Power System Performance

OBJECTIVE QUESTIONS FROM AMIE EXAMS

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Per Unit Method of Calculation

Because of various advantages involved, it is customary in power system analysis calculations to use impedances, currents, voltages, and powers in per-unit values (which are scaled or normalized values) rather than in physical values of ohms, amperes, kilovolts, and megavolt-amperes (MVA; or megavars, or megawatts).

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

Per unit value = Actual value/Base value

ADVANTAGES PER-UNIT METHOD

- Network analysis is greatly simplified since all impedances of a given equivalent circuit can directly be added together regardless of the system voltages.
- It eliminates the 3 multiplications and divisions that are required when balanced three phase systems are represented by per-phase systems.
- Usually, the impedance of an electrical apparatus is given in percent or per unit by its manufacturer on the basis of its nameplate ratings.
- Differences in operating characteristics of many electrical apparatus can be estimated by a comparison of their constants expressed in per units.
- Average machine constants can easily be obtained.
- The use of per-unit quantities is more convenient in calculations involving digital computers.

SINGLE PHASE SYSTEM

In a single phase system, suppose the base MVA and base kV ratings are given, then

$$Base\,current\,(kA) = \frac{base\,MVA}{base\,kV}$$

$$Base\,impedance(reactance) = \frac{base\,kV}{base\,kA} = \frac{base\,kV}{base\,MVA / base\,kV} = \frac{(base\,kV)^2}{base\,MVA}$$

Per unit impedance of a circuit element = $\dfrac{actual\,impedance}{base\,impedance} = \dfrac{Z(ohms)}{base\,kA^2 / base\,MVA}$

Example

A single-phase transformer is rated at 110/440 V, 2.5 kVA, and its leakage reactance measured from L.T. side is 0.06 Ω. Determine the leakage reactance in p.u.

Solution

Given actual leakage reactance = 0.06 Ω

Base impedance

It is obtained as

$$\frac{base\,kV^2}{base\,MVA} = \frac{(110x10^{-3})^2}{2.5x10^{-3}} = 4.84\Omega$$

Per unit leakage reactance

It is obtained as

= actual reactance/base reactance

= 0.06/4.84 = 0.0124 p.u.

THREE-PHASE SYSTEMS

In a three-phase system, suppose the base MVA and the line-to-line base kV (L-L) ratings are given.

Then, for star connection,

$$Base\,voltage\,/\,phase = \frac{base\,kV\,(L-L)}{\sqrt{3}}$$

$$Base\,current\,/\,phase = \frac{base\,MVA(3\phi)}{\sqrt{3}\,x\,base\,kV\,(L-L)}$$

$$Base\,impedance\,/\,phase = \frac{[base\,kV\,(L-L)]^2}{base\,MVA(3\phi)}$$

Per unit impedance of a circuit element

= actual impedance/base impedance

$$= \frac{Z(in\,\Omega)\,x\,base\,MVA(3\phi)}{[base\,kV\,(L-L)]^2}$$

Change of base value

$$Z_{pu(new)} = Z_{pu(given)}\left[\frac{base\,kV_{given}}{base\,kV_{new}}\right]^2 x \left[\frac{base\,MVA_{new}}{base\,MVA_{given}}\right]$$

Also remember following formula

Base kV on LT side of transformer

$$= base\ kV\ on\ HT\ side\ x\left[\frac{LT\,voltage\,rating}{HT\,voltage\,rating}\right]$$

Example

If a 250MVA,11/400 KV, Three –Phase power Transformer has leakage reactance of 0.05 pu on the base of 250 MVA and the primary voltage of 11 KV,then the actual leakage reactance of the Transformer refereed to the secondary side of 400KV is ——.

Solution

Per unit impedance of a circuit element

= actual impedance/base impedance

$$= \frac{Z(in\,\Omega)\,x\,base\,MVA(3\phi)}{[base\,kV\,(L-L)]^2}$$

From this

$$Z = 0.05\left(\frac{400^2}{250}\right) = 32\,\text{pu}$$

Example

The Direct axis reactance of a synchronous generator is given as 0.4 pu based on the generators name plate rating of 10 KV, 75MVA. The base for calculation is 11KV, 100 MVA. What is the pu value of Generator on the new base?

Solution

We know $$X_{pu(new)} = X_{pu(given)}\left[\frac{base\,kV_{given}}{base\,kV_{new}}\right]^2 x \left[\frac{base\,MVA_{new}}{base\,MVA_{given}}\right]$$

$$\therefore \quad 0.4\left(\frac{100}{75}\right)\left(\frac{10}{11}\right)^2 = 0.44\ pu$$

Example

Given

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 new per unit reactance of generators corresponding to the base values of 200 MVA and 35 kV.

Solution

Reactance of generator 1

Given

$X_{pu(given)}$ = 10% = 0.1 pu

MVA_{given} = 100 MVA

MVA_{new} = 200 MVA

kV_{given} = 33 kV

kV_{new} = 35 kV

Using the formula

$$Z_{pu(new)} = Z_{pu(given)}\left[\frac{base\,kV_{given}}{base\,kV_{new}}\right]^2 x\left[\frac{base\,MVA_{new}}{base\,MVA_{given}}\right]$$

$$= 0.1\left[\frac{33}{35}\right]^2\left[\frac{200}{100}\right] = 0.178\,pu$$

Reactance of generator 2

Given

$X_{pu(given)}$ = 8% = 0.08 pu

MVA_{given} = 150 MVA

MVA_{new} = 200 MVA

kV_{given} = 32 kV

kV_{new} = 35 kV

Using the formula

$$Z_{pu(new)} = Z_{pu(given)}\left[\frac{base\,kV_{given}}{base\,kV_{new}}\right]^2 x\left[\frac{base\,MVA_{new}}{base\,MVA_{given}}\right]$$

$$= 0.08\left[\frac{32}{35}\right]^2\left[\frac{200}{150}\right] = 0.089\,pu$$

Reactance of generator 3

Given

$X_{pu(given)}$ = 12% = 0.12 pu

MVA_{given} = 110 MVA

MVA_{new} = 200 MVA

kV_{given} = 30 kV

$kV_{new} = 35$ kV

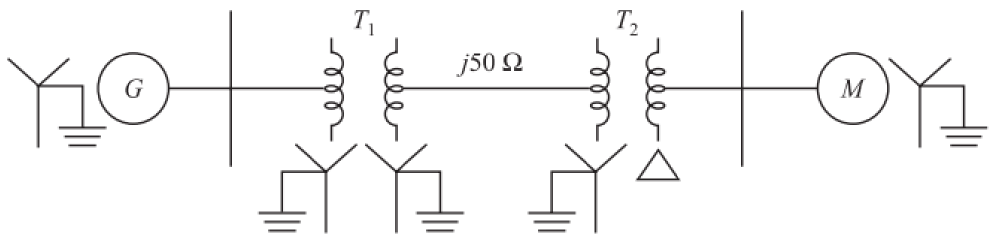
Using the formula

$$Z_{pu(new)} = Z_{pu(given)} \left[\frac{base\,kV_{given}}{base\,kV_{new}}\right]^2 x \left[\frac{base\,MVA_{new}}{base\,MVA_{given}}\right]$$

$$= 0.12\left[\frac{30}{35}\right]^2\left[\frac{200}{110}\right] = 0.16\,pu$$

Example

Draw the per unit reactance diagram for the power system shown in given figure.



Neglect the resistance and use a base of 100 MVA, 220 kV in a 50 Ω line. The ratings of the generator, motor and transformers are as follows:

G : 40 MVA, 25 kV, X'' = 20%

M : 50 MVA, 11 kV, X'' = 30%

T1 : 40 MVA, 33Y/220Y kV, X = 15%

T2 : 30 MVA, 11 D/220Y kV, X = 15%

Load : 11 kV, 50 MW + j68 MVAR

Determine the new per unit values of reactance of transmission line, and new values of per unit reactance of transformer T1 , generator G, transformer T2 and motor M.

Solution

Reactance of transmission line

Actual reactance = 50 Ω

Base reactance = $\frac{kV_{new}^2}{MVA_{new}} = \frac{220^2}{100} = 484\Omega$

Base reactance = $\frac{actual\,impedance}{base\,impedance}$

$$= \frac{Z(ohms)}{base\,kA_{new}^2 / base\,MVA_{new}}$$

$$= \frac{50}{220^2/100} = 0.1033\text{p.u.}$$

Reactance of transformer T1 (primary side)

Given data

$X_{pu(given)} = 0.15$ pu

$MVA_{given} = 40$

$MVA_{new} = 100$

$kV_{given} = 33$

$kV_{new} = ?$

Base kV on LT side of transformer

$$= base\ kV\ on\ HT\ side\ x\left[\frac{LT\ voltage\ rating}{HT\ voltage\ rating}\right]$$

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

This is kV_{new}.

Now, $$X_{pu(new)} = X_{pu(given)}\left[\frac{base\,kV_{given}}{base\,kV_{new}}\right]^2 x\left[\frac{base\,MVA_{new}}{base\,MVA_{given}}\right]$$

$$= 0.15\left(\frac{33}{33}\right)\left(\frac{100}{40}\right) = 0.375\ pu$$

Reactance of the generator G

Given data

$X_{pu(given)} = 0.2$ pu

$MVA_{given} = 40$

$MVA_{new} = 100$

$kV_{given} = 25$

$kV_{new} = 33$

Now, $$X_{pu(new)} = X_{pu(given)}\left[\frac{base\,kV_{given}}{base\,kV_{new}}\right]^2 x\left[\frac{base\,MVA_{new}}{base\,MVA_{given}}\right]$$

$$= 0.2\left(\frac{25}{33}\right)x\left(\frac{100}{40}\right) = 0.278\ pu$$

Reactance of transformer T2 (primary side)

Given data

$X_{pu(given)} = 0.15$ pu

$MVA_{given} = 30$

$MVA_{new} = 100$

$kV_{given} = 11$

$kV_{new} = ?$

Base kV on LT side of transformer

$$= base\ kV\ on\ HT\ side\ x\left[\frac{LT\ voltage\ rating}{HT\ voltage\ rating}\right]$$

$$= 220x\frac{11}{220} = 11kV \text{ (This is } kV_{new}\text{)}$$

Now, $$X_{pu(new)} = X_{pu(given)}\left[\frac{base\,kV_{given}}{base\,kV_{new}}\right]^2 x\left[\frac{base\,MVA_{new}}{base\,MVA_{given}}\right]$$

$$= 0.15\left(\frac{11}{11}\right)^2\left(\frac{100}{30}\right) = 0.5\,pu$$

Reactance of motor M

Given data

$X_{pu(given)} = 0.3$ pu

$MVA_{given} = 50$

$MVA_{new} = 100$

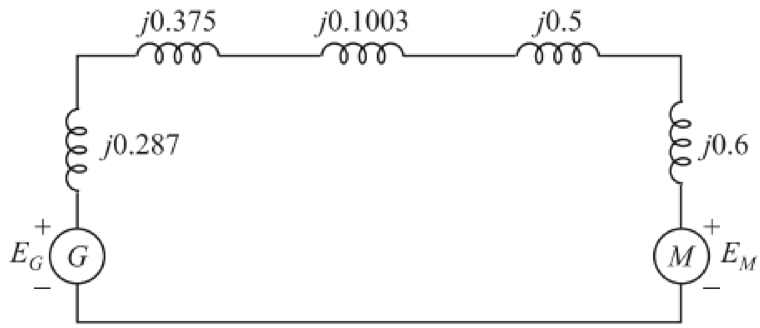
$kV_{given} = 11$

$kV_{new} = 11$

Now, $$X_{pu(new)} = X_{pu(given)}\left[\frac{base\,kV_{given}}{base\,kV_{new}}\right]^2 x\left[\frac{base\,MVA_{new}}{base\,MVA_{given}}\right]$$

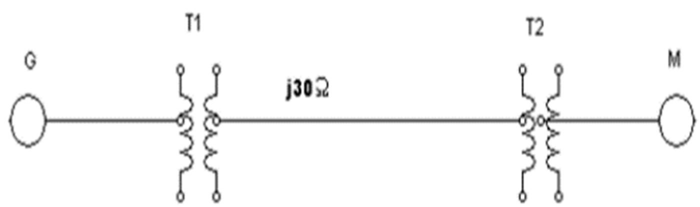
$$= 0.3\left(\frac{11}{11}\right)^2\left(\frac{100}{50}\right) = 0.6\,pu$$

Reactance diagram



Problem

Draw the reactance diagram for the power system shown in figure.



Use a base of50 MVA , 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%

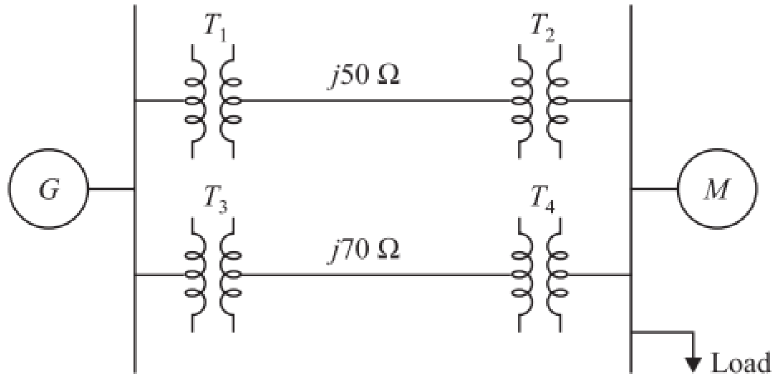
T2 = 45 MVA, 230/13.8 kV (Y/Δ), X=15%

Answer: Reactances are

$G = j0.167$ pu; $T_1 = j0.2$ pu; $TL_{30\Omega} = j0.028$ pu; $T_2 = j0.166$ pu and $M_2 = j0.326$ pu

Example

The single line diagram of a three-phase power system is shown in figure. Select a common base of 100 MVA and 13.8 kV on the generator side. Draw the per unit impedance diagram with new values per unit reactances.



G : 90 MVA, 13.8 kV, X = 18%

T1 : 50 MVA, 13.8/220 kV, X = 10%

T2 : 50 MVA, 220/11 kV, X = 10%

T3 : 50 MVA, 13.8/132 kV, X = 10%

T4 : 50 MVA, 132/11 kV, X = 10%

M : 80 MVA, 10.45 kV, X = 20%

Load : 57 MVA, 0.8 p.f lagging at 10.45 kV

Line 1=j50 Ω;

Line 2 = j70 Ω

Solution

Reactance of generator G1

Given data

$X_{pu(given)} = 0.18$ pu

$MVA_{given} = 90$

$MVA_{new} = 100$

$kV_{given} = 13.8$

$kV_{new} = 13.8$

Now $$X_{pu(new)} = X_{pu(given)}\left[\frac{base\,kV_{given}}{base\,kV_{new}}\right]^2 x \left[\frac{base\,MVA_{new}}{base\,MVA_{given}}\right]$$

$\therefore$ $$X_{pu(new)} = 0.18\left(\frac{13.8}{13.8}\right)^2\left(\frac{100}{90}\right) = j0.2\,pu$$

Reactance of transformer T1 (primary side)

Given data

$X_{pu(given)}$ = 0.1 pu

MVA_{given} = 50

MVA_{new} = 100

kV_{given} = 13.8

kV_{new} = 13.8

Now $$X_{pu(new)} = X_{pu(given)}\left[\frac{base\,kV_{given}}{base\,kV_{new}}\right]^2 x\left[\frac{base\,MVA_{new}}{base\,MVA_{given}}\right]$$

∴ $$X_{pu(new)} = 0.1\left(\frac{13.8}{13.8}\right)\left(\frac{100}{50}\right) = j0.2\,pu$$

Reactance of transmission line j50 Ω

Actual reactance = 50 Ω

Base kV on LT side of transformer, T1

$$= base\ kV\ on\ HT\ side\ x\left[\frac{LT\ voltage\,rating}{HT\ voltage\,rating}\right]$$

$$= 13.8x\frac{220}{13.8} = 220\,kV$$ (This is kV_{new})

Basereactance = $\frac{actual\,reac\tan ce}{base\,reac\tan ce}$

$$= \frac{Z(ohms)}{base\,kA_{new}^2\,/\,base\,MVA_{new}} = \frac{50}{220^2\,/100} = 0.1033\,pu$$

Reactance of transformer T2 (secondary side)

Given data

$X_{pu(given)}$ = 0.1 pu

MVA_{given} = 50

MVA_{new} = 100

kV_{given} = 220

kV_{new} = 220

Now $$X_{pu(new)} = X_{pu(given)}\left[\frac{base\,kV_{given}}{base\,kV_{new}}\right]^2 x\left[\frac{base\,MVA_{new}}{base\,MVA_{given}}\right]$$

$$X_{pu(new)} = 0.1\left(\frac{220}{220}\right)^2\left(\frac{100}{50}\right) = j0.2\,pu$$

Reactance of transformer T3 (primary side)

Given data

$X_{pu(given)}$ = 0.1 pu

MVA_{given} = 50

MVA_{new} = 100

kV_{given} = 13.8

kV_{new} = 13.8

Now $$X_{pu(new)} = X_{pu(given)}\left[\frac{base\,kV_{given}}{base\,kV_{new}}\right]^2 x\left[\frac{base\,MVA_{new}}{base\,MVA_{given}}\right]$$

∴ $$X_{pu(new)} = 0.1\left(\frac{13.8}{13.8}\right)^2\left(\frac{100}{50}\right) = j0.2\ pu$$

Reactance of transmission line j70 Ω

Actual reactance = 70 Ω

Base kV on LT side of transformer, T3

$$= base\ kV\ \ on\ HT\ \ side\ x\left[\frac{LT\,voltage\,rating}{HT\,voltage\,rating}\right]$$

$$= 13.8x\frac{132}{13.8} = 132\,kV$$ (This is kV_{new})

Basereactance = $\frac{actual\,reac\tan ce}{base\,reac\tan ce}$

$$= \frac{Z(ohms)}{base\,kA_{new}^2\,/\,base\,MVA_{new}} = \frac{70}{132^2\,/\,100} = 0.4017\ pu$$

Reactance of transformer T4 (secondary side)

Given data

$X_{pu(given)}$ = 0.1 pu

MVA_{given} = 50

MVA_{new} = 100

kV_{given} = 132

kV_{new} = 132

Now $$X_{pu(new)} = X_{pu(given)}\left[\frac{base\,kV_{given}}{base\,kV_{new}}\right]^2 x\left[\frac{base\,MVA_{new}}{base\,MVA_{given}}\right]$$

$$\therefore \quad X_{pu(new)} = 0.1\left(\frac{132}{132}\right)^2\left(\frac{100}{50}\right) = j0.2\,pu$$

Reactance of motor M

Given data

$X_{pu(given)}$ = 0.2 pu

MVA_{given} = 80

MVA_{new} = 100

kV_{given} = 10.45

kV_{new} = ?

Base kV on LT side of transformer, T4

$$= base\ kV\ on\ HT\ side\ x\left[\frac{LT\ voltage\,rating}{HT\ voltage\,rating}\right]$$

$$= 132x\frac{11}{132} = 11kV$$ (This is kV_{new})

Now $$X_{pu(new)} = X_{pu(given)}\left[\frac{base\,kV_{given}}{base\,kV_{new}}\right]^2 x\left[\frac{base\,MVA_{new}}{base\,MVA_{given}}\right]$$

$$\therefore \quad X_{pu(new)} = 0.2\left(\frac{10.45}{11}\right)^2\left(\frac{100}{80}\right) = j0.2256\,pu$$

The load at 0.8 p.f. lagging is given by

$$S_L(3\phi) = 57\angle -36.87^0$$

Load impedance is given by

$$Z_L = \frac{V_{LL}^2}{S_{L(3\phi)}} = \frac{10.45^2}{57\angle -36.87^0}$$

$$= \frac{10.45^2}{57[\cos(-36.87) + j\sin(-36.87)]}$$

$$= \frac{1.92}{0.8 - j0.6} = \frac{1.92(0.8 + j0.6)}{(0.8 - j0.6)(0.8 + j0.6)}$$

$$= \frac{1.53 + j1.15}{0.8^2 - (j0.6)^2} = \frac{1.53 + j1.15}{0.64 + 0.36}$$ [j^2 = -1]

= 1.53 + j1.15

Base impedance for the load is given by

$$\frac{kV_{new}^2}{MVA_{new}} = \frac{11^2}{100} = 1.21\Omega$$

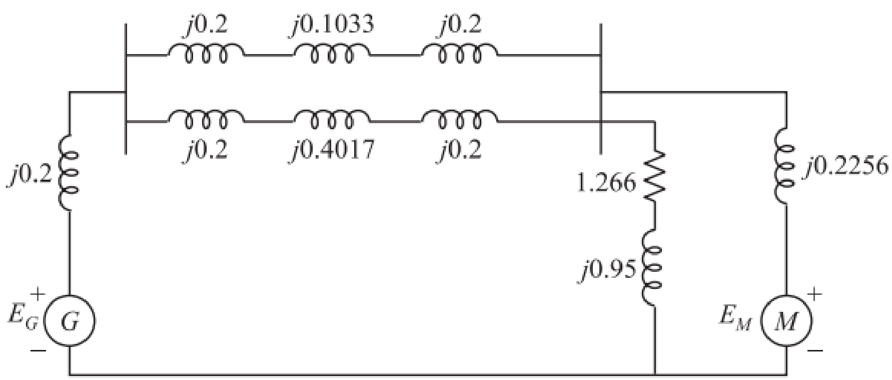
Per unit reactance of the transmission line

= actual reactance (Ω)/base reactance (Ω)

= (1.53 + j1.15)/1.21

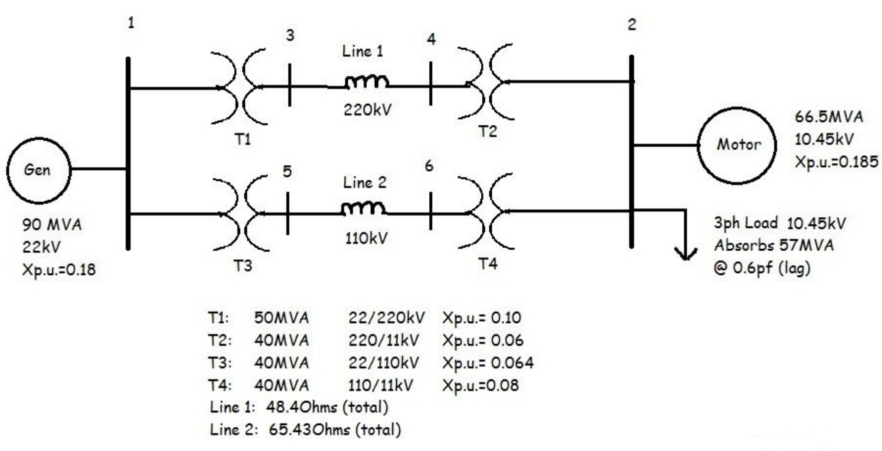
= 1.266 + j0.95) p.u.

Reactance diagram



Problem

The single line diagram of a three-phase power system is shown in figure. Draw the per unit impedance diagram with new values per unit reactances.

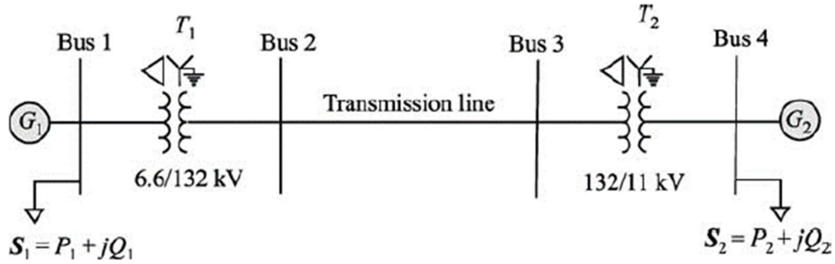


Answer: Reactances are

G = 0.2 pu; T1 = 0.2 pu; T2 = 0.15 pu; T3 = 0.16 pu; T4 = 0.2 pu and M = 0.25 pu

Problem

The power system shown in figure has the following specifications:



G1; 20 MVA, 6.6 kV, X = 0.10 pu

G2; 25 MVA, 11 kV, X = 0.20 pu

T1; 25 MVA, 6.6/132 kV, X = 0.08 pu

T2; 30 MVA, 11/132 kV, X = 0.10 pu

Transmission line; L-L voltage = 132 kV

Impedance Z = (30 + j120)Ω

Load; S1 = 10 MVA at 0.8 pf lagging and S2 = 25 MvA at 0.9 pf leading

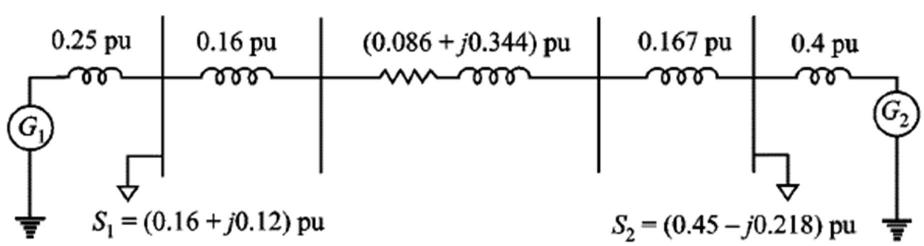
Assuming MvA_{base} = 50 for the system, calculate the pu values of generators, transformers, transmission lines and load. Draw a single line diagram and show the pu values of the system components.

Answer: Reactances are

G1 = 0.25 pu; G2 = 0.4 pu; T1 = 0.16 pu; T2 = 0.167 pu; TL = 0.086 + j0.344;

S1 = 0.16 + j0.12 and S2 = 0.45 - j0.218

Following figure shows the pu diagram for a power system on a system base of 50 MVA.



Example (AMIE Winter 2018, 2020, 5 marks)

Show that the per unit impedance of a transformer is independent of its primary or secondary side.

or

Show that per unit impedance of a transformer is equal on two sides.

Solution

Assume that the volt-ampere rating of the transformer is kVA, its primary and secondary voltages are kV_p and kV_s, and its corresponding primary' and secondary' winding impedances are Z_p and Z_s ohms, respectively.

The primary side base current

$$base\,I_p = \frac{base\,kVA}{base\,kV_p}$$

The base impedance is given by

$$base\,Z_p = \frac{1000(base\,kV_p)}{base\,I_p} = \frac{1000(base\,kV_p)}{base\,kVA}\Omega$$

The pu value of the primary side impedance is

$$Z_{(pu)p} = \frac{Z_p}{base\,Z_p} = \frac{Z_p(base\,kVA)}{1000(base\,kV_p)^2} \quad (1)$$

Similarly

$$Z_{(pu)s} = \frac{Z_p}{base\,Z_s} = \frac{Z_s(base\,kVA)}{1000(base\,kV_s)^2} \quad (2)$$

Dividing these two equations

$$\frac{Z_{(pu)p}}{Z_{(pu)s}} = \frac{Z_p}{Z_s(base\,kV_p / base\,kV_s)}$$

We know that

$$Z_p = Z_s(base\,kV_p / base\,kV_s)$$

So

$$\frac{Z_{(pu)p}}{Z_{(pu)s}} = 1 \Rightarrow Z_{(pu)p} = Z_{(pu)s}$$

Thus, it can be seen that per unit impedance is independent of the two sides of a transformer *or* per unit impedance of a transformer is equal on two sides.

ASSIGNMENT

Q.1. (AMIE S18, 19, 21, W21, 6 marks): What is per unit system in power system calculations and what are the advantages of per unit system?

Q.2. (AMIE S22, 6 marks): Define per unit system and perform the transformer modelling in per unit form of representation and highlight the major takeaways.

Q.3. (AMIE W17, 4 marks): Discuss the need to express electrical quantities in per unit system. Explain how are the impedances in p.u. are converted from one system of bases (MVA_{old}, kV_{old}) to new system (MVA_{new}, kV_{new}).

Q.4. (AMIE S18, 6 marks): How can you obtain the per unit values from a given base to a new base?

Q.5. (AMIE W18, 21, 6 marks): What does a single line diagram depict? How is it drawn?

Q.6. (AMIE W18, 20, 5 marks): Show that per unit impedance of a transformer is equal on two sides.

Q.7. (AMIE S19, 10 marks): Write detailed notes about the per-phase model of a three phase transformer.

NUMERICALS

Q.8. (AMIE S17, 8 marks): A single phase 11 kV/415 V, 100 kVA transformer has primary impedance of (3 + j5) ohm and secondary impedance of (0.01 + j0.04) ohm. Find pu impedance of primary and secondary.

Answer: 0.0248 + j0.0143 Ω; 0.0058 + j0.0232 Ω

Q.9. (AMIE W17, 8 marks): Compute the pu values for a given power system comprising:

Generator, GI: 20 MVA, 6.6 kV, $X_{gl} = 0.1$ pu

Transformer, T_1: 25 MVA, 6.6 kV/132 kV, $X_t = 0.08$ pu

Transmission line: L-L, V = 132 V, Impedance is 3 + 12j

Load: 10 MVA, 0.8 pf lag

Assume the MVA base is 50, compute the new pu impedance value for the above mentioned components.

Answer: $X_{G,pu} = 0.25$ pu; $X_{t,pu} = 0.16$ pu; $X_{l,pu} = 0.00286(3 + j12)$

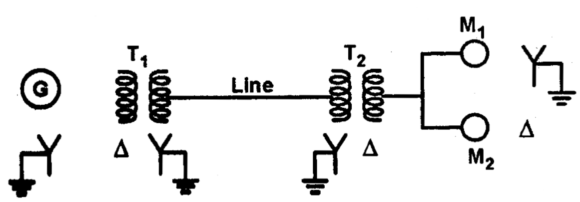
Q.10. (AMIE W12, 17, 8 marks): A three phase, 20 MVA, 10 kV alternator has internal reactance of 5% with negligible resistance. Find the external reactance to be connected in series with the alternator so that the steady state current on short circuit does not exceed 8 times the full load current value.

Answer: 0.375 Ω

Q.11. (AMIE S18, 8 marks): A generator is rated at 500 kVA, 11 kV and 0.2 per unit reactance. Find reactance on 20.0 MVA, 33 kV base.

Answer: 0.8889 pu

Q.12. (AMIE W08, 18, 9 marks): Following figure shows a simple system. Draw reactance diagram. Show reactances in per unit.



Generator G = 90 MV, 11 kV, 3 phase 25% reactance

T_1 = 3 phase, 100 MVA, 10/132 kV, X = 6%

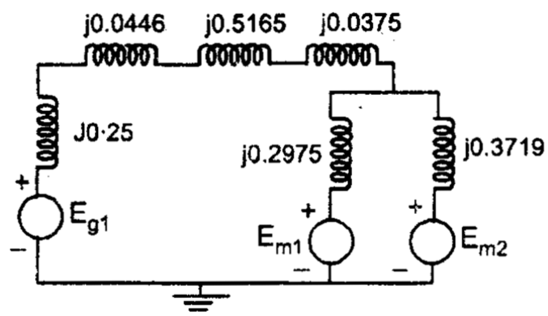
T_2 = 3 single phase units, each 30 MVA, 66/10 kVA, X = 5%

M_1, M_2 each 10 kV, 20% reactance

M_1 = 50 MVA and M_2 = 40 MVA

Line reactance = 100 Ω.

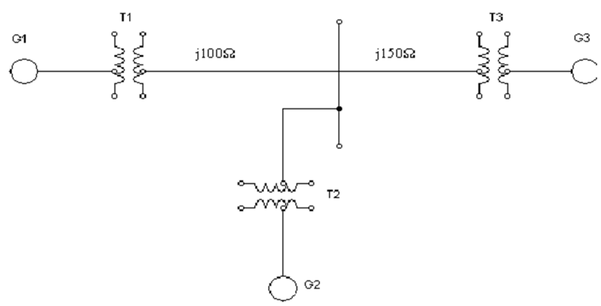
Answer:



Q.13. (AMIE W19, 6 marks): A 75 MVA, 10 kV synchronous generator has X_d = 0.4 pu. Compute X_d in pu to a base of 100 MVA, 11 kV.

Answer: 0.76 pu

Q.14. (AMIE W21, 10 marks): 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%

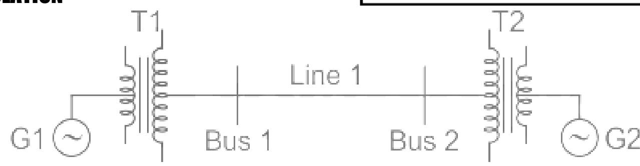
T3 = 15 MVA, 220/20 kV(Y/Δ), X=15%

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

Answer: Reactances are:

G = j0.625 p.u.; T_1 = j0.3 pu; $TL_{100\Omega}$ = j0.103 pu; $TL_{150\Omega}$ = j0.154 pu; T_2 = 0.25 pu; G_2 = j0.4167 pu; T_3 = 0.25 pu and G_3 = j0.35

Q.15. (AMIE S22, 10 marks): A single line diagram of a power system network is shown in the figure, draw the positive sequence reactance diagram for the given specifications of the component which are as follows:



G1: 25 kV, 100 MVA, X = 9%

G2: 25 kV, 100 MVA, X = 9%

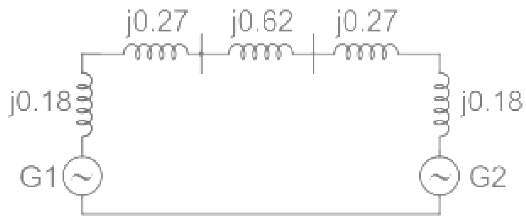
T1: 25/220 kV, 90 MVA, X = 12%

T2: 220 kV/25 kV, 90 kV, X = 150 ohms

Choose 25 kV as the base voltage at the generator G1, and 200 MVA as the MVA base. Draw impedance diagram.

Answer: Reactances are

G1 = j0.18 pu; T1 = j0.27 pu; X1 = j0.62 pu; T2 = j0.27 pu and G2 = j0.18pu



Q.16. (AMIE W16, 8 marks): Two power stations A and B operate in parallel and are interconnected by a short transmission line. The station capacities are 10 MW and 5 MW respectively and the generating set have uniform speed regulation (from no load to full load) of 2% and 4% respectively. Calculate the output of each station and the load of the interconnector when the load of each station bus-bars is 6 MW.

Answer: 7.60 MW; 4.40 MW; 3.2 MW (A to B)

Q.17. (AMIE S22, 4 marks): If a 250 MVA, 11/400 kV, three phase power transformer has leakage reactance of 0.05 pu on the base of 250 MVA and the primary voltage of 11 kV, then determine the actual leakage reactance of the transformer referred to the secondary side of 400 kV.

Answer: 32.0 Ω

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