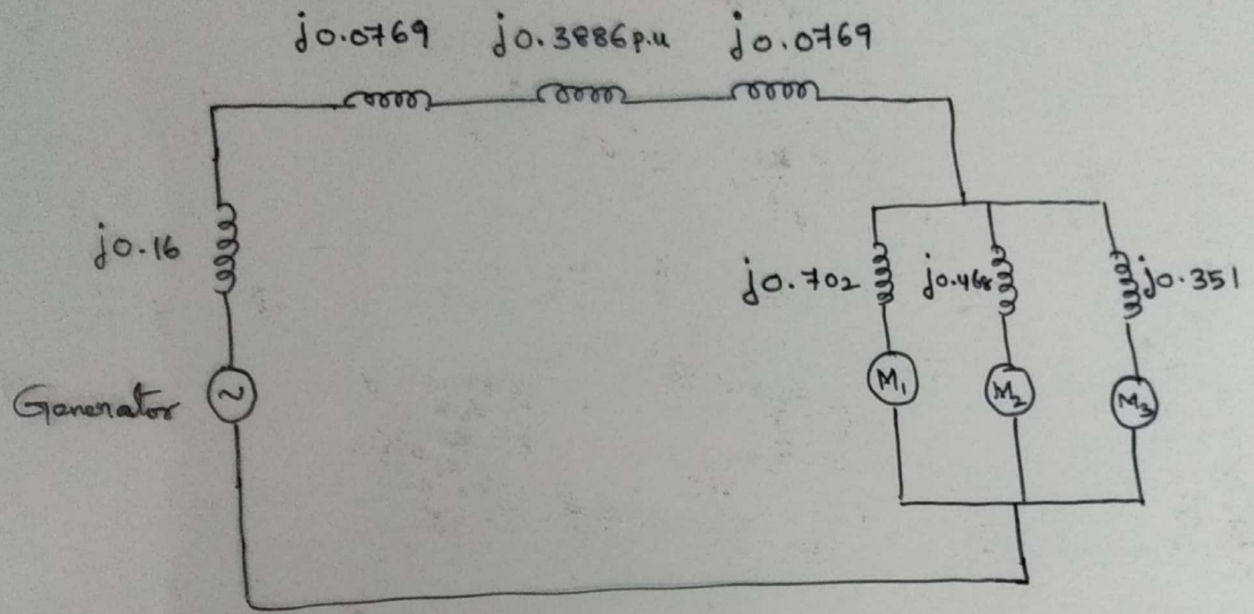
P.u Impedance of line :

$$Z_{p.u\,L} = Z_{(\Omega)} \times \frac{(MVA_b)}{(KV_b)^2}$$

$$= j50 \times \frac{100}{(113.4375)^2} = 0.3886 \text{ p.u}$$



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