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Overhead and underground systems.

The three phase transmission & distribution systems may consist of Overhead lines or underground cables or a combination.

The main advantages of underground sys are that it is less prone to natural hazards like rain, wind & lightning and that it does not interfere with other amenities. However an underground sys. is more costly as compared to overhead system. The approx. ratios are —

sys. vltg (kV)	0.4	11	33	66	132	220	400
Cost Ratio $\frac{\text{underground}}{\text{OH}}$	2	3	5	7	9	13	24

Because of cost consideration, the transmission & subtransmission sys. in India are generally overhead. For distribution, the use of underground cables is limited to densely populated areas.

The underground cables have lower series impedance & higher shunt capacitance as compared to OH lines. In OH lines the power loss is mostly due to I^2R loss in conductor

When the distribution is through OH lines, tappings can be made at desired points on the distributors to provide connections to consumers.

OH lines have considerable inductance due to spacing betn conductors; It causes vltg. drop & hence vltg. regulation is more.

In case of underground cables, spacing betn conductors is small, & hence low vltg. regulation.

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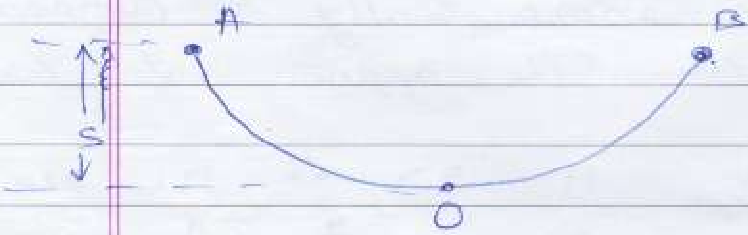
Overhead line conductors.

The material for the conductor of an OH line should have a high tensile strength so that spans betn the towers can be as long as possible & sag as small as possible.

- Sag is defined as the difference in level betn the points of support & the lowest point on the conductor.



AOB is the T.L. conductor. Supports are at point A & B. AB is the horizontal line and from this horizontal line to point O, S is the sag when measured vertically.

With the small sag, the no. & height of towers required are less.

The conductor should have low resistivity to reduce I^2R losses & Vltg. drop.

The cost of its installation & maintenance should be low & it should have long life.

OH line conductors are normally stranded to make them more flexible during erection & also while in service. A stranded conductor has a central wire and one or more layers of conductors over the central wire. Each layer is twisted in the opposite direction of the layer below (the outside layer always right handed) in order

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to increase mechanical strength.

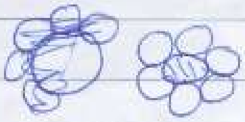
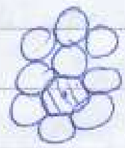
The overall diameter of stranded conductor is given by $(2n - 1) \times$ diamer of each strand, where n is no. of layers ~~and~~ surrounding the central strand.

$$D = (2n - 1) \times d$$

~~Total no. of conductors~~

Total no. of strands (N)

$$N = 3n^2 - 3n + 1$$

C.S. view of ~~bund~~ stranded cond^r.	No. of layers n	N	D
			
	1	1	d
	2	7	$3d$
	3	19	$5d$
	4	37	$7d$

Hard drawn copper has the advantage of high conductivity, good tensile strength & weather resisting property. In earlier days it was widely used, but due to high cost & non-availablity now not used in India & rarely used in the world also.

Aluminium has advantage of low cost & less weight as compared to copper. For the same resistance as that of copper conductor, aluminium has large diameter. However tensile strength of Aluminium is is low & therefore all aluminium conductor (AAC) is rarely used except for low vltg. distribution lines of short distances.

ACSR (Aluminium conductor steel Reinforced) conductor comprises hard drawn aluminium wires stranded around a core of single or multiple ~~gan~~ strand galvanized ~~at~~ steel wire. Here Al provides necessary conductivity while steel provides necessary mechanical strength.

During manufacture, a layer of grease is applied betn aluminium & steel to reduce electrolytic action (corrosion) betn zinc & aluminium (because steel strands are galvanized with zinc).

All transmission lines & most of distr. lines use ACSR conductors.

An ACSR conductor has larger dia. than equivalent copper conductor & hence lesser corona loss. In ACSR, critical voltage is about 30-50% higher than an equivalent copper condr.

The breaking load of an ACSR conductor is considerably higher than equi. copper condr. & weight is about 25% lesser. The sag of OH lines increases with weight but decreases with breaking load. Hence the OH lines with ACSR condr has lesser sag than equivalent copper conductor line.

Cost of ACSR is more than AAC condr.

Since last few years, there is a

development of in conductor systems using optical fibres.

Bundled Conductors.

To cope with an ever increasing demand, it is necessary to transmit large blocks of power over long distances. At voltages above 300kV (EHV), corona causes a significant power loss & interference with communication circuits, if the circuit has one conductor per phase. The use of multiple conductors per phas decreases the voltage gradient in the vicinity of the line & thus reduces the possibility of corona discharge.

* corona loss is caused by ionization of air molecules near the transmission line conductors. These coronas do not spark across lines, but rather carry current (hence the loss) in the air along the wire - Corona discharge in T.L. can lead to hissing or crackling noise, a glow & smell of ozone.

→ such an arrangement is known as bundled conductors. Lines of 400kV & above mostly use it. Each phase consists of two, three or four conductors spaced short distances apart & connected by spacers. The intra-bundle spacing 'd' is around 40 cms.

The advantage is ~~?~~ to reduce the corona loss & minimize interference with communication circuits. Also it leads to reduction in circuit inductance & hence decrease in vltg. drop.

Per Unit Method

P.S. calculations can be made by taking either actual values of different quantities or the per unit values. Taking quantities in p.u. simplifies calculations to a great extent. Normaly the system data is generally available in p.u. Hence it is convenient to adopt the p.u. system for calculations.

The p.u. value of a quantity is the ratio of the actual value of that quantity to an arbitrary selected value of that quantity. This arbitrary selected value is called as base value. Both actual value & base value are expressed in same units so that p.u. value is dimensionless.

The base values are generally indicated by a subscript 'b' & per unit value by a subscript "p.u."

$$\therefore \text{P.u. KVA} = \frac{\text{Actual kVA}}{\text{Base kVA}}$$

$$\text{P.u. Impedance} = \frac{\text{Actual impedance } (\Omega)}{\text{Base impedance } (\Omega)}$$

Out of the 4 system quantities, namely kVA, kV, current and impedance, only two are independent. It is convenient to select the base values of kVA and kV. and calculate the base values of current & impedance from it. In 3-phase systems, the base values usually chosen are 3-ph. kVA and line-to line kV.

Then,

$$\text{Base current} = \frac{\text{Base kVA}}{\sqrt{3}\cdot \text{Base kV}}$$

$$\text{Base impedance} = \frac{\text{Line to neutral value of base vltg.}}{\text{Base current.}}$$

For circuits containing transformers, it is convenient to select same kVA base for both the sides. However ratio of base voltages on two sides is kept same as the transformation ratio. This gives same p.u. impedance on either side of transformer.

It is usually necessary to transform the p.u. impedance from one set of base values to a new set of base values. This can be done by using eqn,

$$\text{P.U. impedance referred to new base} = \left[\frac{\text{Base kV}_{old}}{\text{Base kV}_{new}}\right]^2 \cdot \left[\frac{\text{Base kVA}_{new}}{\text{Base kVA}_{old}}\right]$$

- The three phase circuits are alwas solved in terms of per phase

3, 4, 5, 8, 12, 13, 14, 15, 18, 22, 23, 25, 26, 27, 30, 31, 34, 35, 36, ~~60~~, 46, 48, 50, 53, 56, 62, 64, 65, 68, 70

Example,

Consider a single phase system.

Let,

Base Voltampere $= (VA)_B$

Base voltage $= V_B$

then,

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

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

$= \dfrac{V_B^2}{(VA)_B}$

If the actual impedance is $Z\,\Omega$, then its p.u. value is,

$$Z_{(pu)} = \frac{Z}{Z_B} = \frac{Z \times (VA)_B}{V_B^2}$$

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For a p.s., practical choice of base values are,

Base MVA $= (MVA)_B$
OR
Base kVA $= (kVA)_B$, Base kV $= (kV)_B$

$\therefore$ Base current $= I_B = \dfrac{(MVA)_B \times 1000}{(kV)_B} = \dfrac{(kVA)_B}{(kV)_B}$ A

Base impedance $Z_B = \dfrac{1000 \times (kV)_B}{I_B}$

$$= \frac{(kV)_B^2}{(MVA)_B} = \frac{1000 \times (kV)_B^2}{(kVA)_B} \ \Omega$$

P.U. impedance,

$$Z_{pu} = \frac{Z \times (MVA)_B}{(kV)_B^2}$$

$$= \frac{Z \times (kVA)_B}{(kV)_B^2 \times 1000}$$

*

Representation of P.S. Components.

A complete diagram of power sys. representing all the three phases becomes too complicated for a sys. of practical size. It is much more practical to represent a p.s. by means of simple symbols for each component resulting in the diagram called as "one-line diag." or "single-line diag."

P.u. sys. leads to great simplification of 3-ph networks involving transformers. An impedance diag. drawn on p.u. basis does not require ideal transformer to be included in it.

The extent of information included in the diagram depends on the purpose for which it is to be used.

- If steady state conditions are to be studied, the position of relays, circuit breakers, etc is not important and need not be shown.
- However the position of relays & breakers is imp. in fault & stability studies & hence should be shown in the diag.
- Sometimes CTs & PTs are also shown.
- In many studies it is imp. to know the connections of neutral points to ground.
- Sometimes the ratings & impedances of equipment are also shown in the diag.

A single line diag consists of generators, transformers, lines, buses, etc.

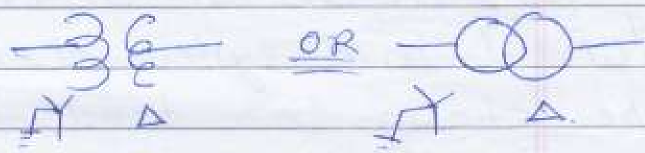
A bus is a node at which one or

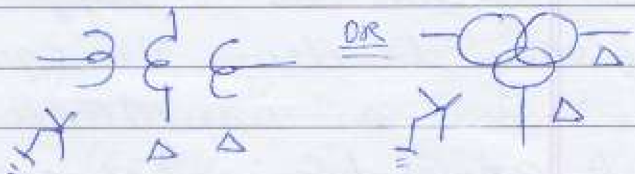
more lines, or loads or generators are connected. One of the nodes in every sys. is taken as reference node. The others independent nodes are the buses. In a single line diag, a bus is shown by a small vertical line.

Symbols of electrical equipment used

Generator 

Motor 

Two wdg. transformer 

Three wdg. transform 

CT 

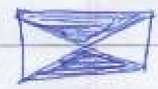
PT 

Circuit breaker 

Isolator 

Bus 

OH line / cable

Lightning arrester 

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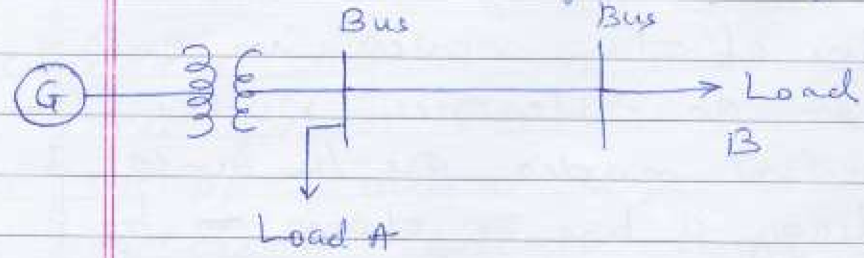
• Sample single line diag.



One line diagram and Impedance or Reactance Diagram

A one line diag. of a p.s. shows the main connections and arrangement of components. Any particular compo. may or may not be shown depending the information required in a system study. eg. CB need not be shown in a load flow study but are must for a protection study.

In order to analyze a system, it is necessary to draw its equivalent circuit (also known as impedance diagram).

• A generator is represented by an emf in series with an impedance.

• Two and three winding transformer is also shown with impedance of wdg.

• A short line is represented by a series impedance

• Medium & long lines are represented by nominal π circuits

• Very long lines are shown with equivalent π circuits

• A static load is represented by a resistance & reactance in series

• Motors are represented by their equi. ckts.

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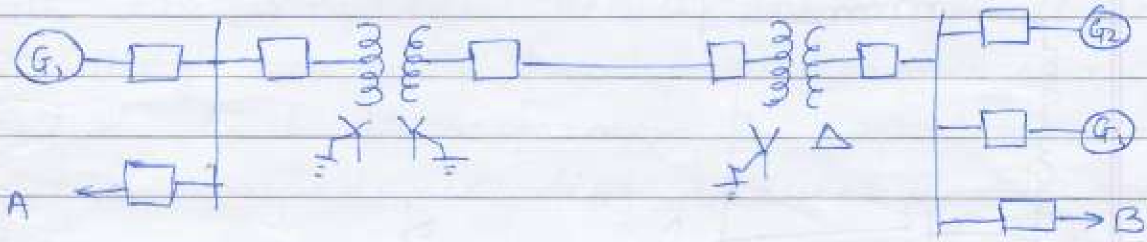
- If the resistance components of the impedances are neglected, an impedance diag reduces to reactance diag.
- It is preferable to use the values in p.u.

Ex. 1. Figure below shows one line diagram of a simple power system.

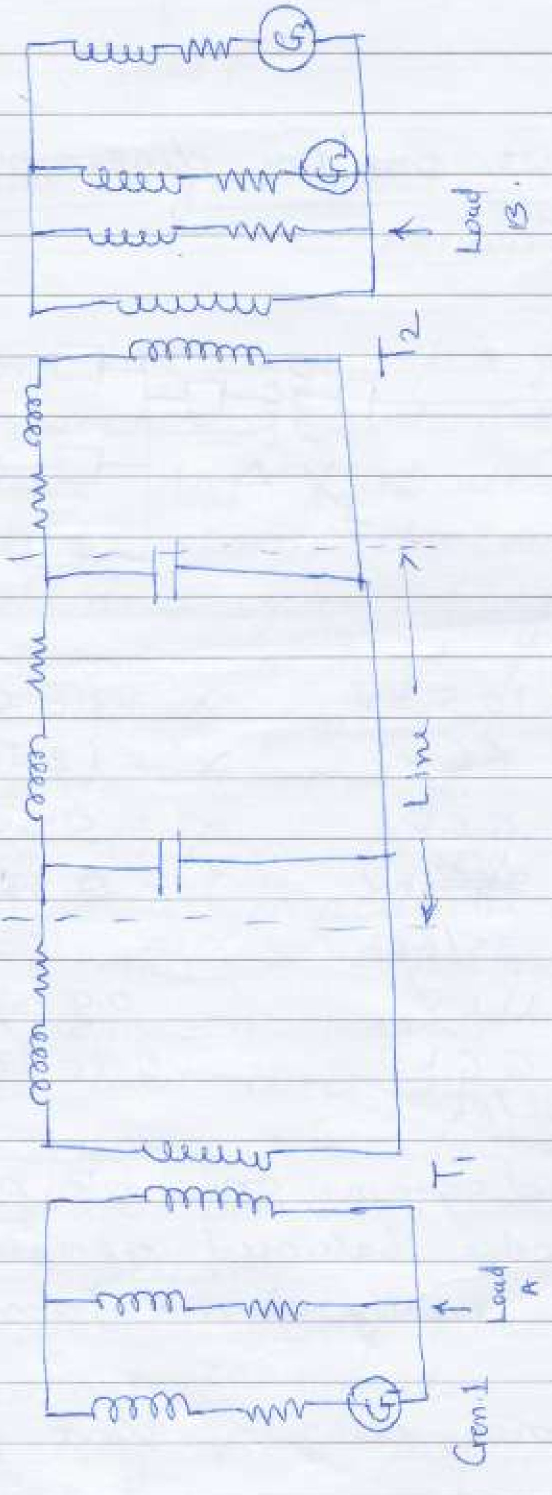


G1	30 MVA	10.5 kV	$X'' = 1.6\ \Omega$
G2	15 MVA	6.6 kV	$X'' = 1.2\ \Omega$
G3	25 MVA	6.6 kV	$X'' = 0.56\ \Omega$
T1 (3ph)	15 MVA	~~33/11~~ 11/33 kV	$x = 15.2\ \Omega/ph$
T2 (3ph)	15 MVA	33/6.2 kV	$X = 16\ \Omega/ph$
Load A	40 MW	11 kV	0.9 lagging p.f
Load B	40 MW	6.6 kV	0.85 lag. p.f.

Transmission line $20.5\ \Omega/ph$

The impedance diagram on single phase basis for using under balanced operating conditions can be easily drawn from one-line diagram.

The impedance diag. of above p.s. is shown below:-



Impedance diag.

Here loads are assumed to be passive (not involving rotating m/c) and are represented by resistance & ~~reactance~~ inductance in series

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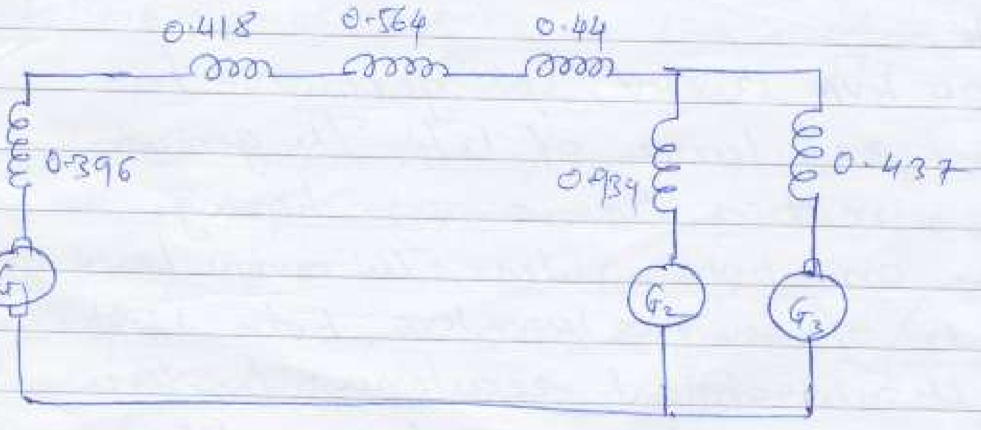
In order to calculate the performance of a system under ~~consideration~~ load condition, one line diag. must be converted into an impedance diag. showing equi. ckt. of each compo.

Resistance is sometimes omitted when doing fault calculations. Omission of resis. introduces some error, but the results may be satisfactory since the inductive reactance of the sys. is much larger than its resistance. If we decide to simplify calculations of fault current by omitting all static loads, all resistances, magnetizing current of each transformer & capacitance of T.L., the impedance diag. reduces to the reactance diagram.

For the above drawn impedance diag., the reactance diag. can be drawn as;



The ~~per~~ p.u. reactances of various compo. are calculated & marked on the reactance diag. For that let common three ph. MVA base = 30 & voltage base = 33kV. → Line to line.

Base vltg. in generator 1 ckt. is 11 kV
" " " 2,3 ckt. = 6.20 kV.

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$$\text{Gen. 1} = \frac{1.6 \times 30}{(11)^2} = 0.396$$

$$T1 = \cancel{20.5}\ \frac{15.2 \times 30}{(33)^2} = 0.418$$

$$T.L. = \frac{20.5 \times 30}{(33)^2} = 0.564$$

$$T_2 = \frac{16 \times 30}{(33)^2} = 0.44$$

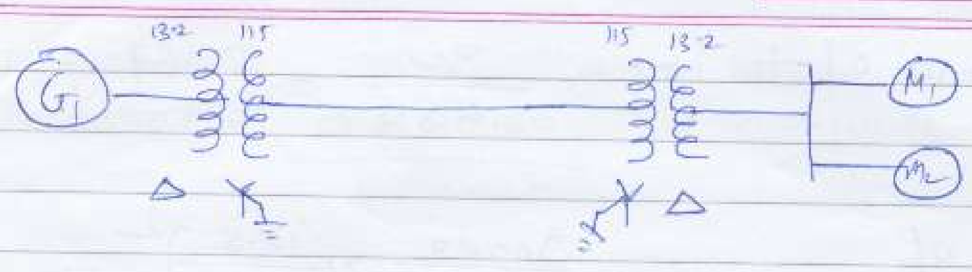
$$G_2 = \frac{1.2 \times 30}{(6.2)^2} = 0.939$$

$$G_3 = \frac{0.56 \times 30}{(6.2)^2} = 0.437$$

** Continued on next page

Example - 2

A 30000 kVA, 13.8 kV, 3ph generator has subtransient reactance of 15%. The generator supplies two motors over a T.L. having transformers on both sides. The motors have rated inputs of 2000 & 10000 kVA, both 12.5 kV with 20% ~~st~~ subtransient reactance. The three ph. transformers are both rated 35000 kVA, 13.2 / 115 kV (Δ-Y) with ~~4~~ leakage reactance of 10%. Series reactance of T.L. is 80Ω. Draw reactance diag with all reactances marked in p.u. Select the generator rating as base in the generator ckt.



A base of 30000 kVA, 13.8 kV of generator ckt. requires to be kVA base in all other ckts.
The voltage bases of T.L. & motor ckt are calculated as;

In T.L. ckt, base vltg. =

* In ckt containing transformers, it is convenient to select same KVA base for both the sides. However ratio of base vltges on two sides is kept same as the transformation ratio.

- $\therefore$ Base vltg. of T.L. $= 13.8 \times \frac{115}{13.2} = 120\,kV$.

- Base vltg. of motor ckt. $= 120 \times \frac{13.2}{115} = 13.8\,kV$

- Reactance of transformer must be converted from a base of 35000 KVA, 13.2 kV to a base of 30000 kVA, 13.8 kV., as follows;

New Transformer Reactance p.u. $= 0.1 \times \frac{30000}{35000} \times \left(\frac{13.2}{13.8}\right)^2$

$= 0.0784$ p.u.

- Base impedance in T.L is, $\frac{(KV)_B^2 \times 1000}{(KVA)_B}$

$= \frac{(120)^2 \times 1000}{30000}$

$= 480\,\Omega$

OR we can calculate as, $\frac{80 \times KVA_B}{(KV)_B^2 \times 1000}$

$= \frac{80 \times 30000}{(120)^2 \times 1000}$

$= 0.167\,\Omega.$

p.u. impedance referred to new base $= \left(\dfrac{\text{Base kV old}}{\text{Base kV new}}\right)^2 \times \left(\dfrac{\text{Base kVA new}}{\text{Base kVA old}}\right)$

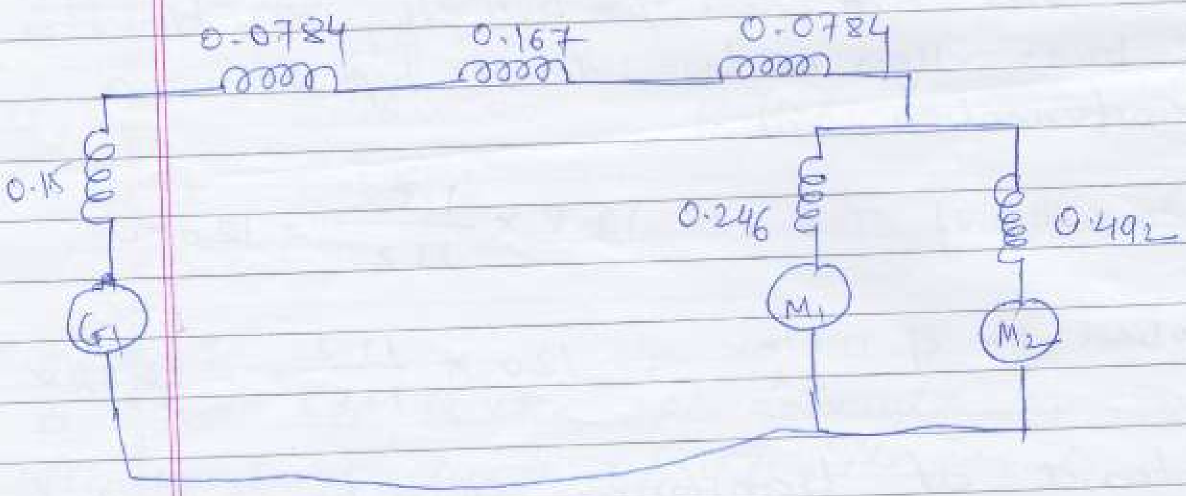
- Reactance of the line is, $\dfrac{80}{480} = 0.167$ p.u.

Reactance of motor 1 $= 0.2 \times \dfrac{30000}{20000} \times \left(\dfrac{12.5}{13.8}\right)^2$

$= 0.246$ p.u.

Reactance of motor 2 $= 0.2 \times \dfrac{30000}{10000} \times \left(\dfrac{12.5}{13.8}\right)^2$

$= 0.492$ p.u.



3] Draw impedance diag. for the p.s. shown below. Neglect resis. and use a base of 100MVA, 220 kV in 50Ω line. The ratings of gen, motor & x'mer are.

Gen → 40MVA, 25 kV, $X'' = 20\%$

Moto → 50MVA, 11 kV, $X'' = 30\%$

Y-Y x'mr → 40MVA, 33/220 kV $X = 15\%$

Y-Δ x'mr → 30MVA, 220/11 kV $X = 15\%$

$(MVA)_B = 100$ MVA

$(kV)_B = 220$ kV.

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$\cancel{Gen = \frac{0.2 \times 100}{(220)^2} = 0.000413}$

$T_1 = 0.15 \times$

at G, the $(kV)_B$ is,

$220 = (kV)_B$ at gen $\times$ trans. ratio

$220 = (kV)_B$ at G $\times \frac{220}{33}$

$220 \times \frac{33}{220} = (kV)_B$. at gen

$\therefore (kV)_B$ at gen. $= 33$ kV.

Similarly, $(kV)_B$ at Motor,

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

$= 11$ kV.

To calculate reactance

$Z_{pu\ new} = Z_{pu} \times \frac{(MVA)_B\ new}{(MVA)_B\ old}$

$G_1 = 0.287$

$M = \cancel{0.06}\ 0.6$

$T_1 = 0.37$

$T_2 = 0.5$

$T_L = 0.103$

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* continued.

Ex.1 is solved where impedances are given in actual values. If p.u. values of reactances are given, like below;

T_1 : 0.209
T_2 = 0.220
G_1 = 0.435
G_2 = 0.413
G_3 = 0.3214

Sol^n with a base MVA of 30, base vltg. of 11 kV in the ckt. of G1 and base vltg. of 6.2 kV in the ckt. of G2 & G3, let's calculate p.u. values of reactances of generators & x'mers. as per relation,

$$Z_{pu(new)} = Z_{pu(old)} \times \frac{(MVA)_{B\,new}}{(MVA)_{B\,old}} \times \frac{(KV)^2_{B(old)}}{(KV)^2_{B(new)}}$$

$$T_1 = 0.209 \times \frac{30}{15} \times \frac{(33)^2}{(33)^2}$$ .... (Base kV old & new are same).

$$= 0.418$$

$$T_2 = 0.220 \times \frac{30}{15} \times \frac{33^2}{33^2} = 0.44$$

$$G_1 = 0.435 \times \frac{30}{30} \times \frac{(\cancel{10.5})^2}{11^2} \;\; 10.5^2 = \cancel{0.396}\;\cancel{0.435}\;\; 0.396.$$

$$G_2 = 0.413 \times \frac{30}{15} \times \frac{6.6^2}{6.2^2} = 0.936$$

$$G_3 = 0.3214 \times \frac{30}{\cancel{2}5} \times \frac{6.6^2}{6.2^2} = 0.437$$

we get the same value as Ex.1

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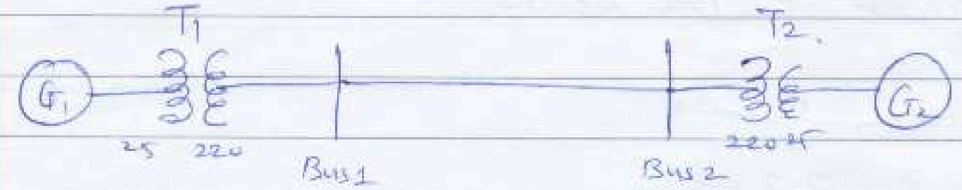
3. For the P.S shown in the figure below, the specifications are,



$G_1 = 25\,kV,\ 100\,MVA,\ x = 9\%$

$G_2 = 25\,kV,\ 100\,MVA,\ x = 9\%$

$T_1 = 25\,kV/220\,kV,\ 90\,MVA,\ x = 12\%$

$T_2 = \cancel{100}\,220\,kV/25\,kV,\ 90\,MVA,\ x = 12\%$

Line $\to$ 220 kV, $x = 150\,\Omega$.

Choose 25kV as base Vltg. at generator G1, and 200 MVA as MVA base.

Soln

$$(kV)_B = 25\ kV$$

$$(MVA)_B = 200\ MVA.$$

Given base kV for G1 = 25kV.

$\therefore$ Base kV for T. Line = Base kV x Transformation ratio

$$= 25 \times \frac{220}{25}$$

$$= 220\ kV.$$

Base kV for G_2 = $\cancel{25}$ 220 x Trans ratio

$$= 220 \times \frac{25}{220}$$

$$= 25\ kV.$$

Z_{pu} for G_1 = $\cancel{Z_{pu}}$

$$Z_{pu\,(given)} \times \frac{(MVA)_{B\,new}}{(MVA)_{Base\,old}} \times \frac{(KV)^2_{B\,old}}{(KV)^2_{B\,new}}$$

$$= 0.09 \times \frac{200}{100} \times \frac{25^2}{25^2}$$

$$= 0.18\ \Omega$$

for $T_1 = 0.12 \times \frac{200}{90} \times \frac{25^2}{25^2}$

$$= 0.266\ \Omega$$

for T.L. $= 150 \times \frac{(MVA)_B}{(KV)^2_B}$

$$= 150 \times \frac{200}{220^2} = 0.62\ \Omega$$

for $T_2 = 0.1\cancel{2} \times \frac{200}{90} \times \frac{25^2}{25^2} = 0.266\ \Omega$

for $G_2 = 0.09 \times \frac{200}{100} \times \frac{25^2}{25^2} = 0.18\ \Omega$