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260

(260)

-: HAND WRITTEN NOTES:-

OF

ELECTRICAL ENGINEERING

-: SUBJECT:-

POWER SYSTEM - I

1

To Get

POWER SYSTEM

→ Section 1:

- Generating station
- Economic aspects of generating stations
- Tariff.
- Economic dispatch of G/r station.
- Operational and control concepts of G/r statn.

→ **Section 2:

- Calculation of resistance, inductance and capacitance
- of transmission line.
- Performance of short T.L.
- Performance of medium T.L.
- Performance of long T.L.
- Concept of travelling waves in T.L.
- Insulators and string efficiency
- Calculation of Sag for various Configurations
- Performance of underground cables

→ *Section 3:

- Circuit Breakers.
- Performance of Relays.
- Protection of Power system equipment

[redacted]

→ Section 4: (Most Imp)

- Per unit System Analysis.
- Concept of symmetrical components in power system.
- Evalution of Positive sequence n/w, negative sequence n/w and zero sequence n/w.
- Fault analysis.
- Load flow analysis.
- Power s/m stability analysis.

PER UNIT SYSTEM ANALYSIS

#

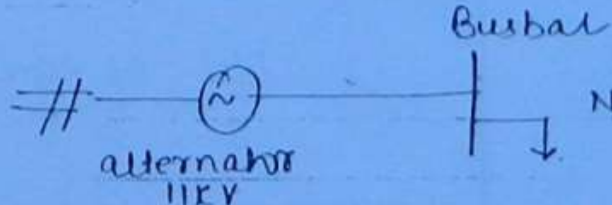
→ the performance of a power system network consisting of several power system equipments like: a

* Alternator — 11 KV
* Transformers 11/132 KV
* Transmission lines 132 KV
* Busbars 11 KV, 33 KV
* loads. etc.

→ these can be obtained by means of Per unit s/m.

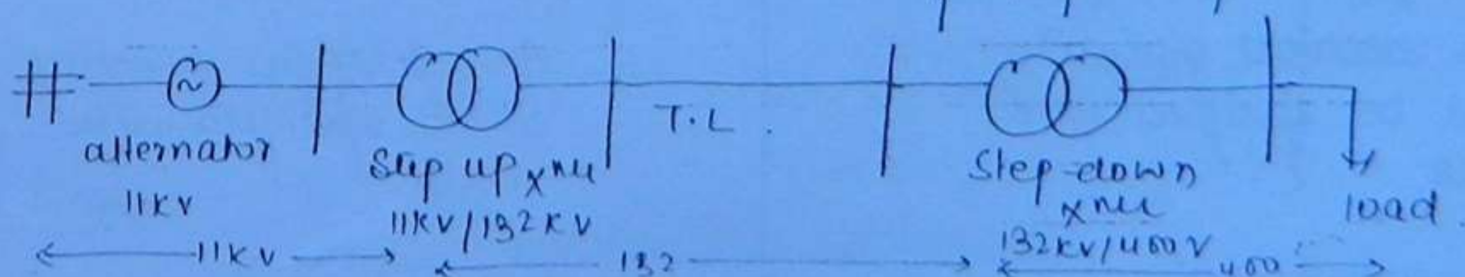
→ Before 1980 the performance of a power system network is obtained by using ABSOLUTE SYSTEM.

Absolute System:



No of Operating level = 1.

No of operating level = 3.



→ Consider a power system network as shown in fig ①. In absolute s/m no of equation required to analyse the performation of power system n/w is equal no of operating level = 1.

Consider a power s/m network shown in figure(2) above. No of equation required to analyse the performance of power s/m network is equal no of operating voltage level = 3.

→ A modern power system network operates at many voltage level. Therefore time required to analyse the performance of power system network increases. Due to these limitatⁿ ABSOLUTE SYSTEM is replaced with per unit s/m.

• ABSOLUTE SYSTEM	• PER UNIT SYSTEM
1) No of equations required is equal to no. of operating voltage level.	1) No. of equation requir 1.
2) An electrical quantity must be specified with units.	2). An electrical quantity is not specified with units.
3) The performance of power s/m equipment is evaluated one after another equipment.	3). The performance of all the equipments are evaluated simultaneously.

$$\frac{\text{Actual}}{\text{Base}} = \frac{\text{Absolute}}{\text{Reference}}.$$

4) The evalution time is ~~less~~ more	4) The evalution time is less.

Per unit system:

Per unit of an electrical quantity	=	$\frac{\text{Actual value of an electrical quantity exp in}}{\text{Base value of same electrical quantity expr in on}}$

→ Actual value is also known as Absolute value.
Base value is also known as a Reference value.

→ The selection of base value is optional

→ Per unit value ranges from 0 to ∞

→ Base values are always consider as positive value.

		Base value = 100	Base value 0.	
Test 1	99	$p.u_1 = \frac{99}{100} = 0.99$	$p.u = \frac{99}{0} = \infty$	$\frac{0}{100} = 0$
Test 2	103	$p.u_2 = \frac{103}{100} = 10.3$	$pu_2 = \infty$	
Test 3	135	$pu_3 = 135/100 = 1.33$	$pu_3 = \infty$	

As resistance is neglible to Reactane in a winding.

Relation b/w ABSOLUTE S/M AND PER UNIT S/M :-

Consider two machines in power s/m network.

Machine 1 : V_1(volt) , I_1(Ampere)

Machine 2 : V_2(volt) , I_2(Ampere)

let $V_b = V_1$; $I_b = I_1$

p.u. current

- $I_1 p.u = \frac{I_1}{I_b} = I_1/I_1 = 1 p.u$
- $I_2 p.u = \frac{I_2}{I_b} = I_2/I_1$ p.u.

P.U of voltage

- $V_1 p.u = \frac{V_1}{V_b} = \frac{V_1}{V_1} = 1 p.u$
- $V_2 p.u = \frac{V_2}{V_b} = \frac{V_2}{V_1}$ p.u.

- A winding in a equipment consist a negligible resistence and significant reactance. therefore resistance is neglected and reactance is only considered to analyse a power system n/w.

As the resistance is neglected the error introduced in s/m is less than 5% and is neglected.

Since resistance is neglected $X = V/I$

Reactance measured in Ω.

$$X_1 \text{ in } \Omega = \frac{V_1 \text{ in volts}}{I_1 \text{ in Ampere}} = V_B/I_B = X_B \text{ in } \Omega$$

$$\boxed{X_2 \text{ in } \Omega = \frac{V_2 \text{ in volts}}{I_2 \text{ in Ampere}}}$$

* P.U Reactance :-

- $X_1 \text{ p.u} = \frac{X_1 \text{ in } \Omega}{X_B \text{ in } \Omega} = \frac{X_1 \text{ in } \Omega}{X_1 \text{ in } \Omega} = 1 \text{ p.u}$

- $X_2 \text{ p.u} = \frac{X_2 \text{ in } \Omega}{X_B \text{ in } \Omega} = \frac{X_2 \text{ in } \Omega}{X \text{ in } \Omega} \text{ p.u}$

$$\boxed{X_{p.u} = \frac{X \text{ in } \Omega}{X_B \text{ in } \Omega}} \quad \text{--- (1)}$$

now from eq (1)

$$X_{p.u} = \frac{X \text{ in } \Omega}{V_B/I_B}$$

$$\boxed{X_{p.u} = X_{\text{in } \Omega}\left(I_B/V_B\right)} \quad \text{--- (2)}$$

Equation (2) expressed per unit reactance in terms of base current and base voltage.

Using equation (2) per unit Reactance of all the equipments can not be determined.

A xmer is specified with VA rating

And voltage rating.

Expressing per unit reactance in terms of base MVA and base KV:-

$$X_{pu} = X_{in\,\Omega}\left(\frac{I_b}{V_b}\right)$$

$$= X_{in\,\Omega}\left(\frac{V_b \cdot I_b}{V_b \cdot V_b}\right)$$

$$= X_{in\,\Omega}\left(\frac{V_b \cdot I_b}{V_b^2}\right)$$

$$= X_{in\,\Omega}\left(\frac{V_b I_b / 10^6}{V_b^2 / 10^6}\right)$$

$$= X_{in\,\Omega}\left(\frac{MVA\ bas}{(V_b/10^3)^3}\right)$$

$$\boxed{X_{pu} = X_{in\,\Omega}\left(\frac{MVA\ base}{KV_b^2}\right)} \quad -③$$

When a new generating station is commissioned to the grid the per unit reactance of the power s/m network changes

Expressing new per unit reactance in terms of old p.u reactance

$$X_{p.u_{new}} = X_{in\,\Omega}\left(\frac{MVA_{b,new}}{KV_b^2{}_{new}}\right)$$

$$X_{p.u_{old}} = X_{in\,\Omega}\left(\frac{MVA_{b\,old}}{KV_b^2{}_{old}}\right)$$

$$\frac{X_{p.u(new)}}{X_{p.u(old)}} = \left(\frac{MVA_{b(new)}}{MVA_{b(old)}}\right)\left(\frac{KV_b^2{}_{old}}{KV_b^2{}_{new}}\right)$$

$$\boxed{X_{p.u(new)} = X_{p.u(old)}\left(\frac{MVA(new)}{MVA(old)}\right)\left(\frac{KV_b^2{}_{old}}{KV_b^2{}_{new}}\right)} \quad \text{--- (4)}$$

Trick $X_{p.u,(new)} = X_{pu\,old}\left(\frac{MVA\,(new)}{MVA\,(old)}\right)\left(\frac{KV_b^2\,(old)}{KV_b^2\,new}\right)$.

$\downarrow$ 10^6 $\quad$ $\downarrow$ 10^3

$M \rightarrow N(new)$

n (numerator)

Question :-

A Generating station has base values 30mVA, 11kV, 1.2. What is the new per unit reactance if the base of generating station is selected as 75mVA, 13.2kV

$MVA_{old} = 30MVA$	MVA_{new} 75MVA
$KV_{old} = 11K$	$KV_{new} = 13.2KV$

$$X_{pu\,(new)} = 1.2\left(\frac{75}{30}\right)\left(\frac{1.1}{13.2}\right)^2$$

$$X_{pu\,(new)} = 2.08\ pu \quad \underline{\text{Ans}}$$

uestn:-

The pu reactance of an alternator with base values 30MVA, 11KV with 6 Ω reactance is

$$X_{pu} = X\left(\frac{MVA\ base}{KV_b^2}\right)$$

$$X_{pu} = 6\left(\frac{30}{(11)^2}\right)$$

$$X_{p.u} = 1.49\ pu$$

uestion:-

What is the per unit reactance, if the capacity (MVA) is doubled and voltage is double.

$$MVA_{b\,(new)} = 2\ MVA_b\,(old)$$

$$KV_{b\,(new)} = 2\ KV_b\,(old)$$

$$X_{pu\,(new)} = X_{pu\,old}\left(\frac{2\,MVA\,(old)}{MVA\,(old)}\right)\left(\frac{KV_b\,(old)}{2KV_b\,(new)}\right)^2$$

$$X_{pu\,new} = \frac{1}{2} X_{pu}\ old.$$ Ans

Question:

What is the pu reactance if capacity and voltage are reduced to 50% of original value..

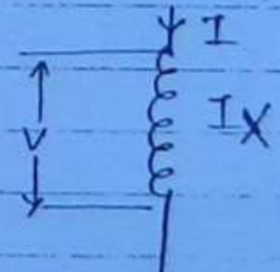
Default perunit

$$X_{pu}(new) = 1 \times \left[\frac{\frac{1}{2} MVA(old)}{MVA(old)} \right] \left[\frac{2kV_b(old)}{kV_b(new)} \right]^2 \quad 1\ p.u.$$

$$X_{pu}(new) = 2\ X_{pu}(old)$$

* the default value of per unit quantity is ~~also~~ always 1.

Defination of Per unit Reactance:



$$X_{p.u} = \frac{IX}{V}$$

With full load current I flowing through the winding the ratio of the reactive drop to the rated voltage applied accross the winding gives the per unit reactance of the winding

$$\boxed{X_{p.u} = IX/V}$$

Percentage Reactance:

$$\boxed{\begin{aligned} \%X &= 100 \cdot X_{pu} \\ \%X &= 100 \cdot \frac{IX}{V} \end{aligned}} \quad \text{—(6)}$$

substitude (3) in equation (6).

$$\%X_{pu} = 100 \cdot X_{p.u}$$

$$\boxed{\%X = 100 \cdot X_{in\,\Omega} \left(\frac{MVA\ base}{kV_b^2} \right)} \quad \text{—(7)}$$

from equation (6).

$$\%X = \frac{IX}{V} \cdot 100$$

now $$\boxed{X_{in\,\Omega} = \frac{\%X}{100} \cdot \frac{V}{I}} \quad \text{—(8)}$$

Expressing base reactance in terms of base MVA and base KV:

$$X_b = V_b / I_b$$

$$= \frac{\frac{V_b}{10^6} \cdot V_b}{\frac{V_b}{10^6} \cdot I_b}$$

$$\frac{V_b^2/10^6}{V_bI_b/10^6}$$

$$= \frac{(V_b/10^3)^2}{(V_bI_b/10^6)}$$

$$\boxed{X_{p.u\ base} = \frac{KV_b^2}{MVA(b)}} \quad -(9)$$

* DIRECT EQUATION :-

- $X_b = \dfrac{KV_b^2}{MVA_b}$

- $X_{p.u} = \underset{in\ \Omega}{X} \times \dfrac{MVA_b}{KV_b^2}$

Checking units

$$\frac{V \cdot ?}{I} = \frac{I \cdot X}{V}$$

- $\% X = 100 \times X_{in\ \Omega}\left(\dfrac{MVA_b}{KV_b^2}\right)$

- $X_{pu(new)} = X_{p.u(old)}\left(\dfrac{MVA\ (new)}{MVA\ old}\right)\left(\dfrac{KV_b^2(old)}{KV_b^2\ (new)}\right)$

Short circuit current And short ckt MVA:

$$I_{sc} = \frac{V\text{ in volt}}{X\text{ in }\Omega}$$

$$\frac{\cancel{V}}{\frac{\%X}{100}\cdot\frac{\cancel{V}}{I}}$$

$\%X = 100 \cdot X_{p.u}$

$\%X = 100\,\frac{XI}{V}$

$X = \frac{\%X}{100}\cdot\frac{V}{I}$

$$\boxed{I_{sc} = \frac{100}{\%X}\cdot I} \quad \text{— (10)}$$

I - full load current.

I is the full load current flowing through the winding / circuit

Imp

To limit the short circuit current increase $\%X$ or increase reactance of the winding measured in ohms.

from equation (10)

$$\frac{I_{sc}\cdot V}{10^6} = \frac{100}{\%X}\,\frac{I\cdot V}{10^6}$$

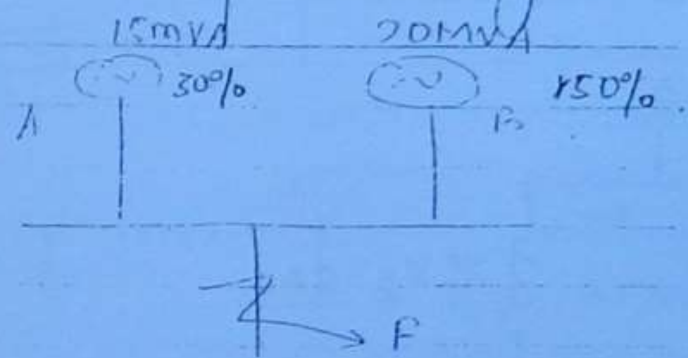
$$MVA_{sc} = \frac{100}{\%X}\,MVA$$

$$= \boxed{MVA_{sc} = MVA \times \left(\frac{100}{\%X}\right)} \quad \text{— (11)}$$

In above formulae MVA corresponds to full load current flowing through the winding.

Question:-

The single line diagram of a 3ϕ system is shown below. The % reactance of each alternator is based on its own capacity. Find the short circuit current flowing in the n/w due to 3ϕ S.C at point F. Evaluate by considering base MVA as 35 MVA.



STEP 1: Reactance diagram

→ In the reactance diagram the %age reactance of the power s/m equipment calculated w.r.t base MVA are represented.

$\% X_A$ w.r.t Base MVA

$30\% \longrightarrow 15\,MVA$

$X_A\% \longrightarrow 35\,MAV$ ∵ more value will be form as ∝ propto

$= \frac{35}{15} \times 30$

$\boxed{X_A\% = 70\%}$

* To protect the alternator always connected to ground through Y connection this must be shown in ~~Reactance diagram~~

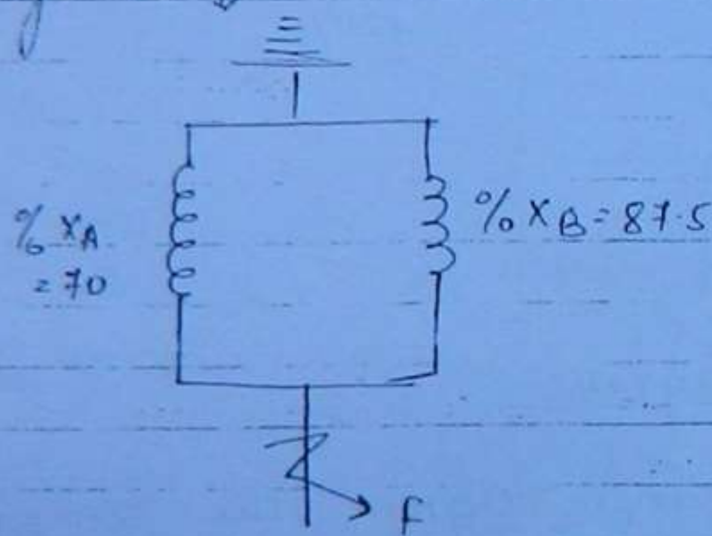
$\% X_B$ w.r.t Base 35 MVA

15% —— base 20 MVA

$$X_B\% = \frac{35 \times \cancel{15}\,3}{\cancel{20}\,2} = 87.5\%$$

$$\boxed{X_B\% = 87.5\%}$$

Reactance Diagram :-

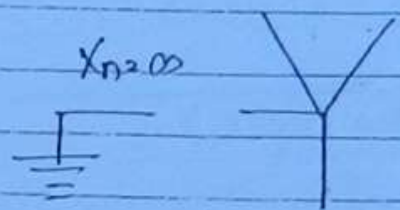


$$\% X = (\% X_A) \parallel (\% X_B)$$

$$= \frac{70 \times 87.5}{70 + 87.5} =$$

$$\boxed{X\% = 38.89\%}$$

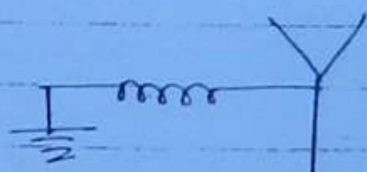
* Method of Grounding:-

① 

→ Isolate grounding

② 

→ neutral grounding

③. 

→ Reactance Grounding

STEP 2: To find Short circuit full load current flowing through the n/w:-

$$1\phi \ VA = V_{ph} \cdot I_{ph}$$

$$3\phi \ VA = 3 \cdot V_{ph} \cdot I_{ph}.$$

$$3\phi : Y : VA = 3 \frac{V_L}{\sqrt{3}} \cdot I_L = \sqrt{3} V_L I_L$$

$$3\phi : \nabla : VA = 3 \cdot V_L \cdot \frac{I_L}{\sqrt{3}} = \sqrt{3} V_L I_L.$$

→ Full load current is calculated w.r.t base MVA

$$35 \times 10^6 = \sqrt{3} \times 12 \times 10^3 \times I_L$$

$$\boxed{I_L - I_{ph} = I = 1684\ A}$$

Step 3: Short circuit current.

$$I_{sc} = \frac{100}{\%X} \cdot I$$

$$\frac{100}{38.89} \times 1684 = 4330A$$

$$\boxed{I_{sc} = 4330A}$$

Question :-

A 3ϕ 20MVA, 10KV alternator ~~A~~ has internal reactance of 5% and negligible resistance. Find the external reactance per phase to be connected in series with ~~a~~ the alternator so that steady current on short circuit donot exceed 8 times the full load current

$$I_{sc} = 8I$$

$$\frac{I_{sc}}{I} = 8 \quad \text{--- (1)}$$

$$I_{sc} = \frac{100}{\%X} \cdot I$$

$$\frac{I_{sc}}{I} = \frac{100}{\%X} = 8$$

$\%X = 100/8 = 12.5\%$

$\%X$ existing $= 5\%$

$\%X$ required $= 12.5 - 5 = 7.5\%$

$$\boxed{\%X_{req} = 7.5\%}$$

For per phase reactance :-

Reactance per phase can be obtained

$$\%X = 100 \cdot X_{pu}.$$

$$\%X_{req} = 100 \cdot \frac{IX}{V}$$

$$\boxed{X_{in\,\Omega} = \frac{\%X_{req} \cdot V}{100 \cdot I}}$$

Full load current I :

I is calculated as

$$VA = \sqrt{3} V_L I_L$$

$$= \frac{20 \times 10^{6}}{\sqrt{3} \times 10 \times 10^{3}} = I_L$$

$$I_L = 1154.7\ A.$$

→ Reactance is per phase so current and voltage must be per phase

per phase reactance in OHMS $= \dfrac{7.5 \times 10 \times 10^3/\sqrt{3}}{100 \times 1154.7}$

∴ Alternator % React^n Base MVA = 10MVA.

$\%X_{alt}$ w.r.t Base MVA.

$$10\% \rightarrow 10MVA$$

$$\%X_{alt} \rightarrow 10MVA.$$

$$\%X_{alt} = \frac{10}{10} \times 10 = \boxed{10\% = X\%_{alt}}$$

∴ Transformer % reactance: w.r.t bas MVA.

$\%X_{Tf}$ w.t Base MVA.

$$5\% \rightarrow 5MVA.$$

$$\%X_{Tf} \rightarrow 10MVA$$

$$\%X_{Tf} \rightarrow \frac{10}{5} \times 5 = \boxed{10\% = X_{Tf}\%.}$$

∴ Transmission line % Reactance: w.r.t MVA_b, KV_b.

$$\%X = 100 \cdot X_{p.u}$$

$$\%X = 100 \cdot X_{line}\left(\frac{MVA_b}{KV_b^2}\right)$$

$$\%R = 100 \cdot R_{in\,\Omega}\left(\frac{MVA_b}{KV_b^2}\right)$$

Single line diagram starts at G/r end to load.

* 95% of fault occur on the T.L ~~and~~ coz 98% of working is on T.L.

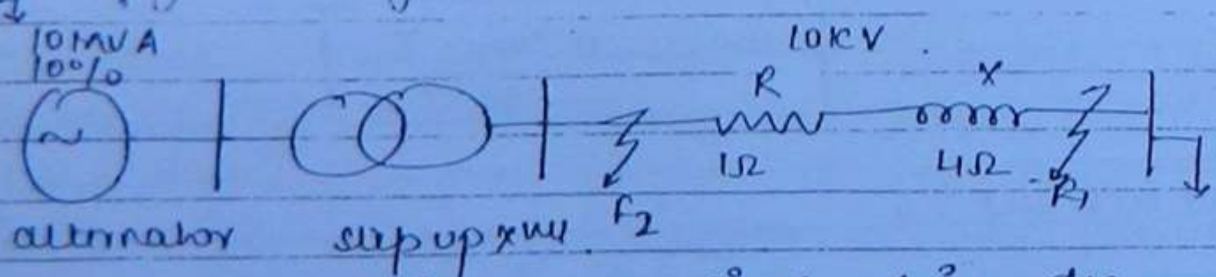
$$\boxed{X_{in\Omega} = 0.375\Omega}$$

Question:-

A 3φ T.L operating at 10KV and having resistance of 1Ω and reactance 4Ω is connected to G/r station busbar through 5MVA step up x'mer having a reactance of 5%. The bus bare are supplied by a 10MVA alternator having 10% reactance determine the short circuit KVA of a symmetrical fault b/w the phases if it occurs.

a) At the load end of T.L.
b) High voltage terminal of x'mer.

Step 1:



single line diagram.

Step 2: Reactance diagram: Here ~~is~~ % reactance of all the equipment are listed.

→ When horizontal line diagram is given base MVA is taken as the MVA of first equipment i.e alternator.

Since T.L operates at 10KV select base KV as 10KV.

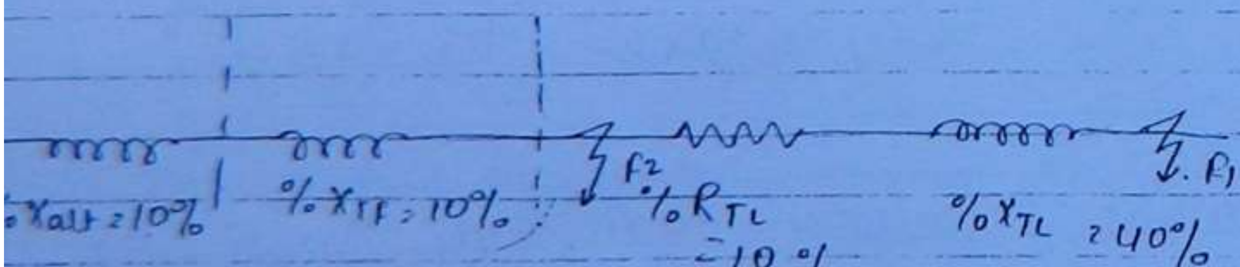
$$\% X_{TL} = \frac{\cancel{100} \times 4 \times 10}{\cancel{100}} = 40\%$$

$$\boxed{\% X_{TL} = 40\%}$$

% Resistance of T.L w.r.t MVA_b, KV_b.

$$\% R_{TL} = \frac{100 \times 1 \times 10}{(10)^2} = 10\%$$

$$\boxed{\% R_{TL} = 10\%}$$



Step 3: Short circuit MVA w.r.t fault point F_1

Total % X upto fault point F_1

$$\% X_T = 10 + 10 + 40 = 60\%$$

Total % R upto fault point F_1 = 10%.

* As we move away from ORIGINATING STATION S.C. MVA DECREASE.

$$\%Z_{F_1}^2 = \%X_{F_1}^2 + \%R_{F_1}^2$$

$$= 60^2 + 10^2$$

$$\boxed{\%Z_{F_1} = 60.83\%}$$

Short circuit MVA upto fault point F_1.

$$MVA_{SC} = \frac{100\ (MVA\ base)}{\%Z_{F1}}$$

$$= \frac{100}{60.83} \times 10 = 1.$$

$$\boxed{MVA_{SC_{F1}} = 16.44\,MVA}$$

Step 4: Short circuit MVA upto fault point F_2.

Total Reactance upto F_2

$$\%X_T = 20\%$$

$$\%R_T = 0$$

$$MVA_{SC} = \frac{100}{2\cancel{0}} \times 1\cancel{0} = 50\,MVA$$

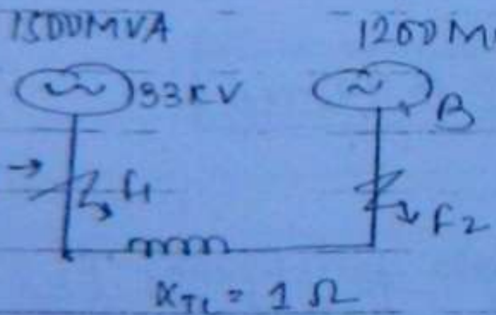
$$\boxed{MVA_{SC_{F_2}} = 50\,MVA}$$

→ The short circuit MVA DECREASES as we move away from originating station.

Question:-

The estimated Short circuit MVA at Busbars of generating statⁿ A and B are 1500 MVA and 1200 MVA. The generated voltage at each station is 33KV. If the generating statⁿ are interconnected through a T.L having a reactance 1 Ω and negligible resistance. Calculate the short circuit MVA at both Generating statⁿ with base MVA equal 100.

Step 1:
Single line diagram →



Base MVA = 100.

Step 2: Reactance diagram:

% Reactance of alternator w.r.t MVA B

$$= \cancel{\times 100}$$

$$MVA_{SC} = \frac{100 \times 10 MVA_b}{\% X_A}$$

$$\% X_{all} = \frac{100 \times 100}{1500} = 6.67$$

$\%X_{a\|B} = \cancel{100}$

→ $\%X_{a\|B}$ @ w.r.t MVA$_b$:

$$\%X_{a\|B} = \frac{100}{MVA_{sc}} \times MVA_b$$

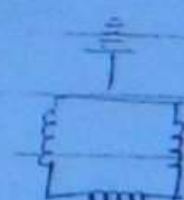
$$= \frac{100 \times 100}{1200} = 8.34\%$$

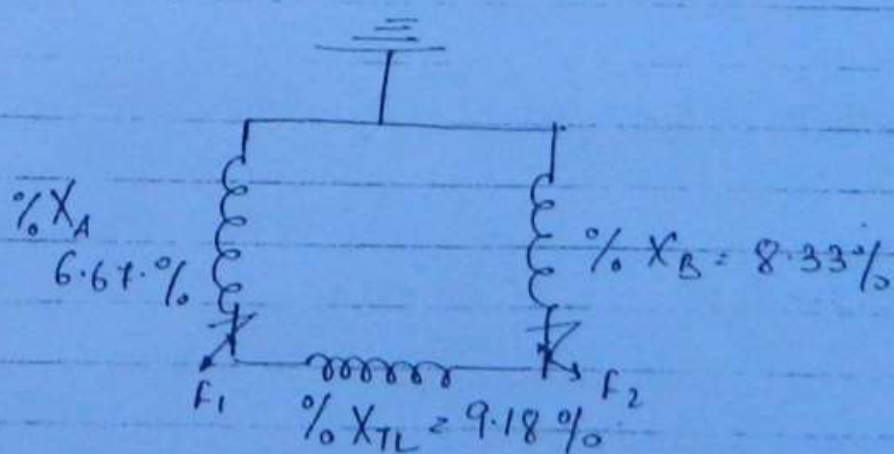
$$\boxed{\%X_{a\|B} = 8.34}$$

→ $\%X_{T.L}$ w.r.t MVA$_b$ and KV$_b$.

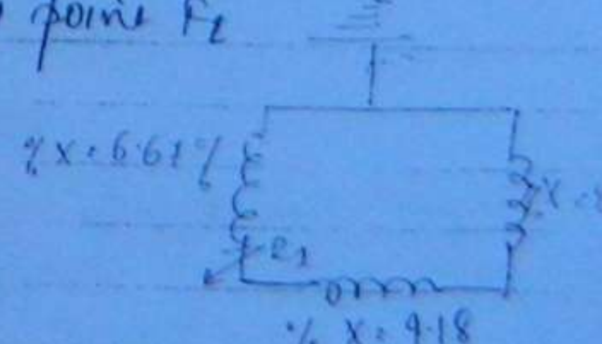
$$\Rightarrow 100 \times 1 \times \frac{100}{(33)^2} = 9.18\%$$

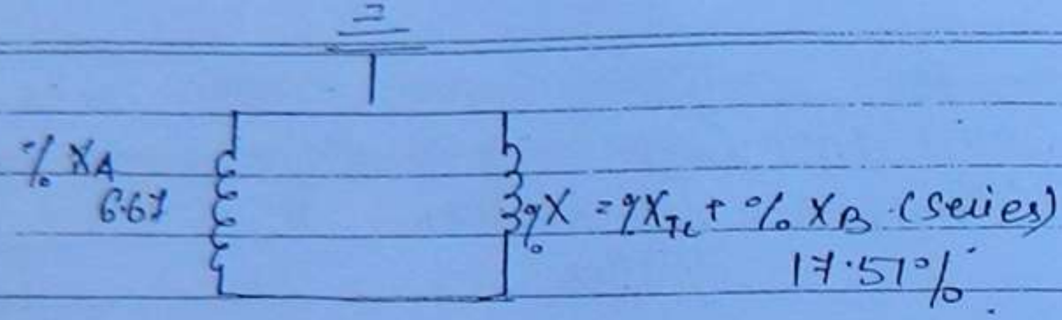
$$\boxed{\%X_{TL} = 9.18\%}$$





Step 3: Short circuit MVA upto fault point F_1





$$\% X_{F_1} = \% X_A \parallel (\% X_B + \% X_{Tc})$$

$$6.67\% \parallel (17.51)$$

$$= \frac{6.667 \times 17.51}{6.67 + 17.51} = 4.8\%$$

$$MVA_{sc} = \frac{100}{4.8} \times 100 = 2070\ MVA$$

<u>Step</u> → <u>Total reactance upto fault F_2:</u>

$$\% X = 6.67 + 9.18 = 15.85\%$$

$$\frac{8.33 \times 15.85}{8.33 + 15.85} = 5.46\%$$

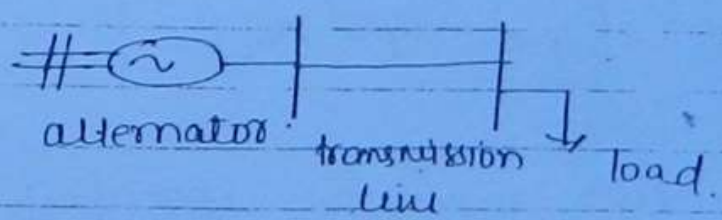
$$MVA_{sc} = \frac{100}{5.46} \times 100 = 1831.39\ MVA$$

TEXT BOOK :- Electrical Power s/m "C.L Wadhwa"
: Power system by Stevenson
: Power System by Anderson & Faud

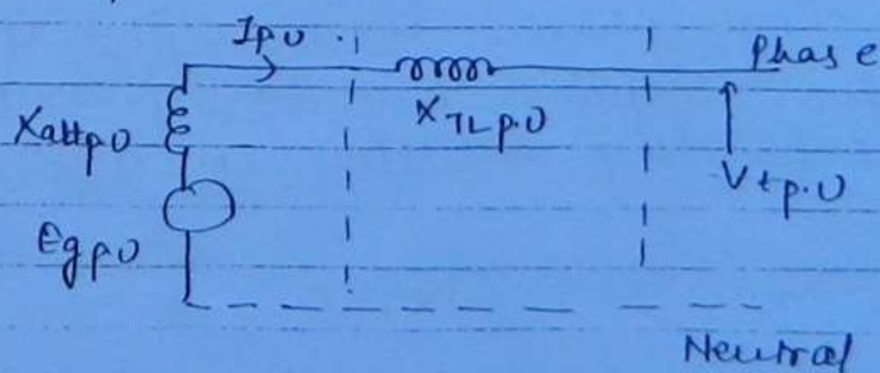
Symmetrical Components :-

Neccessity of symmetrical components :-

Consider a power system n/w as represented by single line diagram



→ The performance of power s/m network can be obtained by representing per phase reactance diagram in per unit value.



→ Per phase reactance diagram is drawn b/w PHASE AND NUETRAL. Phase is indicated by thick line and neutral is indicated by dotted line.

* When S/m is balance draw Reactance for only one phase.

→ Reactance drop in alternator :-

$I_{pu}\, X_{alt\,p.u}$

$I_{pu}\, X_T$

→ Reactance drop in T.L : $I_{pu}\, X_{TL\,p.u}$

→ total Reactance drop $= I_{pu}\,(X_{alt\,pu} + X_{TL\,p.u})$

$I_{pu}\,(X_{eq\,p.u})$

→ Terminal voltage
$$\boxed{V_{t\,pu} = E_{g\,p.u} - I_{pu}\, X_{eq\,p.u}}$$

The above equation represent the performance of power system n/w.

→ For balanced S/m reactance diagram is represented for a single phase. When system is unbalance reactance diagram must be represented. for all the 3φ's saperately resulting in 3 eqn.

R phase : $V_{tR\,pu} = E_{gR\,p.u} - I_{R\,p.u}\, X_{eq\,R\,p.u}$

Y phase : $V_{tY\,p.u} = E_{gY\,p.u} - I_{Y\,p.u}\, X_{eq\,Y\,p.u}$

B phase : $V_{tB\,p.u} = E_{gB\,p.u} - I_{B\,p.u}\, X_{eq\,B\,p.u}$

* Regulation → ~~speed~~ % efficiency → stationary (voltage) → T.L / speed (rotatory)

By solving the above three equatⁿ the performance of power s/m network can be obtained

Unbalanced System :-

• Internal Unbalance s/m	• External Unbalanced s/m
• Internal unbalance occur due to mis operation of the power s/m equipment	• External unbalance occur due to faults
• $I_n \leq 10\% I_{FL}$	• $I_n > 10\% I_{FL}$
• The phase voltage ~~is~~ are approximately equal to each other. $V_R \approx V_Y \approx V_B$	• The phase voltages are not equal. $V_R \neq V_Y \neq V_B$
• The phase voltages are with in regulation level.	• Phase voltages are not with in regulat' level.

In an unbalance system each and every unbalanced quantity can be represented by a set of 3-balanced quantities.

** sign of angle +ve → direction Anticlock.
$\boxed{A \cdot P}$

→ The set of balanced quantities are known as symmetrical components.
The above concept is formulate by 'FORTESCQUE'

3-unbalanced   9-balanced.

$$V_R = V_{R0} + V_{R1} + V_{R2}$$

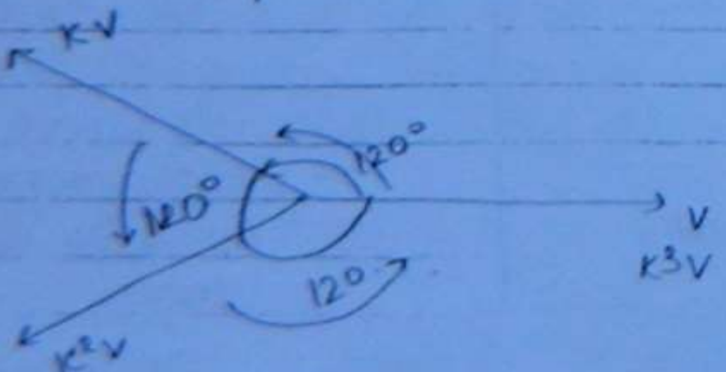
$$V_Y = V_{Y0} + V_{Y1} + V_{Y2}$$

$$V_B = V_{B0} + V_{B1} + V_{B2}$$

→ The nine symmetrical component canbe represent by 3.

OPERATOR K :- (K or a or α).

Operator K rotates a vector in ANTI-CLOCKWISE direction by 120°.



$V = K^3 V$

$\boxed{K^3 = 1}$

→ Operator K has magnitude equal 1.

[redacted]

[redacted] operator K rotates a vector in Anticlock wise direction, phase angle $(+120^\circ)$

$$K = 1\angle +120$$

$$1\{\cos 120 + j\sin 120\}$$

$$1\cdot\left\{-\tfrac{1}{2} + j\tfrac{\sqrt{3}}{2}\right\}$$

$$\boxed{K = -0.5 + j\,0.867}$$

$$K^2 = K\cdot K$$

$$1\angle 120\cdot 1\cdot\angle 120$$

$$1\angle 240$$

$$1\cdot\{\cos 240 + j\sin 240\}$$

$$= 1\left\{-\frac{1}{2} - j\frac{\sqrt{3}}{2}\right\}$$

$$= \boxed{K^2 = -0.5 - j0.867}$$

$$K + K^2 = -0.5 + j0.867 - 0.5 - j0.867$$

$$= -1$$

$$\boxed{K + K^2 + 1 = 0}$$

$$\downarrow$$

$$\Rightarrow \boxed{K + K^2 + K^3 = 0}$$

FAULT ANALYSIS

[redacted]

* Main purpose of fault analysis is design circuit breaker. (switch gear)

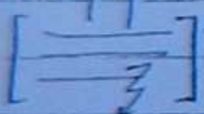
$I_f \rightarrow$ fault current

$I_f \times V_f$ = fault MVA (circuit Breaker rating).

Fault Analysis

Symmetrical fault Analysis

balanced condition during fault :- 3φ phase fault

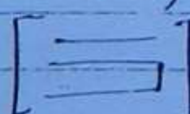


Unsymmetrical fault Analysis

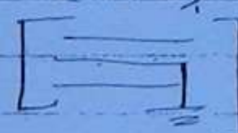
under fault unbalanced condition

Single line to Ground (SLG)

Double line fault (L-L)



Double line to ground (LLG)



• Most severe fault is 3φ fault and least is SLG.

• During design of circuit breaker 3φ fault is counted.

SLG fault is used in relay design (Proper setting)

The unsymmetrical fault analysis is also an important

- Single line diagram:- indicates that original P.S is 3ϕ and working at ~~a~~ balanced conditⁿ.

study since coz the knowledge of all types of fault is important to provide proper setting for the relay.

PER UNIT Analysis:-

Per unit value is unitless value.

$$\boxed{\text{P.U value} = \frac{\text{Actual value in Some unit}}{\text{Base/reference value in same unit}}}$$

Advantage of P.U Method:-

→ It simplifies power s/m calculation.

→ It avoids the discontinuity problem posed by presence of xmer in power system n/w. (Chief advantage)

* Single line diagram:

R

Y

B

N

$I_N = I_R + I_Y + I_B = 0$

$V_n = I_n Z_n = 0$

$S_n = V_n I_n^* = 0$

(no significance) neutral of single line diagram is called as zero power bus *

finally we have

R

Y $=$ R

B

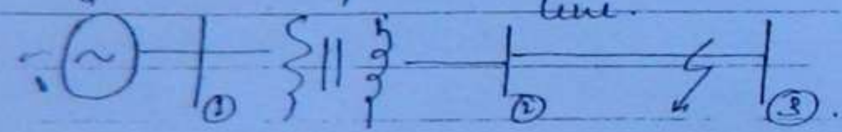
*

Single line diagram: the single line diagram representatⁿ of

+ Circuit Breaker rating should be high

power system indicates that original por system is 3ϕ and its working under balanced condition. When c/ks work under balanced condition, the advantage is by working on single phase basis (by adopting PU method), we can claim that we have completed 3ϕ analysis.

Explanation of point (2):-



Assumption 4 short circuit calculation:

1. Capacitance of circuit neglected (MVA → KV)
2. resistance of individual equipment neglected.

Note : By neglecting the resistance and capacitance the only parameter which limit s.c current is the Inductance.

+ Fault current is inductive, lagging current, lagging reactive power. Fault demands lagging reactive power.

+ Whenever fault occurs, the voltage of other phase decreases due to armature reaction (demagnetizatn - low magnetic field).

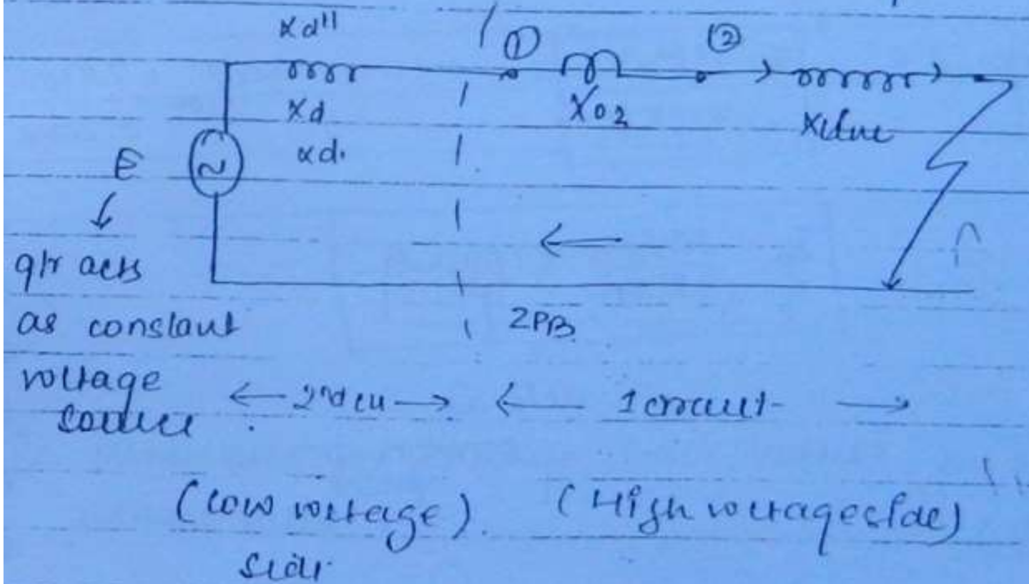
+ Fault current is maxm in subtracient state as minimum reactance.

3. Effect of saliency (silent pole) is neglect ; the

effect of non-uniform air of salient pole is neglected.

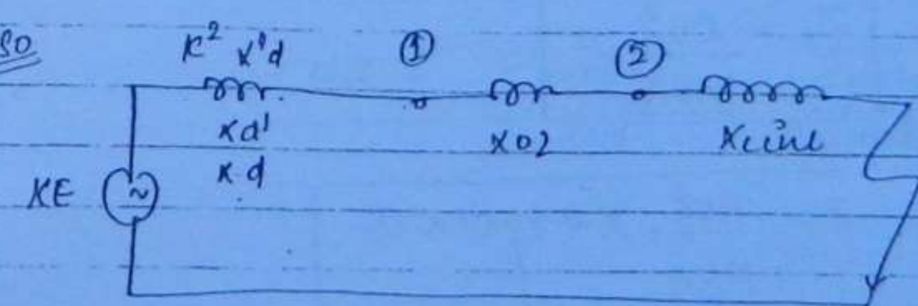
*→During S.C the voltage is effected, frequency constant (Active powe not change whereas reactive).

*. In load analysis the frequency prominently changes



→ X^{mer} can be represented as:
X_{01} (primary)
X_{02} (secondary)

So



converting g/r to high voltage side (K → turn ratio)

This method is practically impossible. So pu method is used.

- $Z_{eq}(LV) \neq Z_{eq}(HV)$
- $Z_{eq}\,L.V_{(pu)} = Z_{eq}\,HV_{(pu)}$

In pu method - X^{mer} are represented as * the series reactance and discontinuity is removed as the value of impedence, current remain same at both ends LV - HV

Selection of base values :- (only 4 P, V, I Z)

(1) We select base value for power and voltage.

→ Base voltage : - KV_b.
→ Base power : KVA_b or MVA_b.

Base voltage = 100 kV
Base power = 200 MVA

→ Base current in (Ampere) = $\boxed{I_b = \frac{KVA_b}{KV_b}}$.

$200/100 = 2 \times 1000$
$= 2000 A$

$$\boxed{I_b = \frac{MVA_b}{KV_b} \times 1000 \ A}$$

acts as conversion factor

→ Base impedence (in Ω) =

$$\boxed{Z_b = \frac{KV_b^2}{MVA_b} \ \Omega}$$

objective

$$\boxed{Z_b = \frac{KV_b^2}{KVA} \times 1000 = \Omega}$$

conversion factor.

objective
→ Base values considered when for calculation of 3φ.
→ 3φ power, line voltage.

$$\boxed{Z_{b,1\phi} = \frac{KV_{b\,1\phi}^2}{MVA_{b\,1\phi}}}$$

$$\boxed{Z_{b,3\phi} = \frac{KV_{b,line}^2}{MVA_{b\,3\phi}}}$$

$$\Rightarrow \quad \frac{(\sqrt{3} \times KV_{b\,1\phi})^2}{3 \times MVA_{b\,3\phi}} = \frac{K^2V_{b\,1\phi}}{MVA_{1\phi}}$$

$$\boxed{Z_{b\,3\phi} = Z_{b,1\phi}}$$

② whenever we change base values, p.u value change (not actual values.

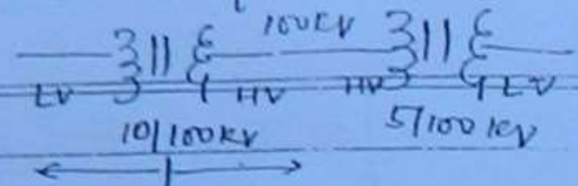
$$Z_{pu,old} = \frac{Z_{actual}}{Z_{b,old}} = \frac{Z_{actual}}{KV_{b}^2 old / MVA,old}$$

$$Z_{pu,res} = \frac{Z_{actual}}{Z_{b,res}} = \frac{Z_{actual}}{KV_b^2 res / MVA_b res}$$

*

$$\boxed{Z_{pu,res} = Z_{pu,old} \times \left(\frac{KV_b old}{KV_{b,res}}\right)^2 \times \left(\frac{MVA_{b,res}}{MVA_{b,old}}\right)}$$

:→ If two xmer are connected in series no of base value is 3
One common, LV T_1, HV (T_1 T_2), LV T_2



Example:

Q) An equipment is having 10 pu impedence on 100MVA, 10KV. Its pu impedence on ~~to~~ 10 MVA, 100KV is ___

$$Z_{pu.new} = 10 \times \left(\frac{10}{100}\right)^2 \times \left(\frac{10}{100}\right)$$

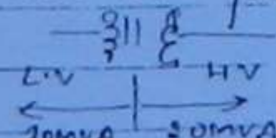
$$10 \times \frac{\cancel{100}}{\cancel{10000}} \times \frac{10}{\cancel{100}}$$

$$= 0.01 \text{ pu.}$$

Rules of selecting base values when xmer is present in n/w:

1) In circuit containing xmer, we have to selects two set of base values one for LV and another for HV side

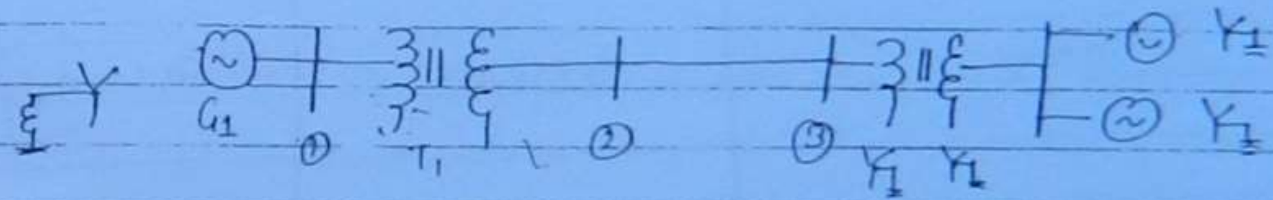
2) Common base power is selected for both sets or for entire n/w.



3) two different base voltages must be selected for LV and HV in such a way their ratio must be equal to transformation ratio of original xmer.

Example :-

Obtain the p.u equivalent reactance diagram for the power s/m shown below



G1: 30 MVA, 10.5 kV, $X'' = 1.6$ p.u

G2: 15 MVA, 6.6 kV X''_d 1.2 p.u

G3: 25 MVA, 6.6 kV $X''_d = 0.56$

T_1 = 15 MVA, 33/11 kV, $X = 15.2\,\Omega$ p ph on HV.

T_2 = 15 MVA, 33/6.2 kV, $X = 16\,\Omega$/ph on HV side

$\frac{N_2}{N_1}$

T.L = 20.5 Ω/ph

15.2

Initial values (reactance)

	LV side of T_1	HV side of T_1 and T_2	L.V side T_2	
G_1	1.6 pu on 30 MVA, 10.5 kV	—	—	
G_2	—	—	1.2 pu on 15 MVA, 6.6 kV	
G_3	$15.2 \times \frac{11}{33}$ = 1.69 Ω	15.2 pu.	0.56 pu on 25 MVA 6.6 kV	
T_1				
T_2		16 Ω/ph	0.86 Ω/ph	0.86 Ω/ph
L		20.5 Ω/ph		

Base value:-

	LV side of T_1	HV side of T_1/T_2	LV side of T_2
MVA_b	30 MVA	30 MVA	30 MVA
KV_b	11 KV	33 KV	6.2 KV
Z_b	$\frac{11^2}{30} = 4.03\,\Omega$	$33^2/30 = 36.33\,\Omega$	$\frac{6.2^2}{30} = 1.28\,\Omega$

Formula used $= \frac{KV_b^2}{MV_b}$.

G1: 1.6 pu on 30MVA, 10.5 KV

$$Z_{pu\,new} = 1.6 \times \left(\frac{30}{30}\right) \times \left(\frac{10.5}{11}\right)^2$$

$$\boxed{Z_{pu\,new} = 1.46\,pu.}$$

$$\boxed{V_{G_1} = \frac{10.5}{11} = 0.96\,pu}$$

$\frac{\text{Actual}}{\text{Base}}$.

G2:- 1.2 pu on 15MVA, 6.6 KV

$$Z_{pu\,(new)} = 1.2 \times \left(\frac{30}{15}\right) \times \left(\frac{6.6}{6.2}\right)^2$$

$= \boxed{Z_{pu(new)} = 2.72 \text{ p.u}}$

$$V_{G2} = \frac{6.6}{6.2} = 1.06 \text{ p.u.} \qquad \boxed{V_{G2} = 1.06 \text{ p.u}}$$

G3:. 0.56 pu on 2.5 MVA 6.6 kV

$$Z_{pu(new)} = 0.56 \times \left(\frac{30}{2.5}\right) \times \left(\frac{6.6}{6.2}\right)^2$$

$$\boxed{Z_{pu(new)} = 0.76 \text{ pu}}$$

$$V_{G3} = \frac{6.6}{6.2} = 1.06 \text{ pu}$$

T1:. $1.69 \text{ p}\Omega$ w.r.t LV side

base impedence on LV side of T1 = $4.03\,\Omega$

$$X_{T.p.u} = \frac{1.69\,\Omega}{4.03\,\Omega} = 0.41 \text{ p.u.}$$

$1.52\,\Omega/\text{ph}$ w.r.t HV side

base impedence = $36.33\,\Omega$ ✓

$$X_{Tpu} = \frac{15.2}{36.33} = 0.41 \text{ p.u.}$$

$$\boxed{X_{Tpu} = 0.41 \text{ p.u}}$$

T2

$0.56\,\Omega/\text{ph}$ w.r.t ~~1.28~~ LV side of T_2

base impedence on LV side of T_2 = $1.28\,\Omega$

$$X_{Tpu} = \frac{0.56}{1.28} = 0.434 \text{ p.u}$$

16Ω/ph w.r.t to H.V side of T2

Base value = 36.33 Ω

$$X_{T_2} = \frac{16}{36.33} = 0.434 \text{ p.u.}$$

$$\boxed{X_{T_2} = 0.434 \text{ p.u}}$$

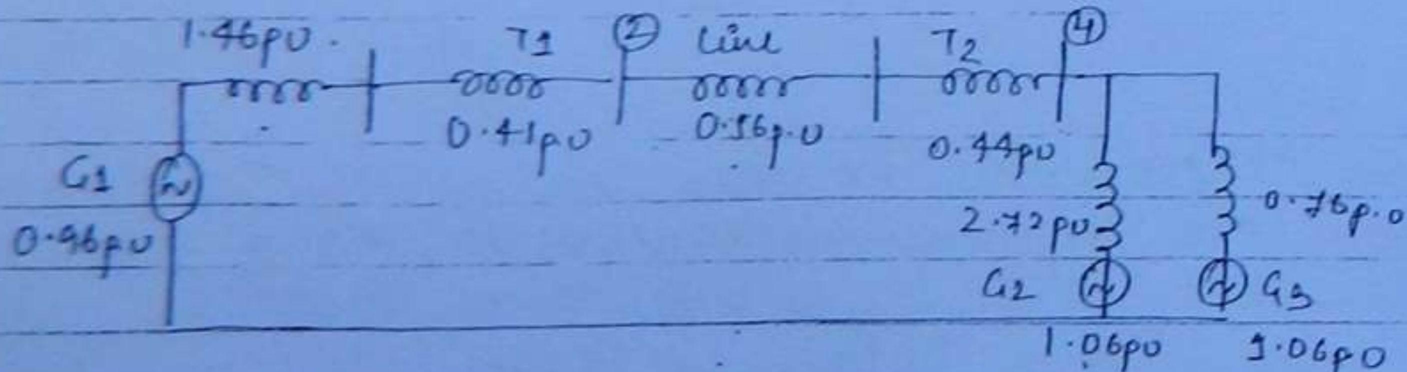
<u>Line</u>

$X_L = 20.5$ on HV side T2 and T1

base value = 36.33Ω

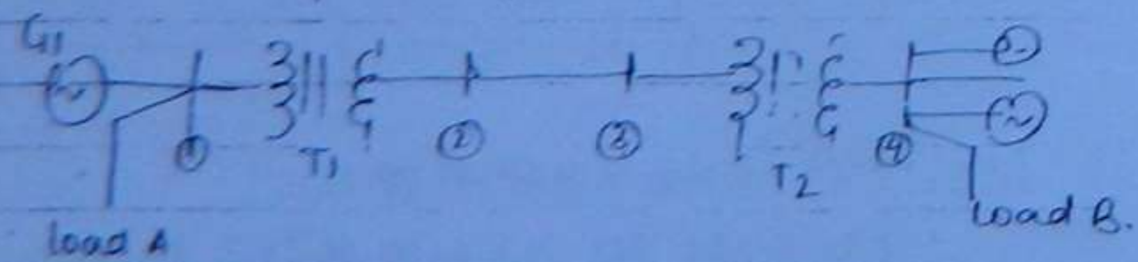
$$X_{line} = \frac{20.5}{36.33} = 0.56 \text{ p.u.}$$

$$\boxed{X_{line} = 0.56 \text{ pu}}$$



<u>Per unit reactance diagram.</u>

b) Two loads Ⓐ and Ⓑ are connected to bus 1 and ~~bus 4~~ 4 respectively



load A is 40MW, 11KV, 0.9 pf lag.

load B 40 MW 66KV, 0.5 pf lag.

represent them in reactance diagram

Solution:

Load A $\quad V = \frac{11\,kW}{11\,kV} = 1\,p.u.$

$\cos\phi = 0.9 \Rightarrow \sin\phi = 0.43$

$P = \frac{40\,MW}{30\,MVA} = 1.33\,p.u.$

$P = 1.33\,p.u. \Rightarrow S = \frac{1.33}{0.9} = 1.48\,p.u.$

$Q = S\sin\phi = 1.48 \times 0.43$
$= 0.64\,p.u.$

$R_{load\,A} = V^2/P = 1^2/1.33 = 0.75\,p.u.$

$X_{load} = V^2/Q = 1.56\,p.u.$

Load B

$V = 40 \times \frac{1.1}{\ } \times \frac{66}{62} = 1.06\,p.u.$

$\cos\phi = 0.5$

$P = \frac{40}{30} = 1.33\,p.u.$

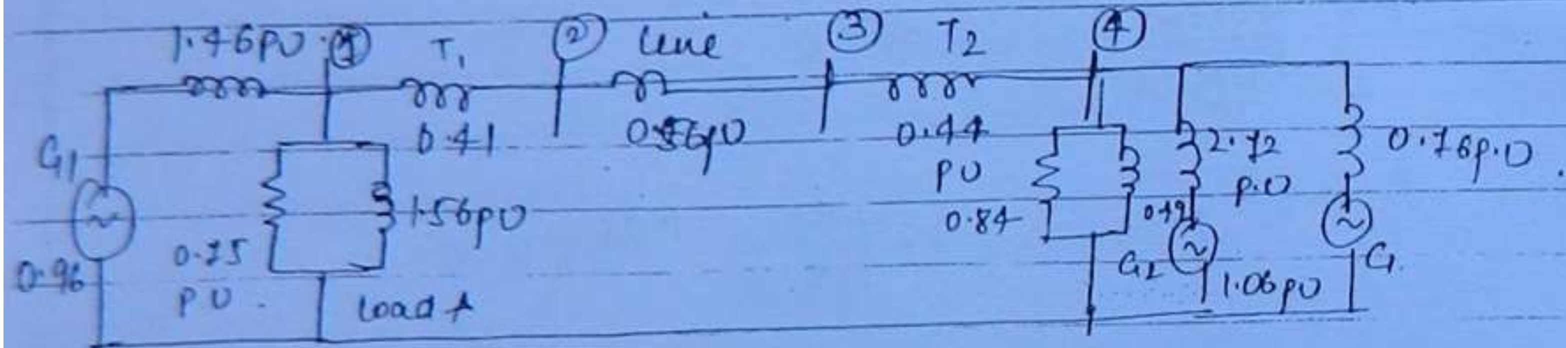
$S = \frac{1.33}{0.5} = 2.66\,p.u.$

$Q = S\sin\phi = 2.26\,p.u.$

* load in S.C → constant impedence
load in stability → constant admittance.

$$R_{loadA} = V^2/P = \frac{1.06^2}{1.33} = 0.84\, p.u$$

$$X_{load B} = \frac{V^2}{Q} = \frac{1.06 p.u}{2.28} = 0.49\ p.u$$



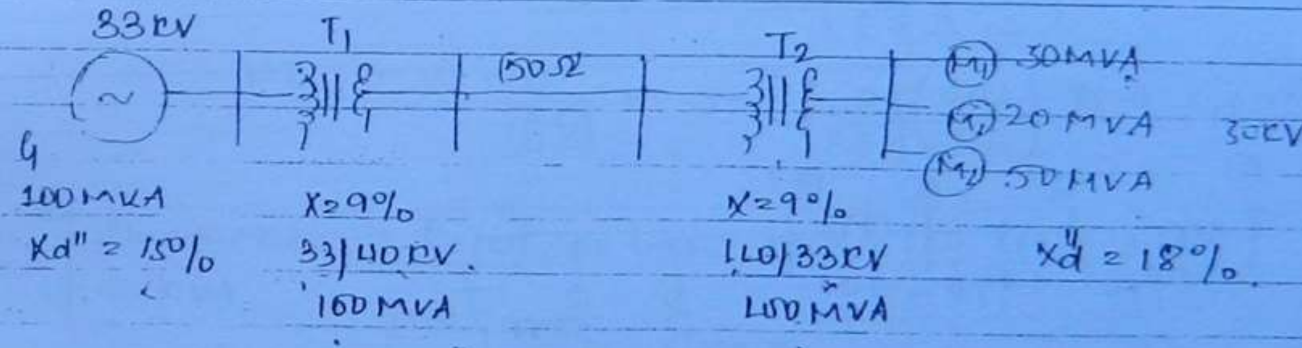
$R_{loadA} = V^2/P = \frac{1.06^2}{1.33} = 0.84 p.u$

$X_{load B} = V^2/Q = \frac{1.06 p.u}{2.28}$

Dated
5-Sept 12

Example:-

A 100 MVA, 33kV 3-ϕ g/r has sub-trasient reac of 15% the g/r is connected to the m/r name rate I/P 30MVA, 20, 50 MVA. At 30kV with 18% subtransient reactan the 3-ϕ T/F's are rated at 100 MVA, 33/110kV with leakage reactance of 9%. the line has a reactance of 50Ω obtain pu equivalent reac. diagram.



1) Common base MVA : 100 MVA
Base voltage of LV side of T_1/T_2 = 33kV
" " of HV side of T_1 & T_2 = 110kV

1) $X_{G1} = 0.15\,pu$ (Related value of equipment & selected base value are same).

2) $X_{T_1} = 0.09\,pu$ (" " ")

3) $Z_b = \frac{(KV_b)^2}{MVA_b} = \frac{(110)^2}{100} = 121\Omega$

$Z_b = 121\ \Omega$

$X_{line}(pu) = \frac{50}{121} = 0.41\,pu$

$\boxed{X_{line}(pu) = 0.41\,pu}$

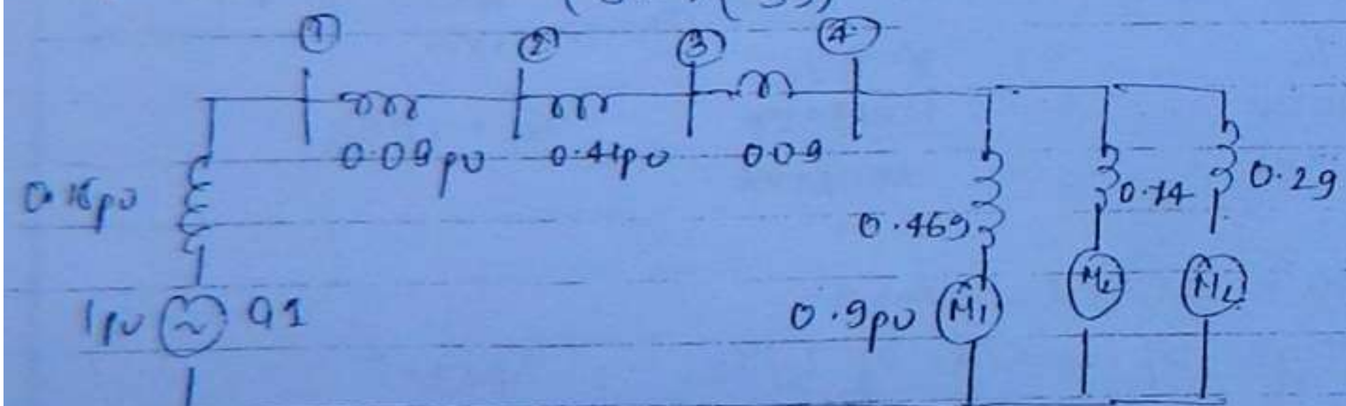
4) $X_{T_2} = 0.09\, pu$

$$X_{m_1} = X_m \left(\frac{MVA_b(new)}{MVA_b\, old}\right)\left(\frac{KV base\, old}{KV base(new)}\right)^2$$

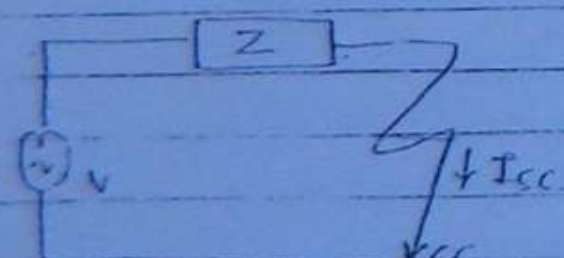
$$= 0.18\left(\frac{100}{300}\right)\left(\frac{30}{33}\right)^2 = 0.496\, p.u$$

$$X_{m_2} = 0.18\left(\frac{100}{20}\right)\left(\frac{30}{33}\right)^2 = 0.74\, p.u$$

$$X_{m_3} = 0.18\left(\frac{100}{50}\right)\left(\frac{30}{33}\right)^2 = 0.24\, p.u$$



Short circuit KVA :-



V = Rated voltage
I = Rated current
Z = internal impedance

$$\boxed{I_{sc} = V/Z} \quad -(1)$$

$Z_{base} = V/I$

$Z_{pu} = Z/Z_{base} = \frac{Z}{V/I}$

Note: Ratio of rated current to short ckt current of equipment given p.u impedance!

$$\boxed{Z_{pu} = \frac{I}{V/Z} = \frac{I}{I_{sc}}}$$

$$\% Z = \frac{I}{I_{sc}} \times 100$$

$$I_{sc} = \frac{I \times 100}{\% Z}$$

$$V I_s = \frac{V I \times 100}{\% Z}$$

$$\boxed{\text{Short ckt KVA} = \frac{\text{Rated or base KVA} \times 100}{\% Z}}$$

Procedure of short circuit calculation:

1) Convert the given single line diagram of power s/m. N/w into p.u equivalent impedence diagram.

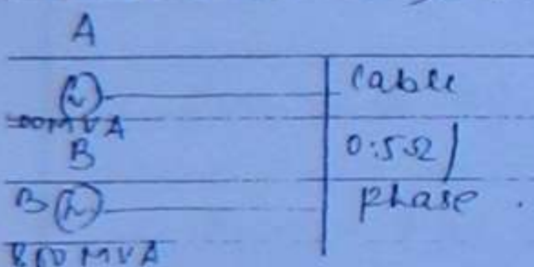
2) Identify the fault terminal. Across the fault terminals reduce the n/w into thevenins equivalent ckt

3) Using the %age thevenins equivalent impedence short ckt KVA can be calculated using the following formulae.

$$\boxed{\text{Short ckt KVA} = \text{Common base KVA} \times \frac{100}{Z \text{ in } \%}}$$

Example:-

A, 2 generating station having S.C capacities of 1200MVA, 800 MVA resp. & operating at 11 KV or linked by an interconnected cable having a reactance of 0.5Ω/phase. Determine short ckt capacities of each statn. (how much power flows when SC occurs)



Let the rated base MVA = 1200

∴ for station A, the %X is

$$1200 = \frac{1200 \times 100}{\% X}$$

$$\Rightarrow \% X_A = 100$$

station B %age Reactance is

$$800 = \frac{1200 \times 100}{\% X_B}$$

$$\% X_B = 150\%$$

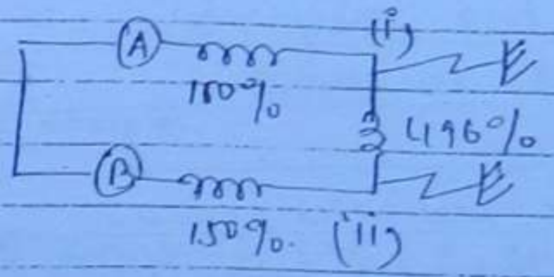
$$Z_{base} = \frac{KV_b^2}{MVA_b} = \frac{(11)^2}{1200} = 0.1008\Omega$$

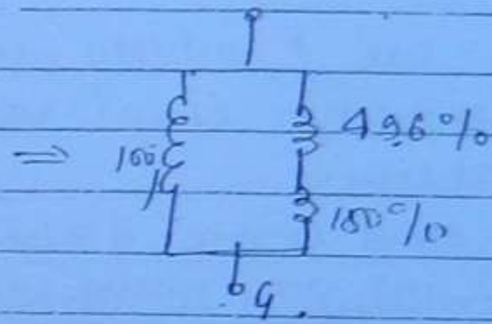
$$X_{cable} = \frac{0.5}{0.1008} = 4.96 \text{ p.u.}$$

$$\boxed{\% X_{cable} = 496\%}$$

Now we can calculate short ckt capacities of each statn when fault occurs on the terminal of statn (A-)

and sectn (B-ii).





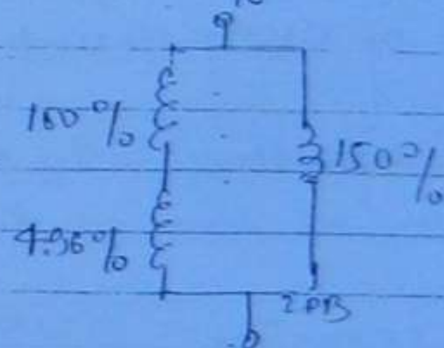
$\%Z_{th} = 86.59\%$.

Short circuit MVA of statn A $= 1200\,MVA \times \frac{100}{86.59} = 1385\,MVA$

When fault occurs on terminal of statn B short ckt MVA of stat B, $X_{th} = 119.84\%$

Short circuit MVA $= \frac{1200 \times 100}{119.84}$

1001 MVA



→ If we want to keep the ckt breaker at P & Q shown, then they must have braking capacities of 1385 & 1001 MVA resp.

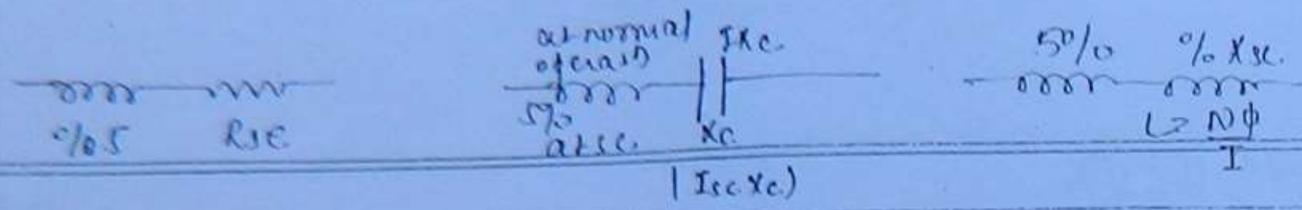
Questn

If we have ckt breaker of lesser capacity then how can it be effectively used?

Answer

1) To limit the short ckt current, resistance is not used due to continous power loss.

2) Series capacitors are not used due to break down of dielectric during short ckt (At SC it has high voltage $I_{sc} X_c$ across & act as punctured dielectric)



3) Series Reactors are widely used but they are designed with no core material to avoid saturation problem.
(As the current starts to rise, ϕ also rises but after certain time, even increment of SC current, ϕ becomes saturated thus the value of L keeps on ↓sing with ↑sing Isc & thus behaves as a short ckt path. This is becoz air core is used as ϕ in airgap is never saturated).

→ Purpose of using series Reactor – to limit SC current

Purpose of using shunt reactors – to avoid ferranti effect

Series capacitors – To ↑ steady state power limit
(As when we have inductance then power delivered is less)

Shunt capacitor – → to improve P.F

* Feeder reactors are very commonly used compared to generator & bus bar reactors.

Example:-

150 KVA equipment is having 5% reactance, To limit the short ckt KVA to 500 KVA the value of % Reactance reqd for series reactors is –

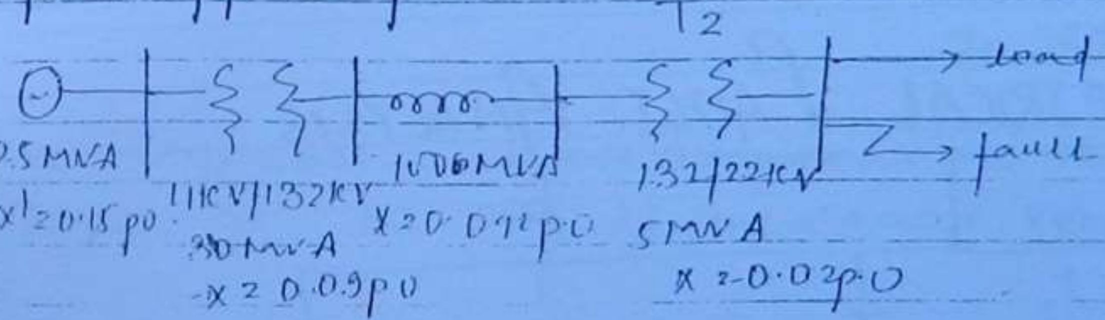
$$500 = \frac{150 \times 100}{5\% + X_{sc}\%}$$

$5\% + X_{se} = 20$

$\% X_{se} = 15\%$

Example:-

A symmetrical 3-φ short ckt occur on the 22kV busbar as shown in the fig. Calculate fault current the fault apparent power.



Let the common base MVA = 100MVA

$$X_{G1} = 0.15 \times \left(\frac{100}{25}\right)\left(\frac{11}{11}\right)^2 = 0.6 p.u$$

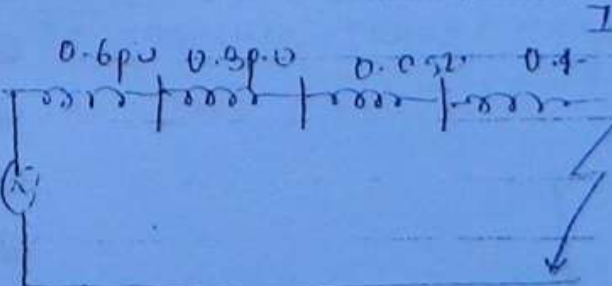
$$X_{T_1} = (0.09) \times \left(\frac{100}{30}\right) = 0.3 p.u$$

$$X_{line} = 0.092 p.u$$

$$X_{T_2} = 0.02 \times \frac{100}{5} = 0.4 p.u$$

Base current on LV side of T_2 is

$$I_{base} = \frac{100 \times 10^6}{\sqrt{3} \times 22 \times 10^3} = 2624.31 \text{ Amp}$$



$$I_f = \frac{1\angle 0^\circ}{j(0.6 + 0.3 + 0.92 + 0.4)} = \frac{V_{pu}}{\text{Total pu X}}$$

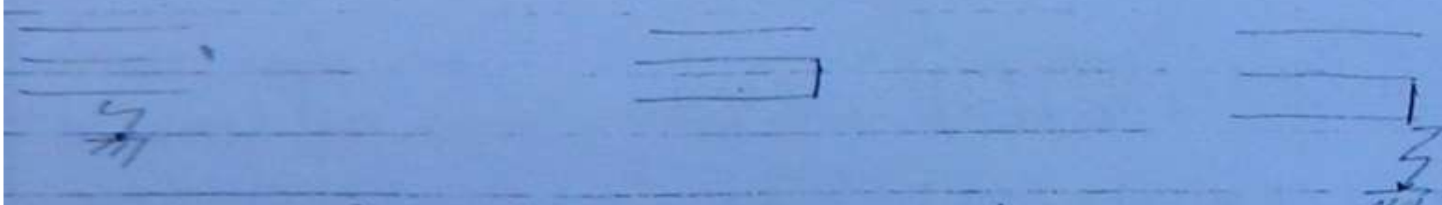
I_f (actual) = I_f(p.u) × I_f(base)

I_f(actual) = 0.718 × 2624.3 = 1884.27 Amp.

Fault MVA = 0.718 pu
= 0.718 × 100 MVA
= 71.8 MVA

UNSYMMETRICAL FAULT ANALYSIS

- LG Fault
- LL Fault
- LLG Fault



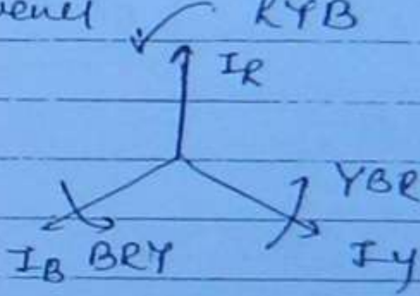
→ Symmetrical fault all the 3ϕ are at different condition

∴ By working on 1-ϕ base, we cann't claim that we have complete 3ϕ analysis

$$\begin{bmatrix} I_R \\ I_Y \\ I_B \end{bmatrix} = \begin{bmatrix} \\ \\ \\ \end{bmatrix} + \begin{bmatrix} \\ \\ \\ \end{bmatrix} + \begin{bmatrix} \\ \\ \\ \end{bmatrix}$$

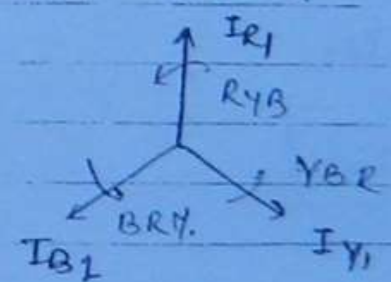
$$\begin{array}{l} I_R = \\ I_Y = \\ I_B = \end{array} \begin{bmatrix} I_{R_1} \\ I_{Y_1} \\ I_{B_1} \end{bmatrix} + \begin{bmatrix} I_{R_2} \\ I_{Y_2} \\ I_{B_2} \end{bmatrix} + \begin{bmatrix} I_{R_0} \\ I_{Y_0} \\ I_{B_0} \end{bmatrix}$$

$\downarrow$ +ve sequence $\quad \downarrow$ -ve seq. $\quad \downarrow$ zero sequence

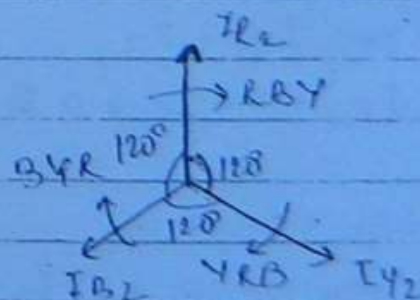


Sequence Components:

+ve sequence — these component are having exactly same as the original unbalanced vectors.

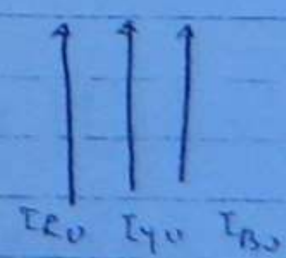


-ve sequence: these component have a sequence exactly opposite to that of original unbalance vector.



Zero Sequence —

these components have no sequence. (equal magnitude)



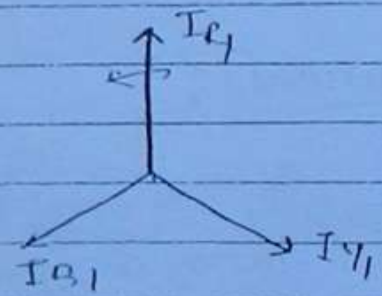
→ If we want to convert B, Y component component then we have 'a' operator

$$\boxed{\begin{array}{l} a = 1\angle 120^\circ \\ a^2 = 1\angle 240 \end{array}}$$

$I_{R_1} = I_{R_1}\angle 0^\circ$

$I_{Y_1} = I_{R_1}\angle 240^\circ$
$a^2 I_{R_1}$

$I_{B_1} = I_{R_1}\angle 120$
$a I_{R_1}.$



$\boxed{I_{R_0} = I_{Y_0} = I_{B_0}}$

$I_{R_2} = I_{R_2}\angle 0^\circ$
$I_{Y_2} = I_{R_2}\angle 120^\circ$
$a I_{R_2}$
$I_{B_2} = I_{R_2}\angle 240^\circ$
$a^2 I_{R_2}$

$I_R = I_{R_0} + I_{R_1} + I_{R_2}$

$I_Y = I_{Y_0} + I_{Y_1} + I_{Y_2}$
$I_{R_0} + a^2 I_{R_1} + a I_{R_2}$

$I_B = I_{B_0} + I_{B_1} + I_{B_2}$
$I_{R_0} + a I_{R_1} + a^2 I_{R_2}$

$$\begin{bmatrix} I_R \\ I_Y \\ I_B \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} I_{R_0} \\ I_{R_1} \\ I_{R_2} \end{bmatrix}$$

$$[I]_{RYB} = [A][I]_{012}$$

$$[V]_{RYB} = [A][V]_{012}$$

Relation of operator 'a' →

('a') → also known as transformation

→ $a = 1\angle 120^\circ = 1(\cos 120 + j\sin 120)$
$= -0.5 + j0.866$

→ $a^2 = 1\angle 240 = 1(\cos 240 + j\sin 240)$
$-0.5 - j0.866$

→ $a^3 = 1\angle 360^\circ = 1$

→ $a^4 = a^3 . a = a$

→ $a^5 = a^3 a^3 = a^2$

→ $1 + a^2 + a = 0$

→ $1 - a^2 = 1 - (-0.5 - j0.866) = \frac{3}{2} + j\frac{\sqrt{3}}{2} = \sqrt{3}\left(\frac{\sqrt{3}}{2} + j\,\frac{1}{2}\right)$

$\sqrt{3}\angle 30^\circ$

→ $1 - a = \sqrt{3}(\angle -30^\circ)$

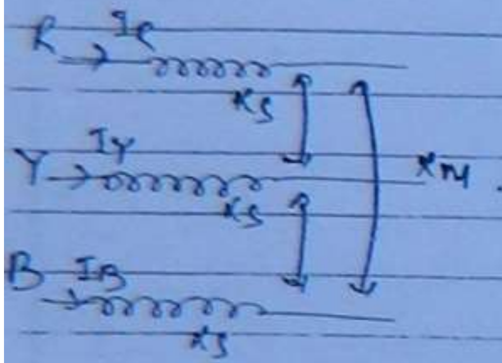
→ $[I]_{RYB} = [A][I]_{012}$

→ $[I]_{012} = [A^{-1}][I_{RYB}]$

where $[A]^{-1} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a^2 \\ 1 & a & a \end{bmatrix}$

* The original N/W are mutually fixed.

* The three sequence N/w +ve, -ve, zero sequence N/w's are mutually disjoined



$$\begin{bmatrix} V_R \\ V_Y \\ V_B \end{bmatrix} = \begin{bmatrix} X_S & X_M & X_m \\ X_M & X_S & X_M \\ X_M & X_m & X_S \end{bmatrix} \begin{bmatrix} I_R \\ I_Y \\ I_B \end{bmatrix}$$

$$\boxed{[V]_{RYB} = [X]_{RYB} [I]_{RYB}}$$

$$[A][V]_{012} = [X]_{RYB} [A] [I]_{012}$$

$$[V]_{012} = [A]^{-1} [X]_{RYB} [A] [I_{012}]$$

$$[X]_{012} = \begin{bmatrix} X_S + 2X_m & 0 & 0 \\ 0 & X_S - X_m & 0 \\ 0 & 0 & X_S - X_m \end{bmatrix}$$

The off diagonal elements are zero in the above matrix, we can conclude that the -ve, zero sequence N/w's are mutually disjoined.

Example:-

A transmission line has self reactance of j0.6Ω/phase & mutual reactance of j0.1Ω b/w any 2 phase. Find +ve, -ve & zero sequence reactance of the transmission line

$$X_0 = X_s + 2X_m$$
$$j0.6 + 2(j0.1)$$
$$= j0.8\,\Omega$$

$$X_1 = X_s - X_m$$
$$= j0.6 - j0.1$$
$$= j0.5\,\Omega$$

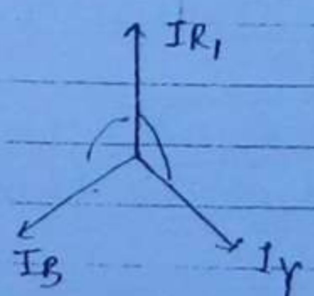
$$X_2 = X_s - X_m$$
$$= j0.6 - j0.1$$
$$= j0.5\,\Omega$$

→ for static devices phase sequence is not imp.

Example:

In a 3φ balanced s/m, the current in each phase is 10 Amp. the phase sequence is RYB. find the sequence current. Find the sequence components.

Soln:-



$$I_R = 10\angle 0^\circ$$
$$I_Y = 10\angle 240^\circ = a^2 10$$
$$I_B = 10\angle 120^\circ = a\,10$$

$$[I]_{RYB} = [A][I]_{012} \Rightarrow [I]_{012} = [A^{-1}][I]_{RYB}$$

$$\begin{bmatrix} I_{R0} \\ I_{R1} \\ I_{R2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} 10 \\ a^2 10 \\ a10 \end{bmatrix}$$

$$I_{R_0} = \frac{1}{3}(10 + a^2 10 + a 10) = 0$$

$$I_{R_1} = \frac{1}{3}(10 + a^3 10 + a^3 10) = 10.$$

$$I_{R_2} = \frac{1}{3}(10 + a^4 10 + a^2 10) = 0$$

→ By this we can say that in a balanced s/m the only current in the N/C is +ve sequence current.

Example:-

The fuse in Y & B are removed find seq components

Sol^n = $I_R = 10\angle 0^\circ$ $\quad I_Y = I_B = 0$

$$\begin{bmatrix} I_{R_0} \\ I_{R_1} \\ I_{R_2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} 10 \\ 0 \\ 0 \end{bmatrix}$$

$$I_{R_1} = I_{R_2} = I_{R_0} = 10/3\ A$$

SEQUENCE IMPEDENCES:

[strictly speaking X_{a_2} is slightly less than X_{a_1}]

Generator:- $\boxed{X_{G_1} \simeq X_{G_2}}$

(+ve seq Reactance) (-ve seq Reactance)

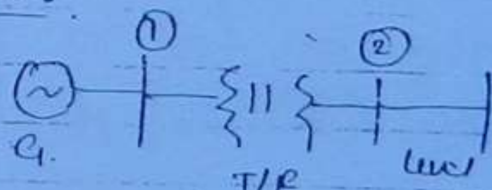
$$X_{a_1} \begin{cases} \xrightarrow{\text{(salient R/r)}} X_{a_1} = \dfrac{X_d'' + X_q''}{2}, \dfrac{X_d' + X_q'}{2}, \dfrac{X_d + X_q}{2} \\ \xrightarrow[\text{(cylindrical r/r)}]{} X_{a_1} = X_d'', X_d', X_d. \end{cases}$$

$$\boxed{X_{G_0} << X_{a_1}}$$

- For static devices like (T/F & Transmission line)

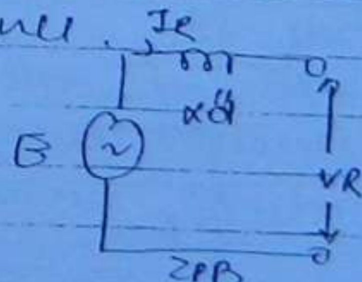
$$X_1 = X_2$$
$$X_0 >> X_1$$

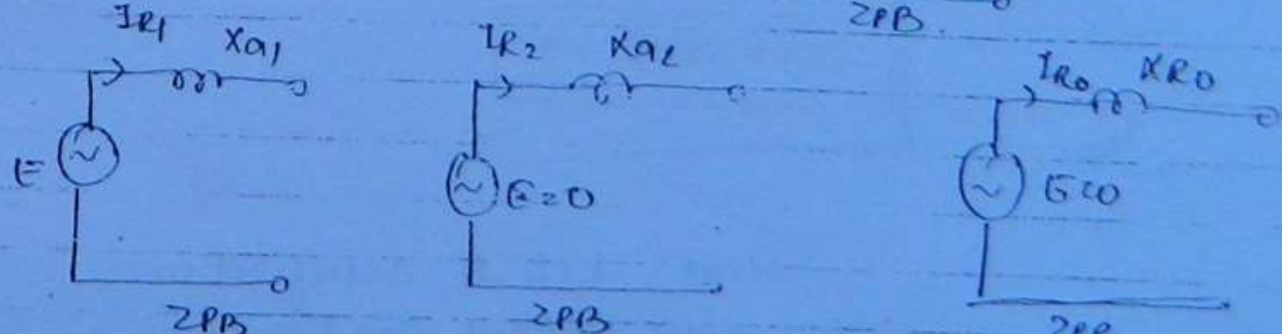
Sequence N/W :-



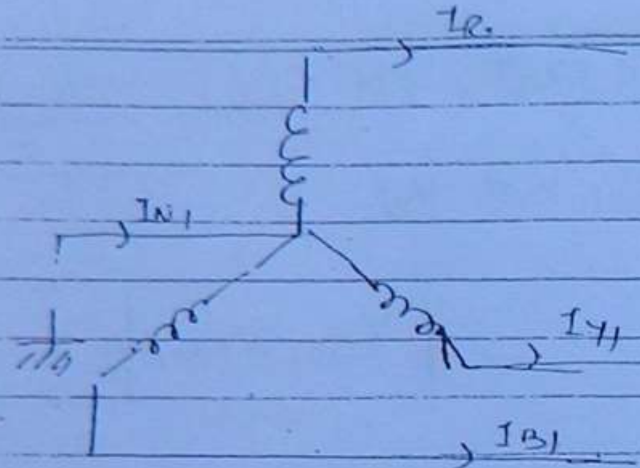
Generator Representation :

In original N/W with symmetrical fault analysis Gen. is used as const voltage element behind the reactance.





(positive) (Negative) (zero)



$I_N = I_{n1} + I_{n2} + I_{n0}$

$= (I_{R1} + I_{Y1} + I_{B1}) +$
$(I_{R2} + I_{Y2} + I_{B2}) +$
$(I_{R0} + I_{Y0} + I_{B0})$

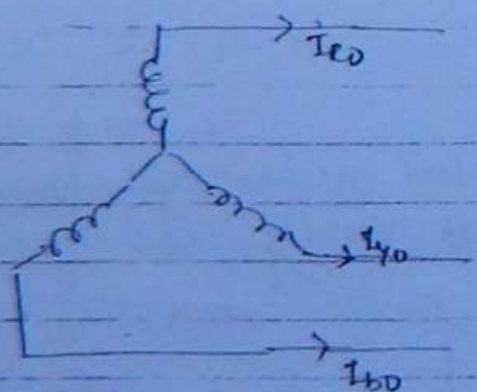
I_{n2} ∴ sum of outgoing current $= 0$

$\boxed{I_N = 3I_{R0}}$

∴ positive seq current will flow whether neutral is ground or not

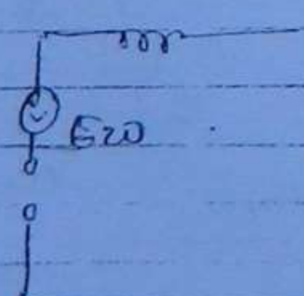
→ If neutral grounded with inductor then

1)

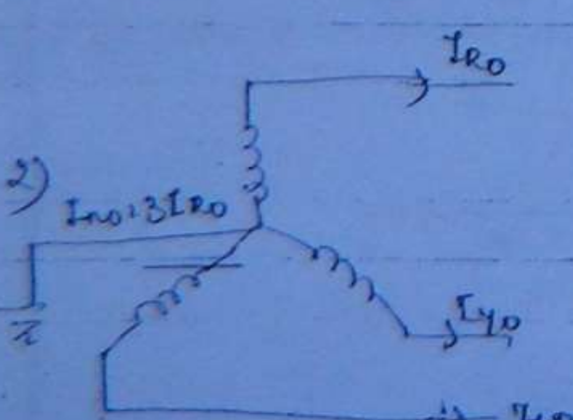


sum of incoming current $= 0$
Sum of out going current $= 3I_{R0}$
KCL not satisfied.
So such current doesnot exist

∴ open circuit

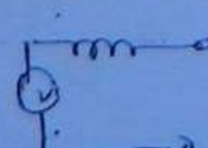


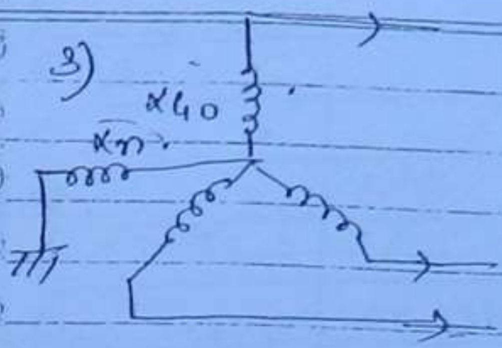
2)



Here KCL is satisfied so now current can flow

So



3) 

Now neutral is not ZPB

it has drop of $3 I_{n0} x_n$.

∴ unbalanced condn.

$V_{R_1} = 3 I_{R0} X_{n0} + I_{n0} X_{G0}$.

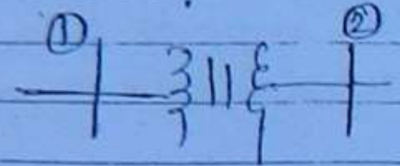
$$\boxed{X_0 = (X_{G0} + 3X_n)}$$

Notes

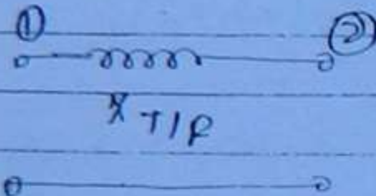
1) Only positive seq n/w contain voltage source
2) Negative & zero seq donot contain voltage sources
3) Condition of neutral has got no effect in the representatn of gen. both in +ve & -ve seq N/w
4) However, conditn of neutral has got effect in the representatn of gen, in the zero seq N/w
If neutral is unloaded show open ckt. If neutral is solidly grounded show a S.C.
If the neutral is grounded with reactance X_n, $3X_n$ must be added to zero sequence reactance of g/r. X_{G0} to get total zero sequence reactance

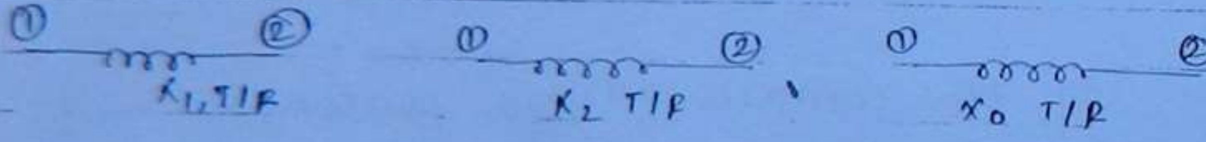
$$\boxed{X_0 = X_{G0} + 3X_n}$$

Transformer Representatⁿ:



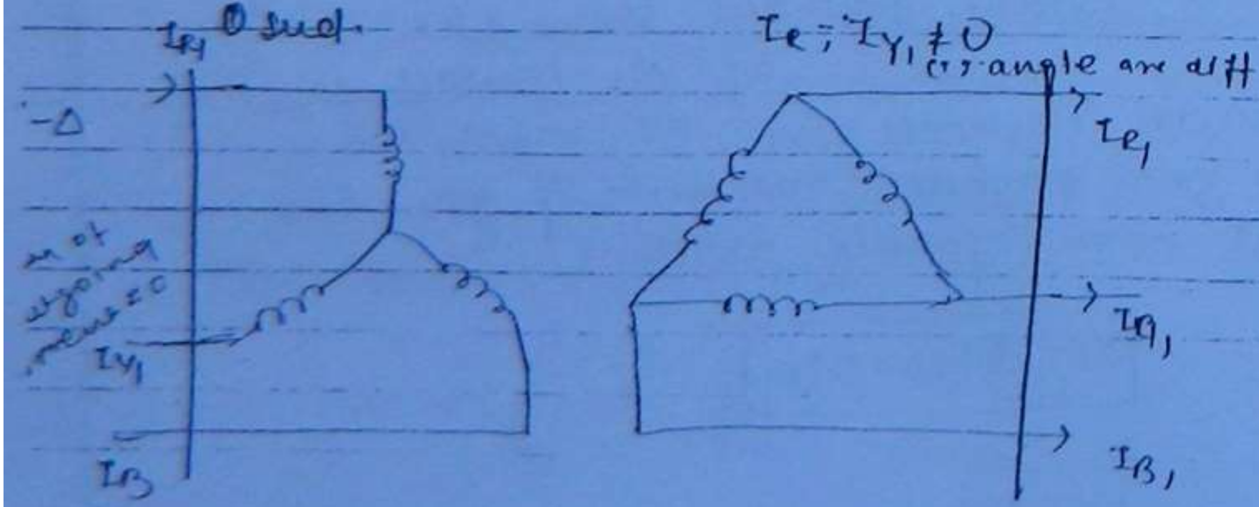
→ In original n/w T/F is shown as series reactance.





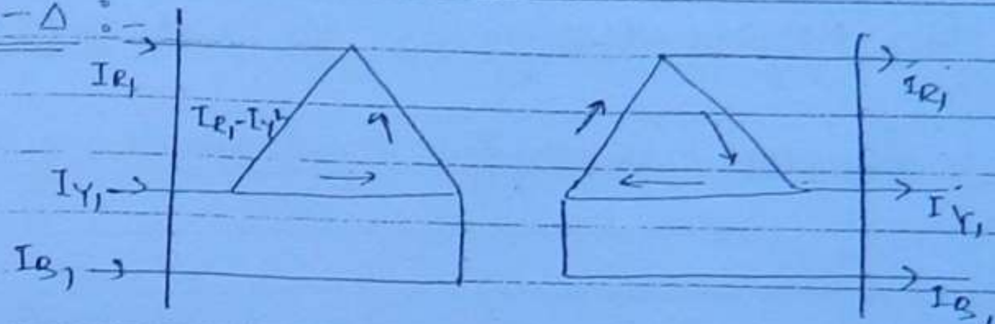
ZPB	ZPB	ZPB
positive Seq	Negative Seq	Zero Seq

→ Power xmer primary & secondary can be connected in both star & delta.



∴ type of windg has no reactance of T/P

$\underline{\Delta - \Delta}$:-



Condition:

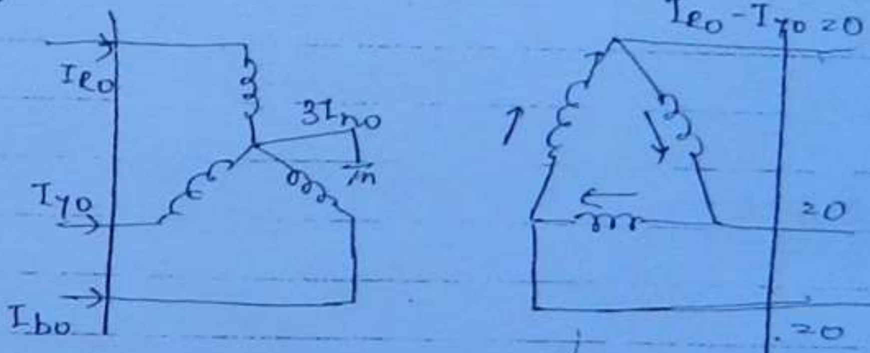
x^{mer} has no effec of type of n/w whether Y or Δ no effect due to neutral ground

$I_{R_1} - I_{Y_1} \neq 0$

∵ Mag is same but phase angle = 120°

Zero Sequence:

1) Y–Δ

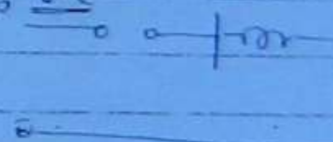


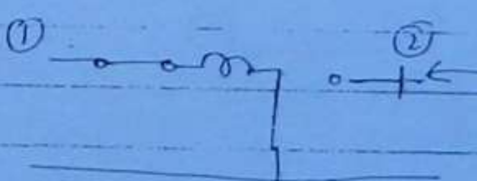
KCL is not satisfied

∵ in coming = $3I_R$

Outgoing = 0

∴ O.C

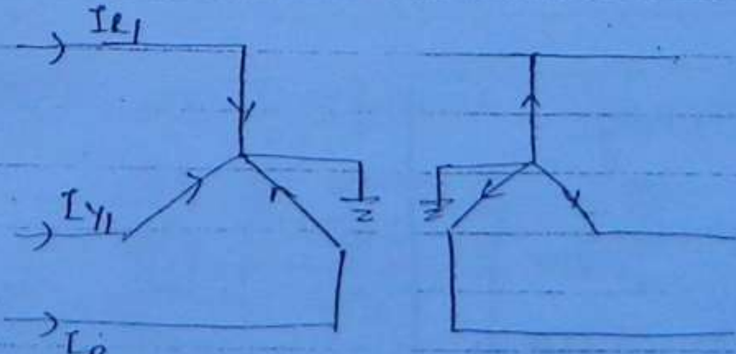




→ If star part is grounded then KCL is satisfied

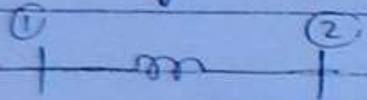
SC

2) Y–Y

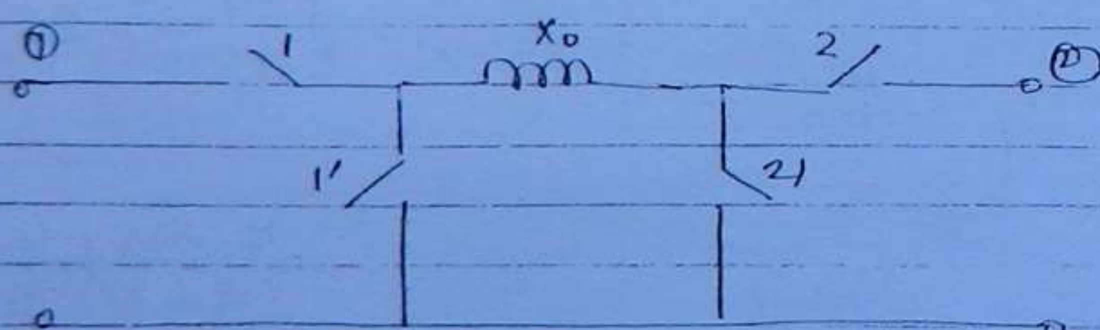


→ If secondary is ungrounded.

→ If it is grounded.



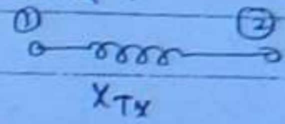
SWITCH DIAGRAM:



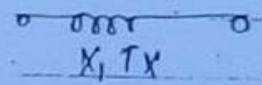
* $1, 1' \rightarrow$ Primary
  $2, 2' \rightarrow$ Secondary
  $1, 2 \rightarrow$ Series switches
  $1', 2' \rightarrow$ Shunt switches

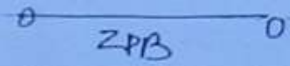
Representatⁿ of Transmission Line :-

In cymmetrical fault represented as series reactance.



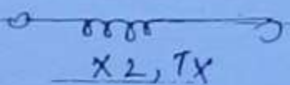
① +ve sequence

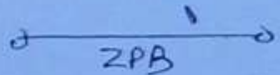




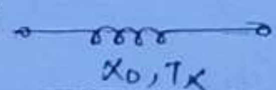
→ No conditⁿ for T.L

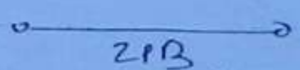
② -ve sequence





③ Zero sequence

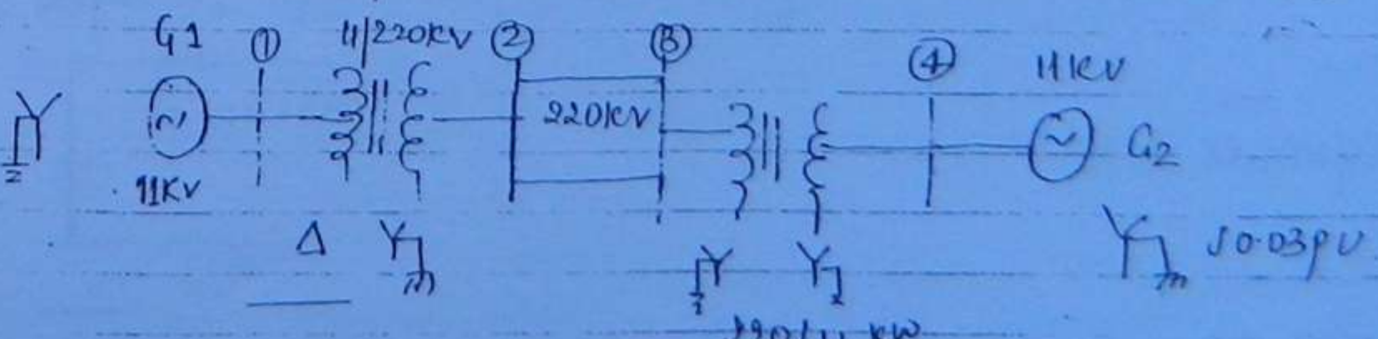




* Without verifying any conditⁿ a T.L can be simply represented as series reactance element in all 3-sequen n/w

Problem :-

Obtain the 3-sequence n/w for the n/w shown in figure



→ G_1 → $X_1 = X_2 = j0.25$; $X_0 = j0.05$ pu.

G_2 → $X_1 = X_2 = j0.2$; $X_0 = j0.05$ pu.

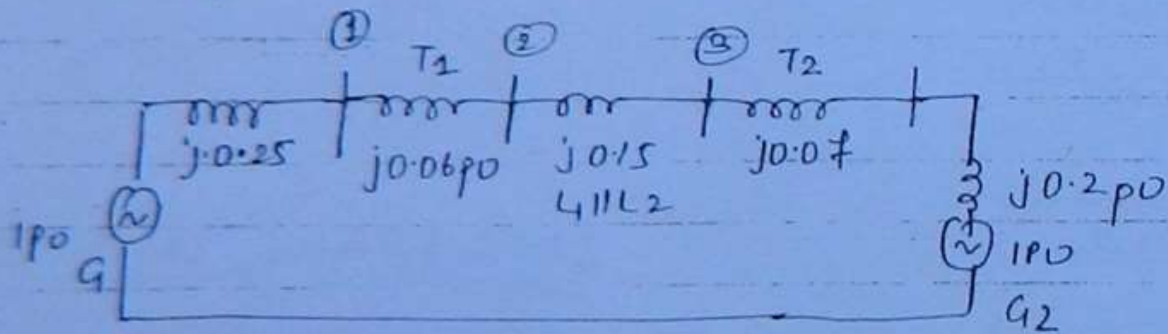
T_1 → $X_1 = X_2 = X_0 = j0.06$ p.u.

T_2 → $X_1 = X_2 = X_2 = j0.07$ p.u

L_1, L_2 → $X_1 = X_2 = X_0 = j0.3$.

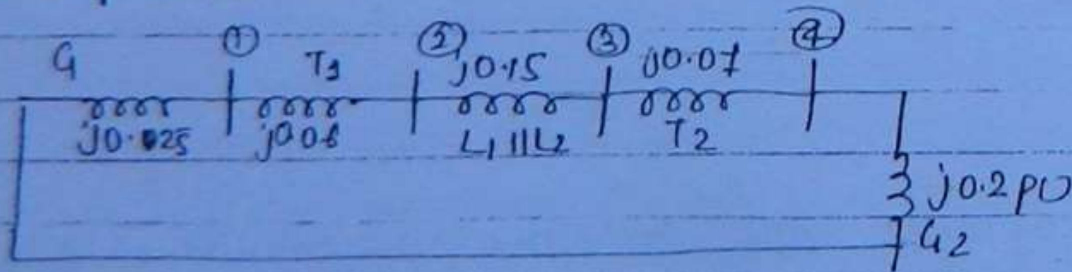
Common base MVA = 100.

Solution: I

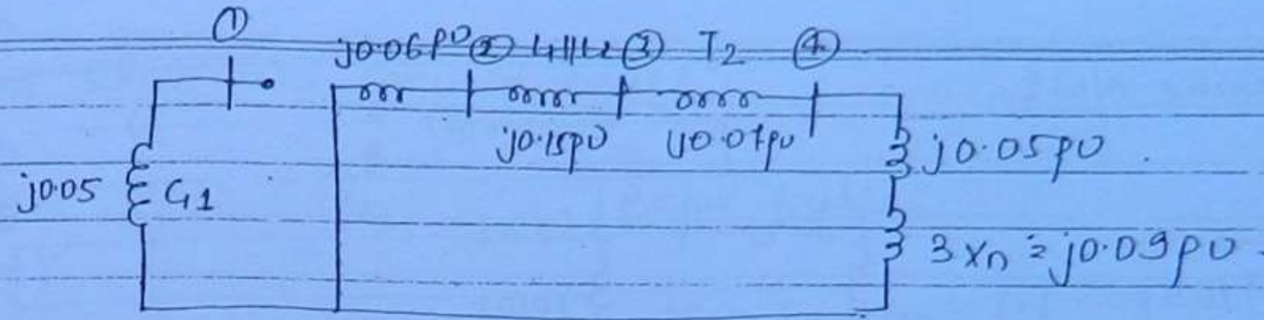


↳ Positive sequence N/W.

→ Negative sequence N/W: (without voltage source rest same)



→ Zero sequence N/W:

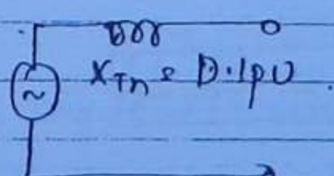


Part B

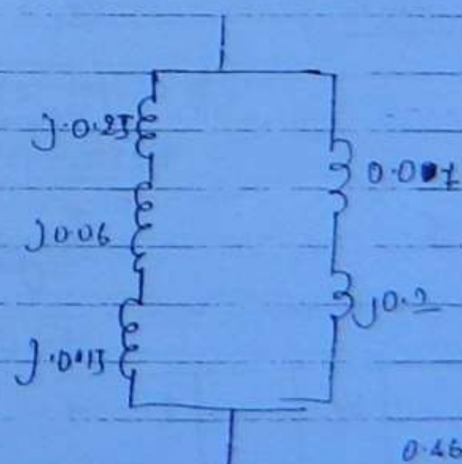
Let the fault is occured on bus ③, reduce the 3-sequence n/w into thevenin equivalent n/w.

∴ as the voltage on both side is same so circulating current is zero, so drop is also zero, so the same voltage 1pu appears across bus ③. (parallel).

Thevenin's equa equivalent $V_{th} = 1pu$; $X_{Th} = j0.17pu$.



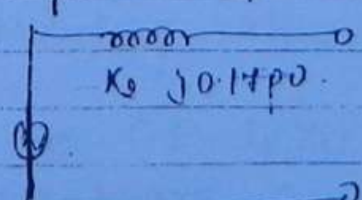
Positive sequence.



0.46j =

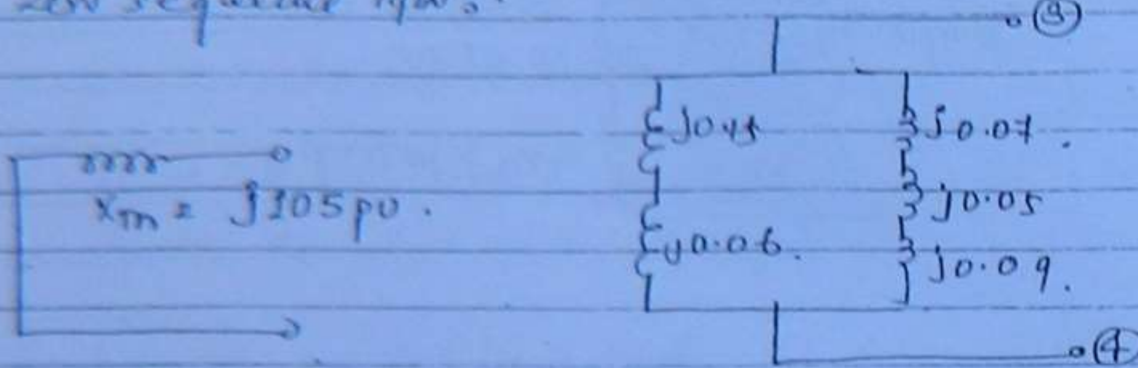
0.27j

-ve sequence n/w same with no voltage



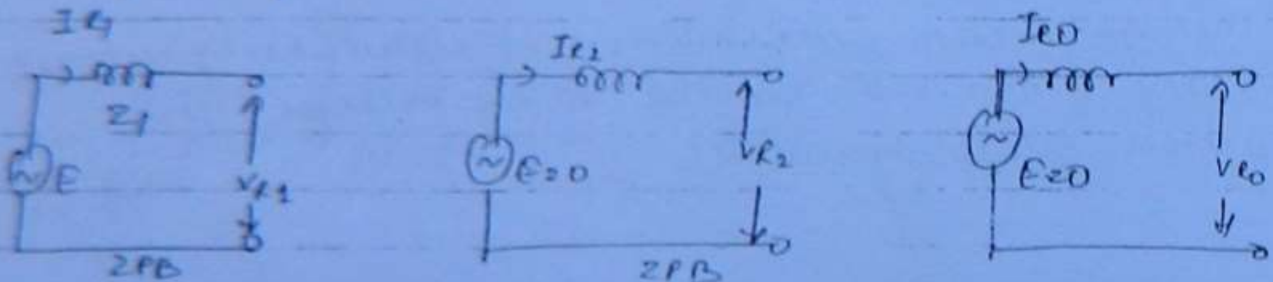
Zero sequence n/w flow 4m (Q2)

→ Zero sequence n/w:-



0.21P

Voltage Sequence:-



$\boxed{V_{R_1} = E - I_{R_1} Z_1}$

$V_{R_2} = E - I_{R_2} Z_2$

$\boxed{V_{R_2} = -I_{R_2} Z_2}$

$V_{R0} = E - I_{R0} Z_0$

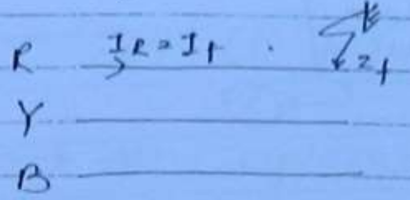
$\boxed{V_{R0} = -I_{R0} Z_0}$

Positive S. Negative Zero

$$\begin{bmatrix} V_R \\ V_Y \\ V_B \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} V_{R_0} \\ V_{R_1} \\ V_{R_2} \end{bmatrix}$$

→ Power s/c not connected to s/m is distributed s/m

Single Line Ground Fault:



Befor fault:-

$$\boxed{I_R = I_B = I_Y = 0}$$

During Fault.

$$\boxed{I_R = I_F}$$

$$\boxed{I_Y = I_B = 0}$$

$$\begin{bmatrix} I_{R0} \\ I_{R1} \\ I_{R2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} I_f \\ 0 \\ 0 \end{bmatrix}$$

$$\boxed{I_{R0} = \tfrac{1}{3} I_f = I_{R_1} = I_{R_2}}$$

$$\therefore \boxed{I_{R1} = I_{R2} = I_{R0} = I_F/3 = I_R/3} \longrightarrow (1)$$

→ All sequence current are equal 4 LG fault.

$$V_R = V_f = I_f Z_f = I_R Z_f = 3 I_{R_1} Z_f$$

$$V_{R1} + V_{R2} + V_{R0} = 3 I_{R_1} Z_f$$

substituting value of V

$$\Rightarrow (E - I_{R_1} Z_1) - I_{R_2} Z_2 - I_{R0} Z_0 = 3 I_{R_1} Z_f$$

Current are equal.

$$\Rightarrow E - I_{R_1} Z_1 - I_{R_1} Z_2 - I_{R_1} Z_0 = 3 I_{R_1} Z_f$$

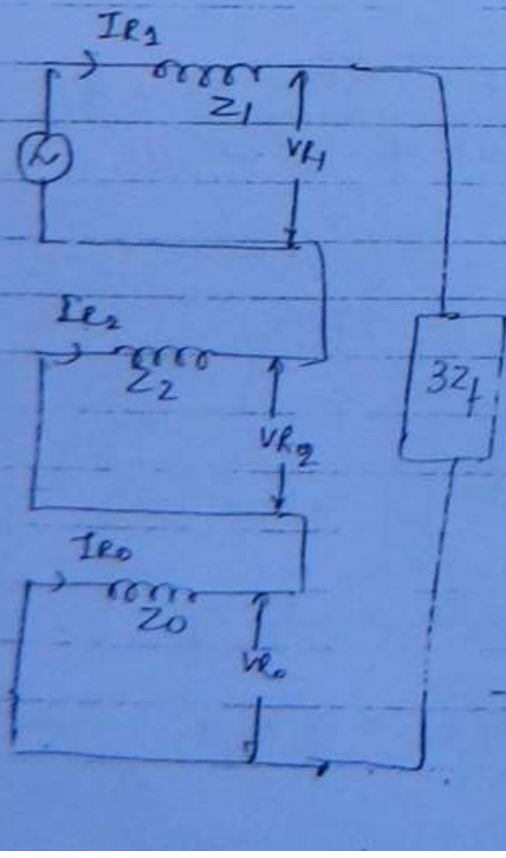
$$\boxed{I_R = \frac{E}{Z_1 + Z_2 + Z_0 + 3Z_f} = I_{R2} = I_{R0}} \rightarrow (2)$$

$$\boxed{I_{f_{LG}} = I_R = 3I_{R1}}$$

$$\therefore \boxed{I_{f_{LG}} = \frac{3E}{Z_1 + Z_2 + Z_0 + 3Z_f}}$$

Objective:-

→ Particular fault for all sequence current equal → LG fault.



→ for LG fault.

→ Zero sequence is possible with Grounding only

§ Comments

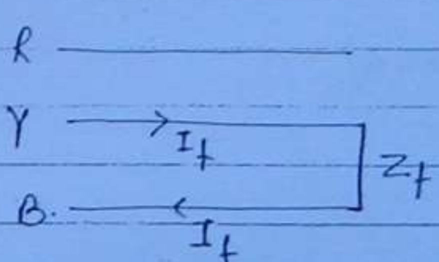
For LG fault :-

→ All sequence n/w are connected in series

→ All sequence currents are equal.

→ $I_{f_{LG}} = 3I_{R_1} = 3I_{R_2} = 3I_{R_0} = \dfrac{3E}{Z_1+Z_2+Z_0+3Z_f}$.

Line to line fault :-

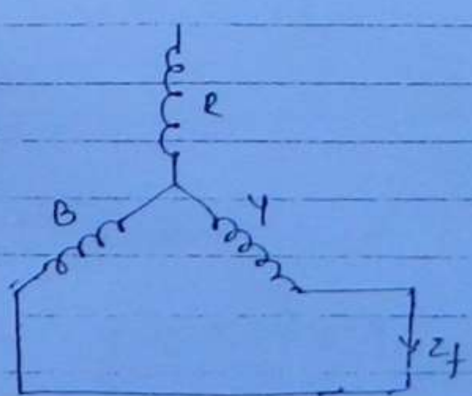


Before fault

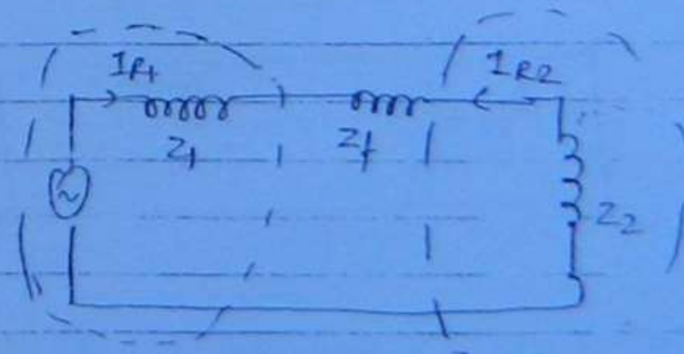
$I_R = I_Y = I_B = 0$

During fault :-

$I_f = I_Y = -I_B$



(Current circulates as shown)



→ Fault in which fault current is $\sqrt{3}\, I_{R_1}$ or $\sqrt{3}\, I_{R_2}$ → LL Fault.
$1,\ a^2-a$

$$\boxed{I_{R_1} = -I_{R_2}} \quad \& \quad \boxed{I_{R_0} = 0}$$

Two sequences are connected in series opposition

Magnitude :-

$$\boxed{I_{R_1} = -I_{R_2} = \frac{E}{Z_1 + Z_2 + Z_f}}$$

Calculating I_Y

$$I_{f,LL} = I_Y = I_{R_0} + a^2 I_{R_1} + a I_{R_2}$$

$$= (a^2 - a)\, I_{R_1}$$

$$\because \quad (a^2 - a) = (-0.5 - j.866 + 0.5 - j0.866)$$

$$= -j1.732 = -j\sqrt{3}$$

$$I_{f\,L-L} = -j\frac{\sqrt{3}E}{Z_1 + Z_2 + Z_f}$$

$$\boxed{|I_{f\,L-L}| = \frac{\sqrt{3}E}{Z_1 + Z_2 + Z_f}}$$

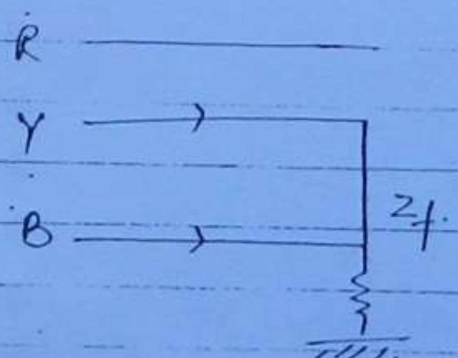
Comments:

For Line to Line fault :-

- Positive and negative sequence n/w are connected in series opposition.
- $\boxed{I_{R_1} = -I_{R_2}}$ and $\boxed{I_R = 0}$
- Magnitude of fault current is

$$\boxed{I_{fLL} = \sqrt{3} I_d R_1 = \sqrt{3} I R_2 = \frac{\sqrt{3}E}{Z_1 + Z_2 + Z_f}}$$

Double line Ground fault:



Before fault

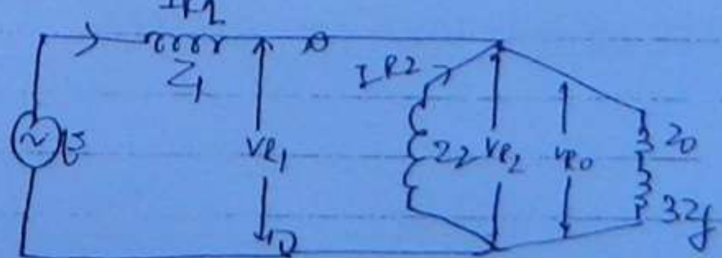
$I_R = I_B = I_Y = 0$.

During fault

$$\boxed{I_f = I_Y + I_B}$$

$$\boxed{V_f = V_Y = V_B = I_f Z_f}$$

Derivation:-



All sequences are in parallel. so

$$\rightarrow \boxed{V_{R_1} = V_{R_2} = V_{R0}}$$

$$\boxed{I_{R_1} = -(I_{R_2} + I_{R0}).}$$ → objective

<u>Magnitude:</u>

$$\boxed{I_{R_1} = \frac{E}{Z_1 + (Z_2 \parallel (Z_0 + 3Z_f))}}$$

$$\boxed{I_{R2} = -I_{R1} \times \frac{Z_0 + 3Z_f}{Z_2 + Z_0 + 3Z_f}}$$

$$\boxed{I_{R0} = -I_{R1} \times \frac{Z_2}{Z_2 + Z_0 + 3Z_f}}$$

using sequence current find I_Y and I_B.

$$\boxed{I_f = I_Y + I_B}$$

Magnitude of double line fault is 3 times the zero fault.

$$I_R = 0$$

$$I_{R_1} + I_{R_2} + I_{R0} = 0$$

$$I_{fLLG} = I_Y + I_B$$

$$= (I_{R0} + a^2 I_{R1} + a I_{R2}) + (I_{R0} + a I_{R1} + a^2 I_{R2})$$

$$I_{fLL-G} = [2I_{R0} + (a^2+a) I_{R1} + (a^2+a) I_{R2}]$$

$$I_{fLLG} = 2I_{R0} - I_{R1} - I_{R2} \qquad \because a^2 + a = -1$$

$$2I_{R0} - (I_{R1} + I_{R2})$$

** $\boxed{I_{fLLG} = 3I_{R0}}$ $\qquad \because I_{R1} + I_{R2} = -I_{R0}$

Problem:-

In a balanced 3-φ s/m.

Comment: →

→ All sequence n/w are connected in parallel.

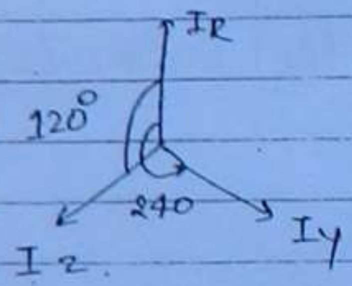
→ $V_{R1} = V_{R2} = V_{R0}$.

→ $I_{R1} = -(I_{R2} + I_{R0})$

Problem:-

The current in each phase of a balanced 3ϕ s/m is 10 the phase sequence is RYB. Find the resultant sequence current.

Solution:



$I_R = 10\angle 0^\circ = 10.$

$I_Y = 10\angle 240 = a^2 10$

$I_B = 10\angle 120^\circ = a10$

$$\begin{bmatrix} I_{R_0} \\ I_{R_1} \\ I_{R_2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} 10 \\ 10a^2 \\ 10a \end{bmatrix}$$

$I_{R_0} = \frac{1}{3}[10 + 10a^2 + 10a] = 10/3 \times 0 = 0\,A$

$I_{R_1} = \frac{1}{3}[10 + a^3 + a^3] = \frac{1}{3} \times 30 = 10A$

$I_{R_2} = \frac{1}{3}[10 + a^4 + a^3] = \frac{1}{3}[10 + a10 + a^2 10] = 0A.$

Problem 2:

In above c/m the fuses in Y and B phase are removed

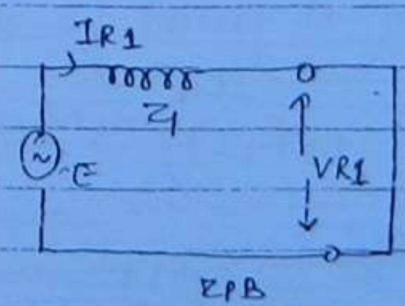
$I_y = I_b = 0$; $I_R = 10$

$$\begin{bmatrix} I_{R0} \\ I_{R1} \\ I_{R2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix}\begin{bmatrix} 10 \\ 0 \\ 0 \end{bmatrix}$$

$$I_{R0} = I_{R_1} = I_{R_2} = 10/3$$

* Under balanced condition we only have +ve sequence curr

3-ϕ fault using sequence N/W (+ve sequence):-



$$\begin{bmatrix} I_R \\ I_Y \\ I_B \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix}\begin{bmatrix} 0 \\ I_{R_1} \\ 0 \end{bmatrix}$$

$$\boxed{I_{f,3\phi} = I_{R_1} = E/Z_1}$$

$I_R = I_{R_1}$

$I_Y = a^2 I_{R_1}$

$I_B = a I_{R_1}$

→ In phase fault the fault current ~~impedence~~ ~~will not~~ is not

not limited by impedence Z_f, hence Z_f is not considered in 3ϕ fault.

→ Ground also donot effect the 3ϕ fault current. Also no difference b/w 3ϕ fault and Ground fault.

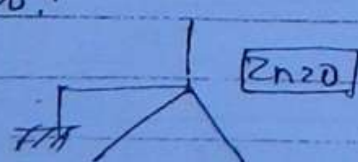
→ All the 3ϕ voltage including the sequence voltage is zero.

<u>Comparison:-</u>

<u>3-φ fault</u> | <u>Line to Ground fault.</u>

$I_{f-3\phi} = \frac{E}{Z_1}$; $Z_f = 0$ → $I_{fLG} = \frac{3E}{Z_1+Z_2+Z_0}$

<u>Case: 1</u> <u>Solidly grounded alternator:</u>



$Z_0 = Z_{a0} + 3Z_n$

$= Z_{a0}.$

∵ 4 alternal sequence current

$Z_2 \simeq Z_1$

$Z_0 >> Z_1$

$I_{f3\phi} = \frac{E}{Z_1}$ —(1)

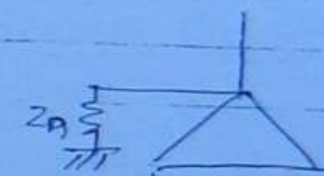
$I_{fLG} = \frac{3E}{Z_1+(\simeq Z_1)+(<<Z_1)}$

$$= \frac{3E}{2Z_1} \simeq 1.5 \times \frac{E}{Z_1}$$

$\boxed{I_{fLG} > I_{f3\phi}}$ $= \boxed{1.5 \times I_{f3\phi}}$

- For solidily grounded alternator LG fault is severe.

Case 2: Alternator neutral grounded with the impedance Z



$\boxed{Z_0 = Z_{n0} + 3Z_n}$

Z_0 dependes on Z_n.

$$I_{f3\phi} = \frac{E_1}{Z_1}$$

$$I_{fLG} = \frac{3E}{Z_1 + Z_2 + Z_{g0} + 3Z_n}$$

- Here severity of fault is decided by Z_n

If $Z_n = \frac{1}{3}(Z_1 - Z_0)$

then $$I_{fLG} = \frac{3E}{Z_1 + (\simeq Z_1) + Z_{g0} + 3\left[\frac{1}{3}(Z_1 - Z_0)\right]}$$

$$\simeq \frac{3E}{3Z_1} \simeq I_{f3\phi}$$

*

$\boxed{I_{f3\phi} = I_{fLG} \quad \text{for } Z_n = 1/3(Z_1 - Z_0)}$

$$\text{If } Z_n \begin{cases} \to < \frac{1}{3}(Z_1 - Z_{g0}) ; I_f LG > I_f 3\phi \\ \cancel{I_f LG > I_f 3\phi} \\ \to = \frac{1}{3}(Z_1 - Z_0) \Rightarrow I_f LG = I_f 3\phi \\ \to > \frac{1}{3}(Z_1 - Z_{g0}) \Rightarrow I_f 3\phi > I_f LG \end{cases}$$

Objectives.

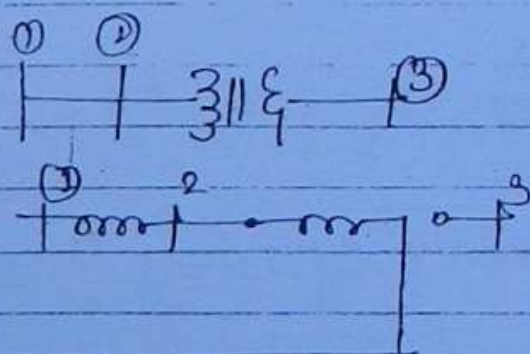
(1) Zero sequence current can flow from a line into a x'mer bank if the winding of x'mer are.

a) $\curlywedge$Y – Δ

b) Δ – Y

c) Y – Y⏚

d) Δ – Δ



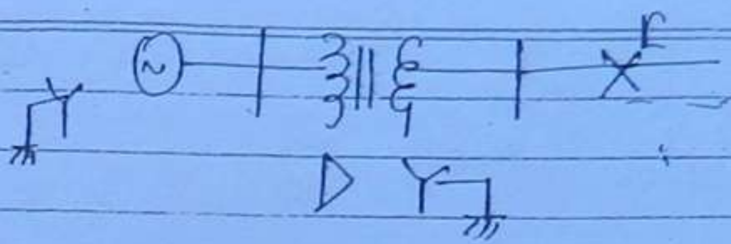
(2) for s/m shown in figure what is the L-G fault on ~~right~~ side of x'mer equivalent to

a) L-G fault on G/r side of x'mer

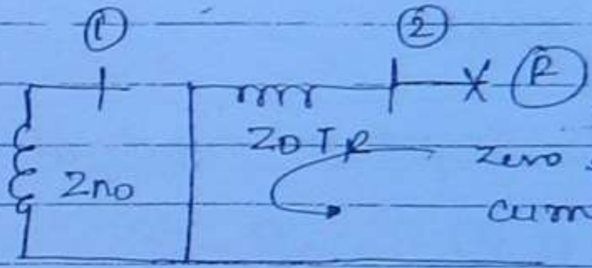
~~b)~~ L-L fault on G/r of x'mer

c) LLG fault on G/r side of x'mer

d) 3ϕ fault on G/r x'mer.



zero sequence diagram.



zero sequence current comes 4m del side

ZPB.

not supplying the zero sequence current so L-L fault on G'r side

(3) The L-G fault and the 3φ fault at the terminal of unloaded synchronous G/r is to be same. If terminal voltage is 1pu, $Z_1 = Z_2 = Z_1$ j0.1 and $Z_0 = j0.05$ p.u for the alternator, then the required inductive reactance 4 nodal grounding is_

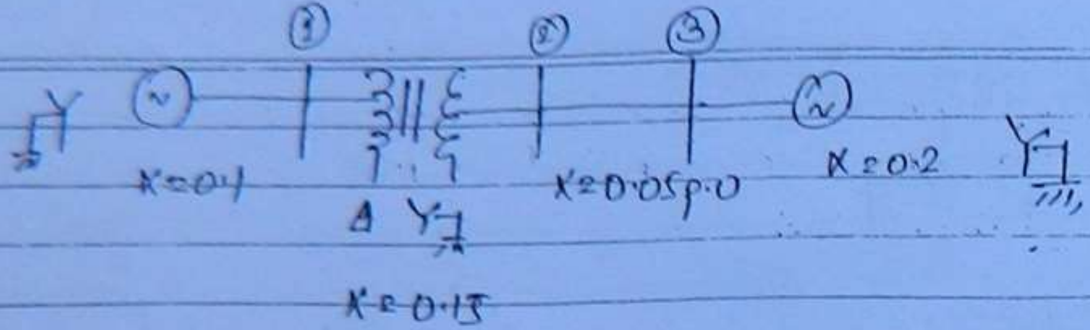
$$Z_n = \frac{1}{3}(Z_1 - Z_{G0})$$

$$\frac{1}{3}(j0.1 - 0.05j)$$

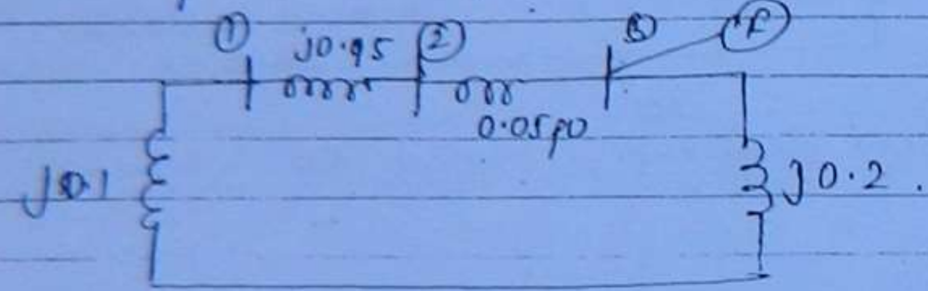
$$\Rightarrow 0.0166j$$

0.0166
0.05
0.01
0.015

(4) The ~~zero~~ sequence reactances are indicated in n/w shown below. All the equipment have equal sequence impedences, if L-G fault occurs on bus 3 φ the p.u fault current is



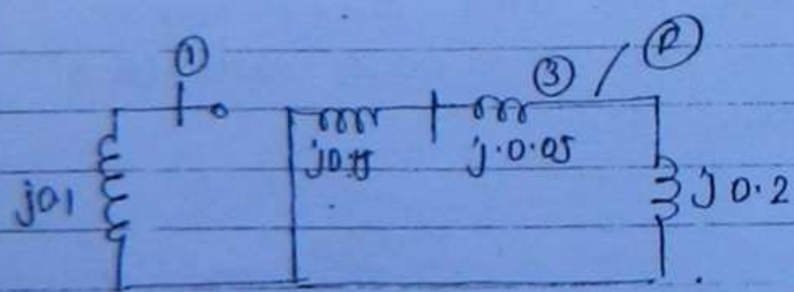
→ Reducing two sequence reactance :-



(+ve and -ve)

$\Rightarrow \quad (0.1j + j0.15 + j0.05) \,||\, j0.2$

$= \quad Z_{1Th} = Z_{2Th} = j0.12 pu$



ZPB

$(j0.15 + j0.05) \,||\, j0.2$

$Z_{0Th} = j0.1 pu.$

$$I_f = \frac{3E}{Z_1 + Z_2 + Z_0} = \frac{3 \times 1}{j0.12 + j0.12 + j0.1} = 8.823\angle -90^\circ p.u$$

4. In an unbalanced $3\text{-}\phi$ s/m the currents are measured as $I_R = 0$, $I_Y = 6\angle 60^\circ$; $I_B = 6\angle -120^\circ$. The corresponding sequence currents will be.

a) $0 \quad 3 - j\sqrt{3} \quad -3 + j\sqrt{3}$

b) $0 \quad -3 - j\sqrt{3} \quad 3 - j\sqrt{3}$

c) $0 \quad -9 + j\sqrt{3} \quad 9 - j3\sqrt{3}$

d) $0 \quad 9 - j\sqrt{3} \quad -9 + j3\sqrt{3}$

$$\begin{bmatrix} I_{R_0} \\ I_{R_1} \\ I_{R_2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} 0 \\ 6\angle 60^\circ \\ 6\angle -120^\circ \end{bmatrix}$$

$$I_{R_0} = \frac{1}{3}\left[0 + 6\angle 0^\circ + 6\angle -120^\circ\right]$$

$$I_{R_1} = \frac{1}{3}\left[0 + a^2 6\angle 60^\circ + a6\angle -120^\circ\right]$$

$$I_{R_2} = \frac{1}{3}\left[0 + a6\angle 60^\circ + a^2 6\angle -120^\circ\right]$$

5) A Star connect 3ϕ, 11KV, 25MVA alternator well it nodal grounded with 0.033pu reactance and +ve, -ve, and zero reactances of 0.2, 0.1, 0.1 repectively. A SLG fault on one of its terminals would result a fault MVA of

Z_n^2 0.033p.u

a) 150 MVA
b) 125 MVA
c) 100 MVA
d) 50 MVA

$$I_{sc} = I \times \frac{100}{\% Z}$$

$$\frac{I}{I_{sc}} = Z_{p.u}$$

$$\boxed{I_{sc} = \frac{1}{Z_{pu}}}$$

$$I_{fLG} = \frac{3E}{Z_1 + Z_2 + Z_0 + 3Z_n} = \frac{3 \times 1}{0.2 + 0.1 + 0.1 + 3 \times 0.033} = -j6\,p.u$$

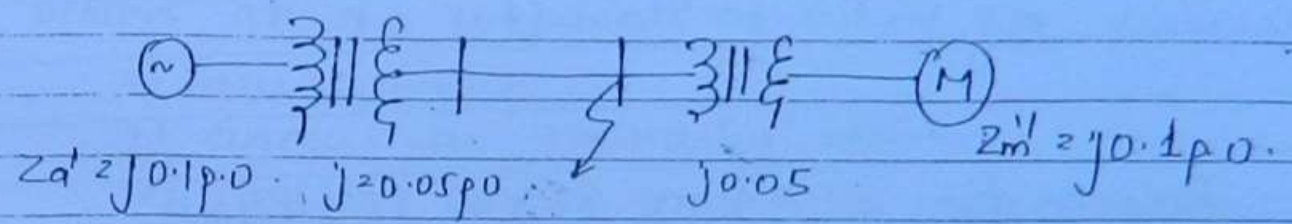
$\therefore$ $I_{fLG} = 6\,p.u$

Since MVA = 6p.u.

Base MVA = 25MVA

Since MVA = 6×25 = 150MVA.

6.) Figure shows a single line diagram with all reactance in per unit on same base. The s/m is on no load when a 3φ fault occurs at pt 'F' on H.V side, the fault current will be ___



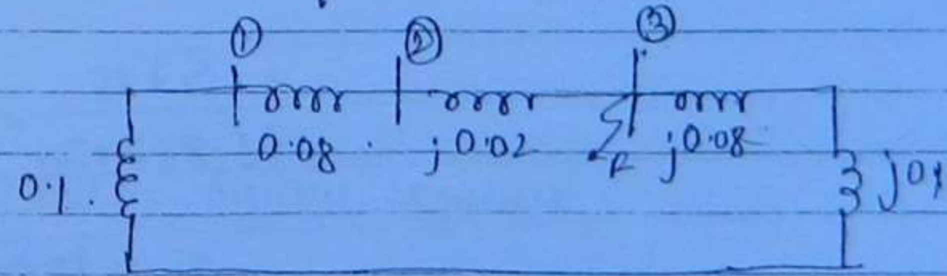
Hint: $\frac{I}{I_{sc}} = Z_{p.u}$; I, I_{sc} — in pu

$I = 1\,pu.$

$\Rightarrow \boxed{\frac{1}{I_{sc}} = Z_{pu}}$

Equivalent reactance diagram:

0.7i



$Z_{TH}\,pu = j0.122\,pu$

$I_{sc} = \frac{1}{j0.122} = -j8.19\,pu$

7.) A 20 MVA 33 kV 3φ alternator is subjected to different types of faults. $I_{f3\phi} = 319\,A$

$I_{fLG} = 659$ Amp.

$I_{fLL} = 435$ Amp.

determine X_1, X_2, X_0 of the g/r neglect resistances.

Solution

$$I_{f3\phi} = \frac{E_1}{Z_1} = 319 = \frac{33/\sqrt{3}}{Z_1} = 59.72\,\Omega$$

$$I_{fLL} = \frac{\sqrt{3}E_1}{Z_1+Z_2} = \frac{\sqrt{3}\times 33/\sqrt{3}}{59.72+Z_2} = 435$$

$$= 16.137\,\Omega$$

$$I_{fLG} = \frac{3E_1}{Z_1+Z_2+Z_0} = \frac{3\times 33/\sqrt{3}}{59.72+16.137+Z_0} = 659.$$

$$= \frac{57.15}{75.857+Z_0} = 659$$

$$Z_0 = 10.863\,\Omega$$

[redacted]

[redacted]

Example:-

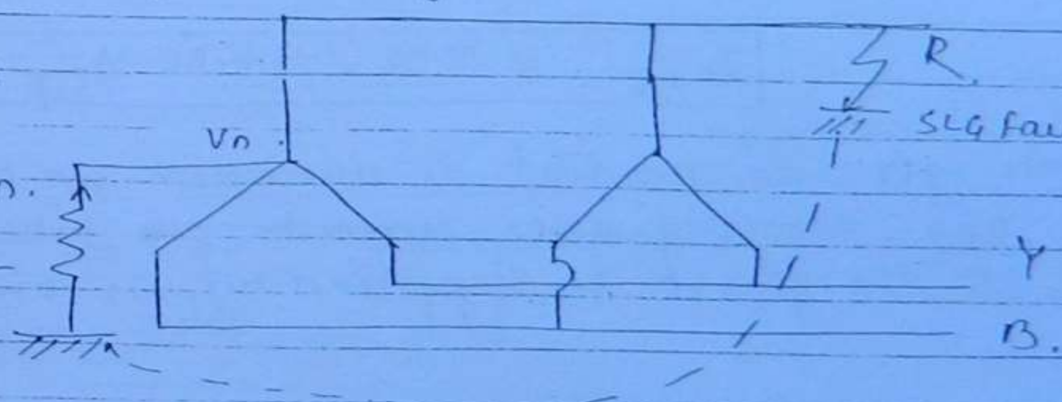
Two 11 KV 20MVA, 2 of 3φ ; Y connected g/r operated in parallel. The positive, negative and zero sequence reacton of each being j0.18, j0.15, and j0.1 p.u. The star point of one of the g/r is isolated and that of the other is ~~earthed~~ earthed with 2Ω resistor. The SLG fault occurs at the terminals of one of g/r, estimate.

a) fault current

b) current in grounding resistor

c) voltage across grounding resistor (phase voltage)

Solution:-



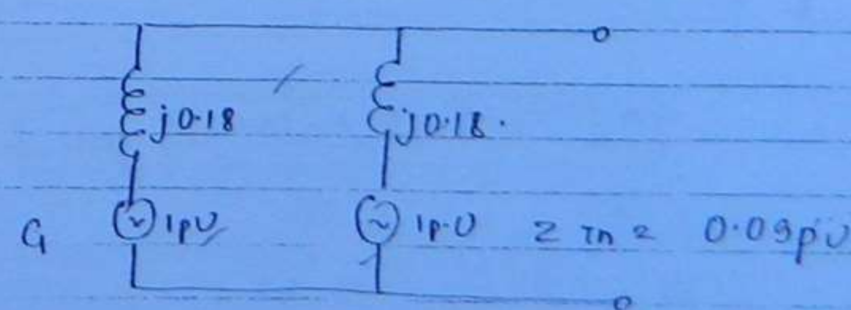
To find

a) I_{FSLG}

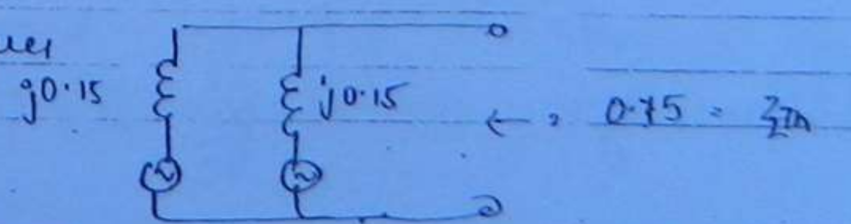
b) I_n

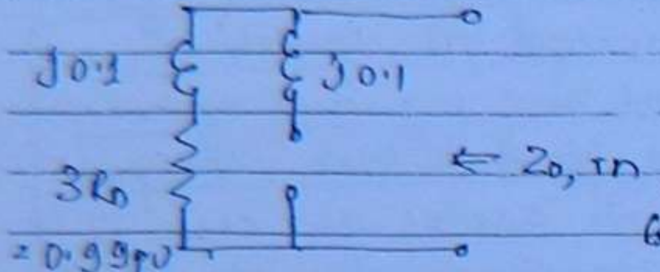
c) V_n

Sequence N/W :- Positive Sequence.



-ve Sequence





$Z_{base} = \frac{kV_b^2}{MVA} = \frac{11^2}{20} = 6.05$

$R_n = \frac{2}{6.05} = 0.33$pu.

$$I_{fsec} = \frac{3E}{Z_1+Z_1+Z_0+3} = \frac{3 \times 1}{j0.05+j0.15+(0.99+j0.1)}$$

$$\boxed{I_{fLG} = 2.92 \angle -14.98 \text{ Amp.}}$$

Note:

a) Since g/r to neutral is unloaded we cannot supply any zero sequence current. The total zero sequence to the fault is supplied by G_1 only

→ only zero sequence current flow thr neutral to ground.

→ for L-G fault we need return path

b) Current in grounding resistor is equal to fault current since ~~fault~~ ~~of~~ R_L act as return path for fault current

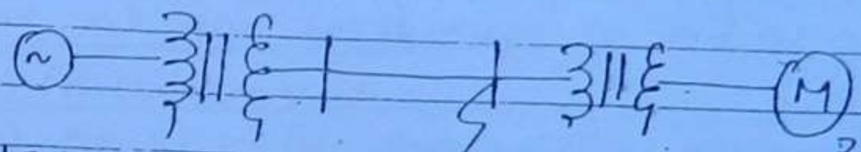
$$\boxed{I_N = 2.92 \angle -14.92^\circ \text{ p.u}}$$

$V_L = 2.92 \times 0.33$

$= 0.9636$ p.u

Per phase voltage $= 0.9636 \times \frac{11000}{\sqrt{3}} = 6.12$ KV.

6.) Figure shows a single line diagram with all reactances in per unit on same base. The s/m is on no load when a 3φ fault occurs at pt 'F' on HV side, the fault current will be ___



$Z_g' = j0.1$ p.u $j = 0.05$ pu $j0.05$ $Z_m'' = j0.1$ p.u.

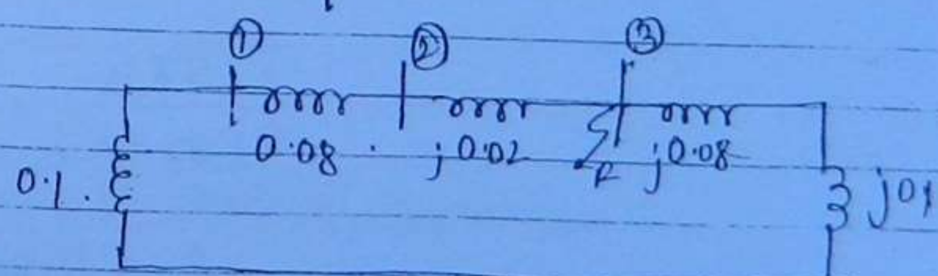
Hint: $\frac{I}{I_{sc}} = Z_{p.u}$; I, I_{sc} – in pu

$I = 1$ pu.

$$\Rightarrow \boxed{\frac{1}{I_{sc}} = Z_{pu}}$$

Equivalent reactance diagram:

0.7i



Z_{TH} pu $= j0.122$ pu

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Example:- [redacted]

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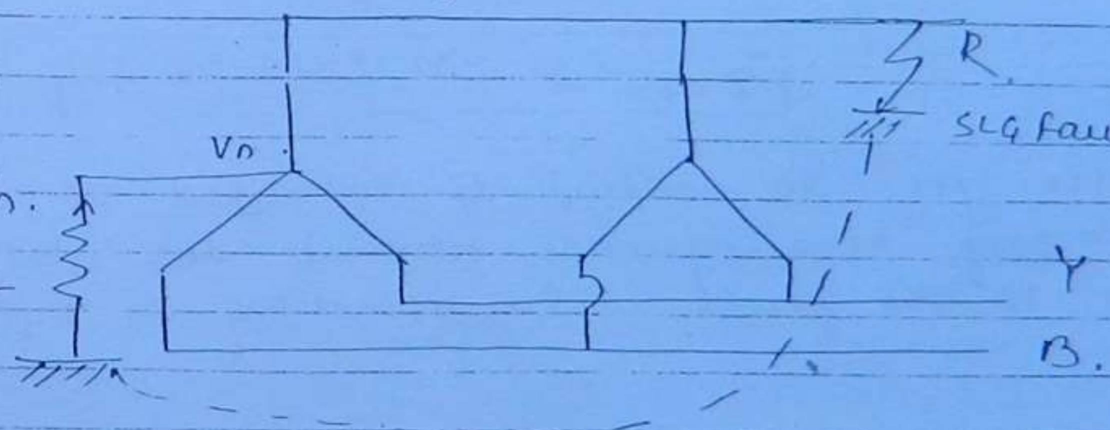
a) fault current

b) current in grounding resistor

c) voltage across grounding resistor (phase voltage

Solution:-



To find

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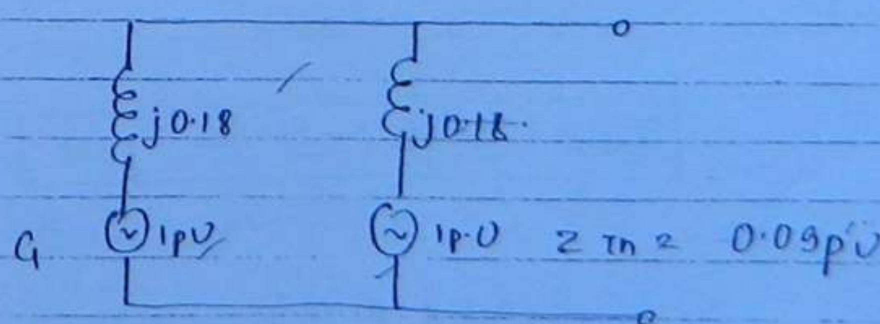
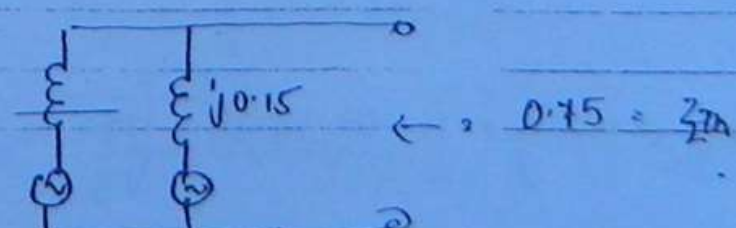
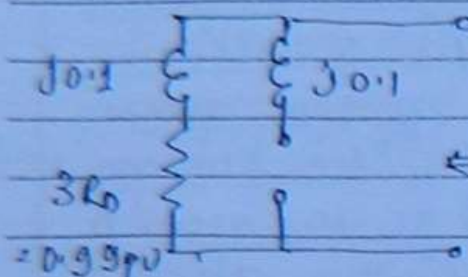
Sequence N/W :- Positive Sequence.



-ve Sequence





$$Z_{base} = \frac{kV_b^2}{MVA} = \frac{11^2}{20} = 6.05$$

$$R_n = \frac{2}{6.05} = 0.33\,pu.$$

$$I_{fSLG} = \frac{3E}{Z_1 + Z_1 + Z_0 + \cancel{3}} = \frac{3 \times 1}{j0.05 + j0.15 + (0.99 + j0.1)}$$

$$\boxed{I_{fLG} = 2.92 \angle -14.98 \text{ Amp.}}$$

Note:

a) Since g/r to neutral is unloaded we cannot supply any zero sequence current. the total zero sequence to the fault is supplied by G_1 only

→ only zero sequence current flow thru neutral to ground.
→ for L-G fault we need return path

b) Current in grounding resistor is equal to fault current since ~~fault~~ ~~or~~ R_L act as return path for fault current

$$\boxed{I_N = 2.92 \angle -14.92^\circ \text{ p.u}}$$

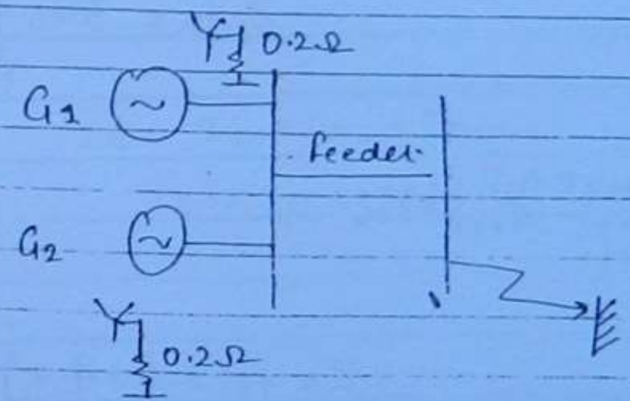
$$V_L = 2.92 \times 0.33$$
$$= 0.9636 \times \cancel{11}\ \text{p.u}$$

$$\text{Per phase voltage} = \frac{0.9636 \times 11000}{\sqrt{3}} = 6.12\ \text{KV}$$

Problem:-

Two identical 11 kV, 50 MVA, 3-ϕ alternators are connected in parallel and supply a substatⁿ by a feeder. The sequence impedences are marked in figure. Calculate the potential of alternator neutra with respect to ground if a LLG fault occur on Y-B phasors of substatⁿ.

Solutⁿ



$G_1, G_2 \rightarrow 11kV, 50MVA$

$X_1 = j0.68\Omega, X_2 = 0.4$

$X_0 = 0.2\Omega$

Feeder $\rightarrow Z_1 = Z_2 = (0.4$

$Z_0 = 0.7 + j3\Omega$.

~~Sequence impe~~: $Z_{base} = \frac{11kV^2}{50} = 2.42\Omega$

G_1 & G_2

$X_1 = j0.68/2.42 = j0.28$ p.u $\quad j0.68/2.42 = 0.28$

$X_2 = j0.4/2.42 = \cancel{j0.4}\ j0.16$ p.u

$X_0 = j0.2/2.42 = j0.08$ pu.

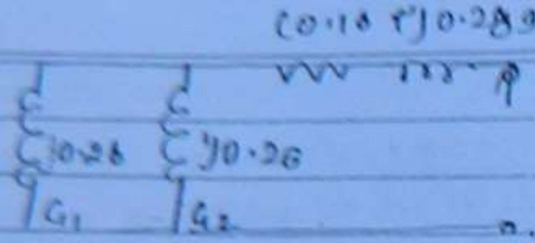
$R_n = j0.2/2.42 = j0.08$ p.u

Feeder

$Z_1 = \frac{(0.4 + j0.7)}{2.42} = (0.165 + j0.289)$ pu.

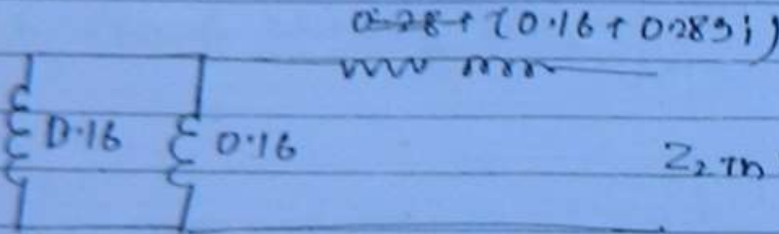
$Z_0 = (0.7 + j3\Omega)/2.42 = (0.28 + j1.239)$ p.u

+ve sequence



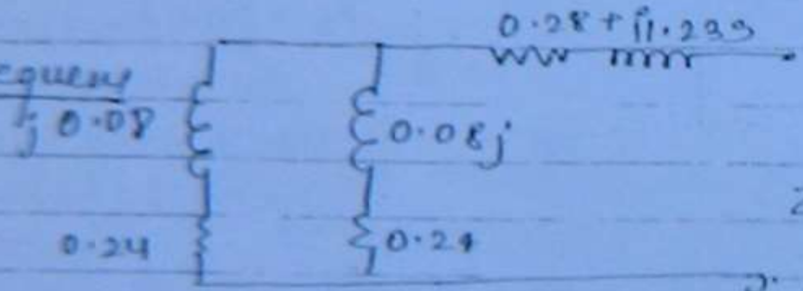
$Z = 0.16 + j\,0.419\ p.u.$

-ve sequence



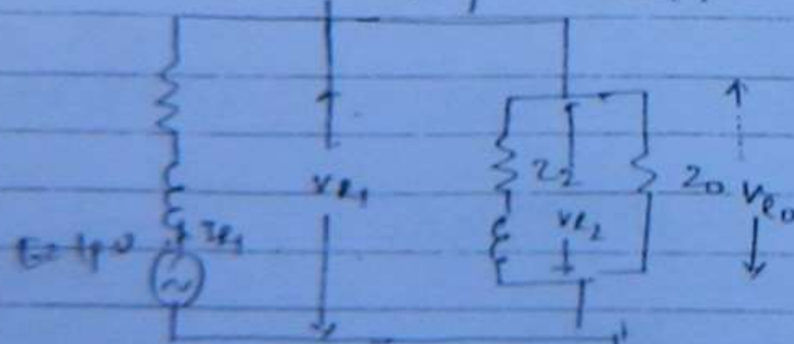
$Z_{2\,th} = 0.16 + j\,0.369\ p.u$

Zero sequence



$Z_0\,th = 0.4 + j\,1.279.$

For 3φ are connected in parallel:



$$V_{R_1} = V_{R_0}$$

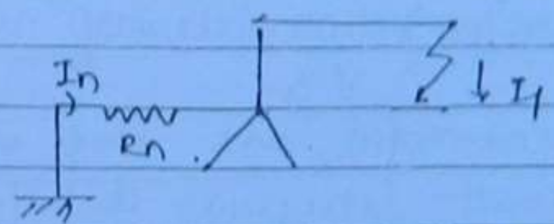
$$V_{R_1} = E - I_{R_1} Z_1$$

$$I_{R_1} = \frac{1\angle 0}{Z_1 + (Z_2 \parallel Z_0)}$$

$$\frac{1\angle 0^\circ}{(0.16+j0.419)+(0.06+j0.369 \,\|\, 0.4+j1.279)}$$

Solve : → Ans $0.496 - j1.223$ p.u.

Note



$$I_n = I_{n1} + I_{n2} + I_{n0}$$

$$I_e = I_f = 3I_{R0}$$ (zero sequence current or fault current)

$$V_{R0} = E - I_{R\phi} Z_\phi$$

$$= 8\ \cancel{(0.496 - j1.223) \times (0.4 + j}$$

$$V_{R0} = 1\angle 0 - (0.496 - j1.223) \times (0.16 + j0.419)$$

$$V_{R0} = \cancel{(0.738 + j0.121)}\ \ 0.408 - j0.012$$

$$I_{R0} = \frac{(0.738 + j0.121)}{0.4 + j1.279} = (0.25 - .498j)\,A$$

$(0.0823 - 0.293i)$

Note

As there are ~~eqn~~ two equivalent parallel path the zero sequence current supplied by each Gr is half of the total sequence current.

$V_n = 3 I_{R_0} R_n$

$$3\left(\frac{0.096 - j0.29}{2}\right) \times 0.083$$

$$(0.012 - j0.036)\,pu \times \frac{1100}{\sqrt{3}}$$

Fault Analysis using Z-bus:-

→ use Z-bus algorithm to draw Z-bus matrix.

Graph theory:- circuit ≃ Network.

:- The purpose to study Graph theory is that computer performs the n/w analysis

:- Subject which deals with Geometrical representation of object :- Topology

Hints:-

→ N/w analysis means finding a current through and voltage across every branch of n/w

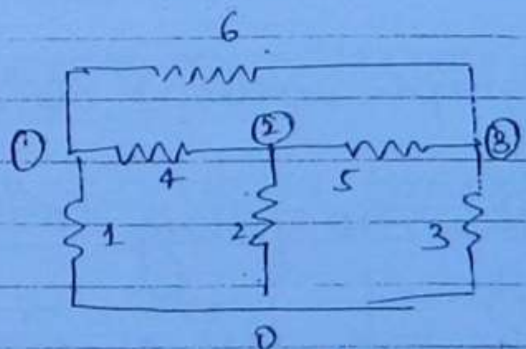
→ N/w analysis can be carried by using either loop analysis or nodal analysis.

→ The basis for loop analysis is KVL and for nodal analysis is KCL

→ The KCL and KVL do not depend upto type of element but it depends upon structure (graph on geometrical representatⁿ of n/w

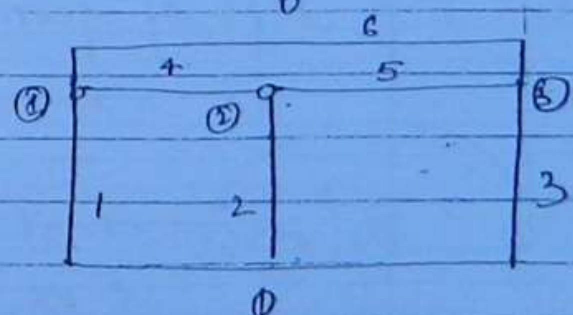
→ We pass the information regarding structure of n/w to computer through incidence matrices (+1,-

Network :→



node = 4
element e = 6.

Graph :→

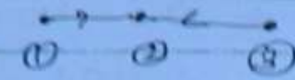


→ structure remains

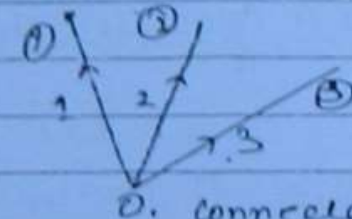
→ when direction is given → oriented graph

→ No overlapping → Planar Graph

* Graph theory cannot be applied on NON-Planar graph

* Sub-graph :- graph from original. 

* connected sub-grap :- One can go from one to another node

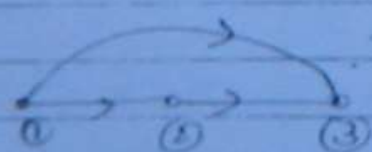


* minimum no of connected Graph $(n-1)$.

* A well connected sub-graph without closed loops → Tree.

1, 2, 3 → Twig / branch, no of twig $(n-1)$.

* Those element which are left, if from the graph then is called as · Co-tree.



$\boxed{\text{Tree} + \text{Co-tree} = \text{Graph}}$

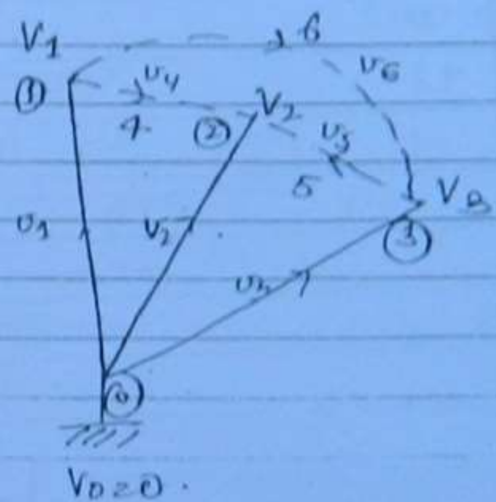
Links = e − (twigs)
= e − (n−1)

$\boxed{\text{links} = e - n + 1}$

(no of node increase by 1.)

* $\boxed{\begin{array}{l}\text{Whenever twig element is added we get} \rightarrow \text{Node (n...} \\ \text{Whenever link element is added we get} \rightarrow \text{Loop. (n...}\end{array}}$

Example :-



- $V_0, V_1, V_2, V_3 \rightarrow V$ (node voltage)
- $v_1, v_2 \dots v_6 \rightarrow$ Branch voltage (voltage drop)

$v_1 = V_0 - V_1 = -V_1$

$v_2 = V_0 - V_2 = -V_2$

$v_3 = V_0 - V_3 = -V_3$

$v_4 = V_1 - V_2$

$v_5 = V_3 - V_2$

$v_6 = V_1 - V_3$

Element Node Incidence Mat

$$A = \begin{array}{c|c} & n-1 \text{ node} \\ \hline \text{element} & a_{ij} \end{array}_{e \times (n-1)}$$

$$a_{ij} = \begin{cases} +1 & \text{if } i\text{th element is incident node and oriented away} \\ -1 & \text{,, ,, ,, ,, toward} \\ 0 & \text{(not connected to } j\text{th node)} \end{cases}$$

	①	②	③
1	-1	0	0
2	0	-1	0
3	0	0	-1
4	+1	-1	0
5	0	-1	+1
6	+1	0	-1

A

$$[V] = \begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ \vdots \\ v_6 \end{bmatrix}$$

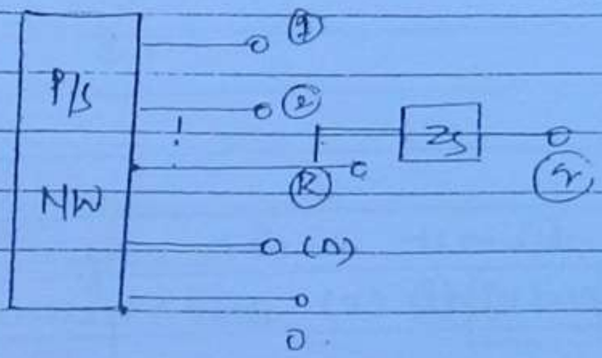
$$[v] = [A][V].$$

$$v_1 = -V_1$$
$$v_2 = -V_2$$
$$v_3 = -V_3$$
$$v_4 = V_1 - V_2$$
$$v_5 = V_3 - V_2$$
$$v_6 = V_1 - V_3.$$

→ Type 2. Modification:

An element with self impedan[ce] (Z_s) is added b/w an already existing bus (K) and new bus (q)

*(new element is added to Kth bus)



$Z_{bus}^{(new)} = Z_{bus}^{(old)}$ qth co[lumn]

$$Z_{bus}(new) = \left[\begin{array}{ccccc|c} & & Z_{1k} & & & Z_{1q} \\ & & Z_{2k} & & & Z_{2q} \\ & & \vdots & & & \vdots \\ Z_{k1} & Z_{k2} & Z_{kk} & \cdots & Z_{kn} & \vdots \\ & & \vdots & & & \\ & & Z_{nk} & & & Z_{nq} \\ \hline Z_{q1} & Z_{q2} & & \cdots & Z_{qn} & Z_{qq} \end{array}\right]$$

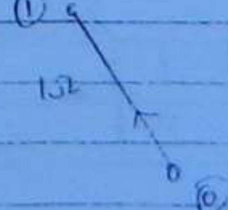
$(n+1) \times (n+1)$

$\boxed{Z_{qq} = Z_{kk} + Z_s}$

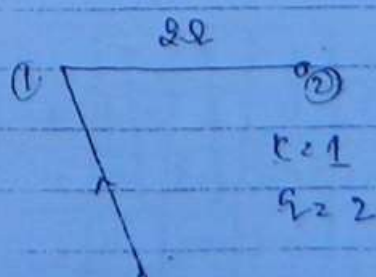
- Z_{kq} (row) is copy for row Z_{q1}
- Z_{1k} (column) is copy for Z_{1q}.

$$Z_{bus}(new) = \left[\begin{array}{c|c} & Z_{1k} \\ & Z_{2k} \\ Z_{bus,old} & \vdots \\ & \vdots \\ & Z_{nk} \\ \hline Z_{k1}, Z_{k2} \cdots Z_{kn} & Z_{kk}+Z_s \end{array}\right]$$

Example:



$Z_{bus}(old) = ①\,[1\Omega]$



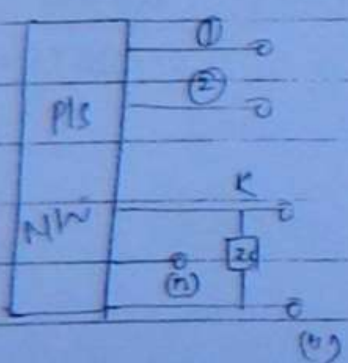
$k = 1$

$q = 2$

$$Z_{bus}(new) = \begin{array}{c|c|c} & ① & ② \\ \hline ① & 1 & K_{1k} \\ \hline ② & Z_{k1} & Z \end{array}$$

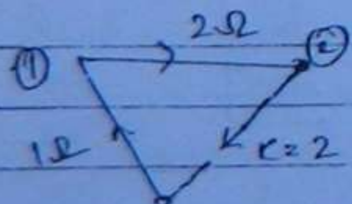
$$Z_{bus}(new) = \begin{array}{c|c|c} k & 1 & 2 \\ 1 & 1 & 1 \\ 2 & 1 & 3 \end{array} \qquad \begin{bmatrix} 1 & 1 \\ 1 & 3 \end{bmatrix}.$$

⇒ **Type 3 Modification :-** An element with self impedance is added b/w old bus (k) and reference bus (0).



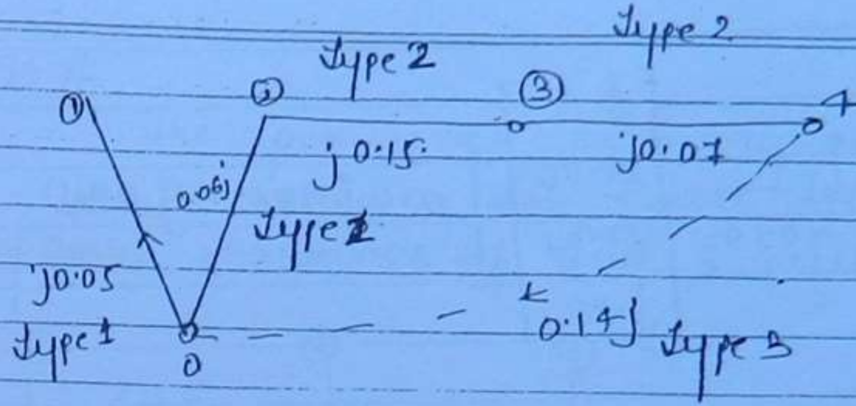
$$\boxed{Z_{bus}(new) = Z_{bus}(old) - \frac{1}{Z_{kk} + Z_s} \underbrace{\begin{bmatrix} Z_{1k} \\ Z_{2k} \\ \vdots \\ Z_{nk} \end{bmatrix}}_{(n \times 1)} \underbrace{\begin{bmatrix} Z_{k1} & \cdots & Z_{kn} \end{bmatrix}}_{(1 \times n)}}$$

Example:



$$Z_{bus}^{new} = \begin{bmatrix} 1 & 1 \\ 1 & 3 \end{bmatrix} - \frac{1}{Z_{kk}+Z_s} \begin{bmatrix} Z_{12} \\ Z_{22} \end{bmatrix} \begin{bmatrix} Z_{21} & Z_{22} \end{bmatrix}$$

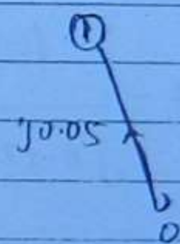
$$= \begin{bmatrix} 1 & 1 \\ 1 & 3 \end{bmatrix} - \frac{1}{3+3} \begin{bmatrix} 1 \\ 3 \end{bmatrix} \begin{bmatrix} 1 & 3 \end{bmatrix}$$



Step 1:

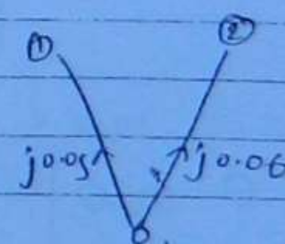
Zbus

	1
1	j0.05



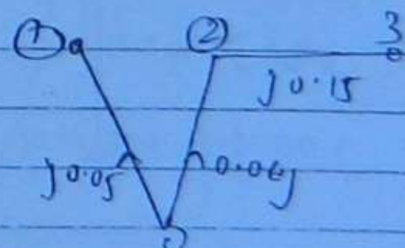
Zbus =

	1	2
1	j0.05	0
2	0	j0.06



Zbus

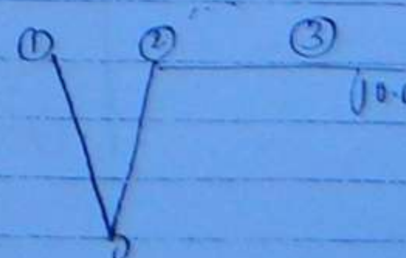
	1	2	3
1	j0.05	0	0
2	0	j0.06	j0.06
3	0	j.06	j0.21



0.06
0.15
121

Zbus =

	1	2	3	4
1	j0.05	0	0	0
2	0	j.06	j0.06	j.06
3	0	j.06	j.21	j0.2
4	0	j.06	j.21	j0.28



0.21
0.7

$$Z_{bus}\,old = \frac{1}{j0.28 + 0.14} \begin{bmatrix} 0 \\ j0.06 \\ j0.21 \\ j.28 \end{bmatrix} \begin{bmatrix} 0 & j0.06 & j0.21 & j.28 \end{bmatrix}$$

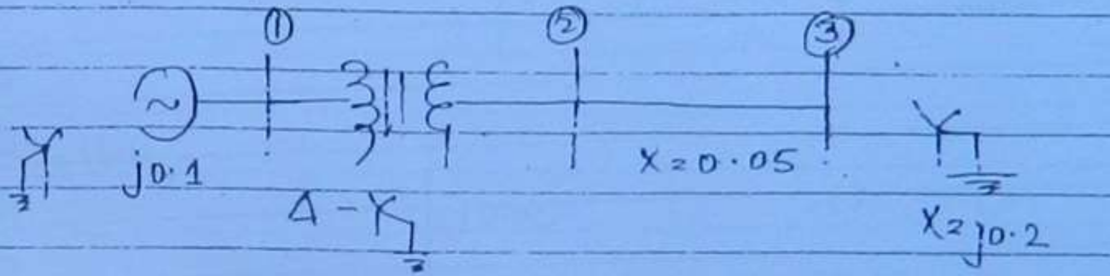
$$= Z_{bus}(old) - \frac{1}{j0.42} \begin{bmatrix} 0 & -3.6\times10^{-3} & -0.0126 & 0.0168 \\ 0 & -3.6\times10^{-3} & -0.0126 & 0.0168 \\ 0 & -0.0126 & -0.0441 & 0.058 \\ 0 & -0.0168 & -0.0588 & 0.078 \end{bmatrix}$$

$$\begin{bmatrix} j0.05 & 0 & 0 & 0 \\ 0 & j.06 & j0.06 & 0.06 \\ 0 & j.06 & j0.21 & 0.21 \\ 0 & j.06 & j.21 & 0.28 \end{bmatrix} - \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & j8.57\times10^{-3} & j0.03 & j0.04 \\ 0 & j0.03 & j0.105 & j0.14 \\ 0 & j0.04 & j0.14 & j0.1866 \end{bmatrix}$$

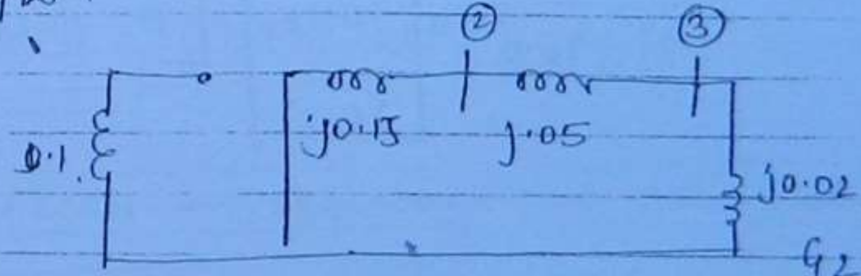
$$Z_{bus}(new) \begin{bmatrix} j.05 & 0 & 0 & 0 \\ 0 & j0.257 & j0.03 & j0.02 \\ 0 & j0.03 & j0.105 & j0.07 \\ 0 & j0.02 & j0.07 & j0.158 \end{bmatrix}$$

IES-1999

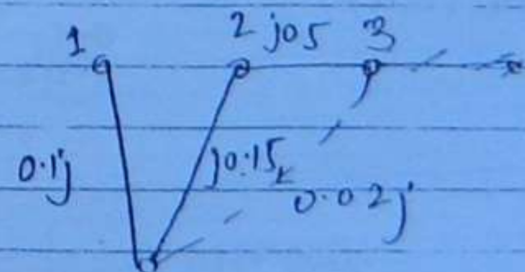
The per unit zero sequence reactances of the n/w are shown in figure. The zero sequence driving point reactance of ~~bus~~ node 3 will be.



Zero sequence n/w.



Graph



$$Z_{bus} = \begin{array}{c|c} & ① \\ \hline ① & \boxed{0.1j} \end{array}$$

$$Z_{bus} = \begin{array}{cc} ① & ② \\ 0.1j & 0 \\ 0 & j0.15 \end{array}$$

Z_{bus} =

	1	2	3
1	j0.1	0	0
2	0	j0.15	j0.15
3	0	j.15	j0.2

0.15
+0.5

Zus.

$$Z_{bus}(old) - \frac{1}{0.2j + j0.2} \begin{bmatrix} 0 \\ j0.15 \\ j0.2 \end{bmatrix} \begin{bmatrix} 0 & j.15 & j0.2 \end{bmatrix}$$

$$Z_{bus}(old) \quad \frac{1}{0.4j} \begin{bmatrix} 0 & 0 & 0 \\ 0 & & \\ 0 & & -0.04 \end{bmatrix}$$

$$j0.2 - \frac{1}{0.04j} \begin{bmatrix} -0.04 \end{bmatrix}$$

$$0. \quad 0.2j - 0.1j$$

$$\boxed{Z_{33} = 0.1j}$$

Calculation of faults using Z_{BUS} :-

$$Z_{1,Bus} = Z_{2\,Bus} = \begin{bmatrix} j0.15 & j0.12 & j0.107 & j0.0799 \\ j0.1266 & j0.157 & j0.132 & j0.0984 \\ j0.107 & j0.132 & j.0154 & j0.114 \\ j0.079 & j0.098 & j0.114 & j0.136 \end{bmatrix}$$

$Z_0(bus)$

$$= \begin{bmatrix} j0.05 & 0 & 0 & 0 \\ 0 & j0.051 & j0.03 & j0.02 \\ 0 & j0.03 & j0.105 & j0.07 \\ 0 & j0.02 & j0.07 & j.093 \end{bmatrix}$$

3-ϕ fault :- (Except +ve sequence no other components)

$$Z^{(2)}_{bus} = Z^{(0)}_{Bus} = I^{(2)}_{bus} = I^{(0)}_{bus} = 0$$

Let fault occur on bus (k).

$$\boxed{I_K^{(1)} = I_f = \frac{E}{Z_{KK}{}^{1}}}$$ — fault current.

at k^{th} bus.

$$I_R = I_K^{(1)} \angle 0^\circ$$

$$I_Y = I_K^{(1)} \angle 240$$

$$I_B = I_K^{(1)} \angle 120^\circ$$

* → at faulted bus k all voltages are zero

$$\boxed{V_k^{(1)} = V_k^{(2)} = V_k^{(0)} = 0}$$

Healthy phase voltage :-

when the fault occurs at bus (k) voltage bus (i) is

$$\boxed{V_i^{(1)} = E - Z_{ik}^{(1)} \cdot I_k^{(1)}}$$

i → healthy bus

k → faulted bus

for $i = 1, 2 \ldots n$

$i \neq k$

$$\boxed{V_i^{(2)} = V_i^{(0)} = 0}$$

L line to Ground fault :-

fault occurs at (k)

$$\boxed{I_k^{(1)} = I_k^{(2)} = I_k^{(0)} = \frac{E}{Z_{kk}^{1} + Z_{kk}^{2} + Z_{kk}^{(0)}}}$$

three phase current at bus(k)

$$\begin{bmatrix} I_R \\ I_Y \\ I_B \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} I_R^0 \\ I_R^1 \\ I_R^2 \end{bmatrix}$$

Zbus Building Algorithm :

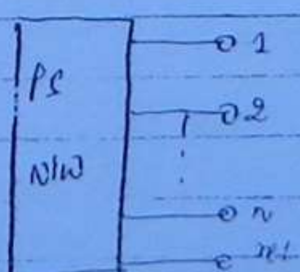
The bus admittance matrix (Ybus) can be obtained easily by taking inverse of Ybus bus impedance matrix Zbus can be obtained. But this method has following disadvantages :-

→ Ybus is higher dimensional matrix. to find inverse of such a big matrix is difficult.

→ N/W changes in Power system takes place regularly for these changes every time we had to modify Ybus and then we have to find Zbus. this is quite difficult process.

→ To avoid above difficulties Zbus Building algorithm is used. for a given power s/m bus impedance matrix Zbus(old) already exist. for the N/W changes now this matrix will be updated

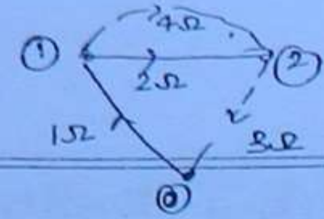
→ There are four types of modification takes place in n/w.



$$Z_{bus}old = \begin{bmatrix} Z_{11} & Z_{12} & \cdots & Z_{1n} \\ \vdots & \vdots & & \vdots \\ Z_{n1} & Z_{n2} & \cdots & Z_{nn} \end{bmatrix}_{n \times n}$$

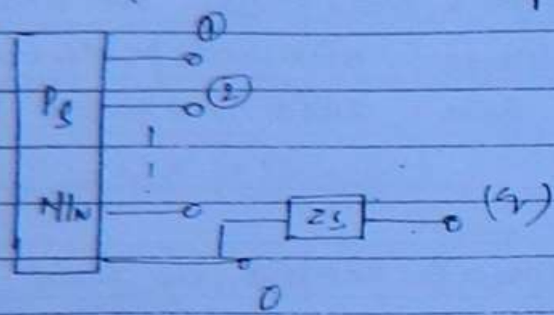
[redacted]

[redacted]



TYPE MODIFICATION :-

An element with self impedance z_s is added b/w the reference bus and new bus 'q'



$$Z_{Bus}(new) = \left[\begin{array}{c|c} & Z_{1q} \\ Z_{bus}(old) & Z_{2q} \\ & \vdots \\ & Z_{qn} \\ \hline Z_{q1} \; Z_{q2} \; \cdots & Z_{qq} \end{array}\right]$$

$(n+1) \times (n+1)$

* All element are zero except diago

$Z_{1q} = Z_{q1} = 0$

$Z_{2q} = Z_{2q} = 0$

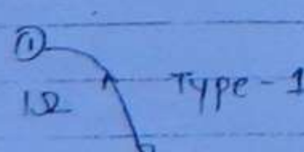
$\vdots$

$Z_{iq} = Z_{qi} = 0$

and $\boxed{Z_{qq} = Z_s}$.

$$\Rightarrow Z_{bus}(new) = \left[\begin{array}{c|c} & 0 \\ & 0 \\ Z_{bus}(old) & \vdots \\ & \vdots \\ & 0. \\ \hline 0 \; 0 \; \cdots \; 0 \; 0 & Z_s \end{array}\right]$$

Example:



$Z_{bus}(new) = ① \boxed{1\Omega.}$

$$\boxed{I_{f\,LG} = I_{fK} = \frac{3E}{Z_{kk}^{1} + Z_{kk}^{1} + Z_{kk}^{0}}}$$

when fault occur at bus (K) the healthy phase voltage V_i.

$$V_i^{(1)} = E - Z_{ik}^{(1)} I_k^{(1)}$$

$$V_j^{(2)} = - Z_{ik}^{(2)} I_k^{(2)}$$

$$\boxed{V_i^{(0)} = - Z_{ik}^{(0)} I_k^{(0)}}$$

at bus (i) the 3-ϕ voltage are

$$\begin{bmatrix} V_R \\ V_Y \\ V_B \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} V_i^{0} \\ V_{0i}^{(1)} \\ V_i^{(2)} \end{bmatrix}$$

Line to line fault :-

fault is occur on any two phases of bus (K).

$$I_k^{(1)} = -I_k^{(2)} = \frac{E}{Z_{kk}^{(1)} + Z_{kk}^{(2)}}.$$

$$\boxed{I_{f\,LL} = \frac{\sqrt{3}E}{Z_{kk}^{(1)} + Z_{kk}^{(2)}}}$$

Healthy bus voltage: $\boxed{V_i^{(1)} = E - I_k^{(1)} Z_{ik}^{(1)}}$

$$V_i^{(2)} = -I_k^{(2)} Z_{ik}^{(2)}$$

$$\text{for } i = 1, 2, \ldots n \quad i \neq k.$$

The 3ϕ voltages at bus (1)

$$\begin{bmatrix} V_R \\ V_Y \\ V_B \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} 0 \\ V_i^{(1)} \\ V_i^{(2)} \end{bmatrix}$$

Numerical:.

A 3ϕ death S.C occurs at bus (2) of system find

a) fault current

b) line to Neutral voltage at bus (3)

1) Fault at bus (2)

$$I_f = I_2^{(1)} = \frac{E}{Z_{kk}'} = \frac{E}{Z_{22}''} = \frac{1\angle 0^\circ}{j0.157} = 6.36\angle -90$$

$$I_{bus} = \frac{100}{\sqrt{3}(220)\times 10^3} = 262.43 \text{ Ams}.$$

$$|I_f| = 6.36 \times 262.43 = 1,669.04 \text{ Amp}$$

$I_R = 1669 \angle -90^\circ$

$I_y \quad 1669 \angle -210 \quad$ or $\quad 1669 \angle 150^\circ$

$I_B = 1669 \angle -330^\circ \quad$ or $\quad 1669 \angle 30^\circ$

Voltages:

$$V_3^{(1)} = E - Z_{32}^{(1)} \; I_2^{(1)}$$

$$1\angle 0^\circ - j1.32 \times j6.36 \angle -90^\circ$$

$$V_3^{(1)} = 0.16 \angle 0 \text{ p.u}$$

$$V_3^{(1)} = \frac{0.16 \times 220}{\sqrt{3}} = 127 \angle 0^\circ \text{ kV}$$

at bus (3)

$V_R = 203.7 \angle 0^\circ$ kV

$V_y = 203.7 \angle -120^\circ$ kV

$V_B = 203.7 \angle 120$ kV

Numerical:
A (SLG) fault occurs at bus (3) find the fault current

$$I_f = I_3^{(1)} = \frac{E}{Z_{33} + Z_{33}^{2} + Z_{33}^{(0)}}$$

$$= 3 \times \frac{1}{j0.15 + j0.15 + j0.105}$$

$$I_f = 7.26 \angle -90^\circ \text{ p.u}$$

*

dear sc → no current flow through the.

$P = \frac{V I \cos\phi}{V I}$ → p.u / $\frac{2}{\cos\theta}$ = MVA (actual)

$I_p LG = 7.26 \angle 269.43 A$

$I_f LG = 1905.4 \angle -90^\circ$

Consideration of Prefault load current:

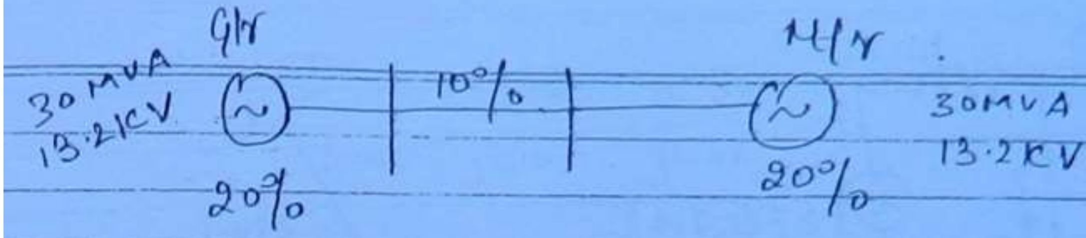
Using the load condition the first step being the calculatn of internal emf's of g/r and M/r. when the fault occurs the two sources at the two ends will drive the current into fault. The following numerical is show below:-

Numerical!

A single line g/r and M/r are rated at 30 MVA, 13.2 KV and both have subtransient reactance of 20%. The line connecting them has a reactance of 10% on base of machine rating. The M/r is drawing 20 MW at 0.8 lead at terminal voltage of 12.8 KV ~~with~~ when a symmetrical 3φ fault occurs ~~at~~ on the M/r terminals. Find subtransient fault current.

Base KV = 13.2 KV

Base MVA = 30 MVA



Power drawn by M/r = 20 MW at 12.8 kV, 0.8 pf

Active power = 20 MW ⇒ P

$= \frac{20}{30} = 0.66$ p.u.

Terminal voltage = 12.8 kV = $\frac{12.8}{13.2}$ = 0.96 p.u

$\cos\phi = 0.8$.

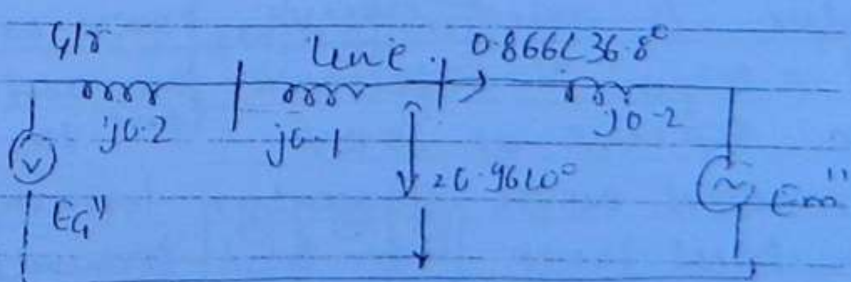
$$\boxed{V_{p.u}\ I_{p.u} \cos\phi = P_{p.u}}$$

$0.96 \times I_{p.u} \times 0.8 = 0.66$

~~$I_{pu} = 0.86$ pu~~

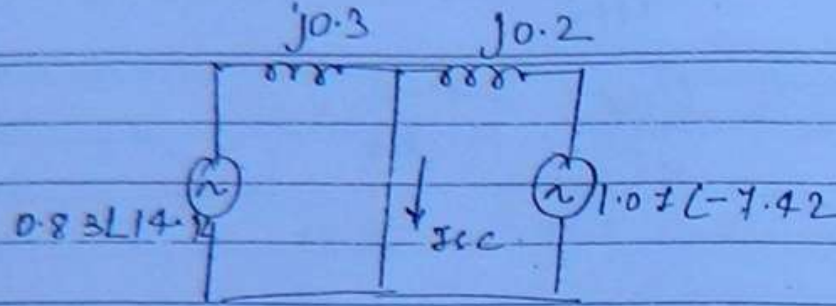
$I_{pu} = 0.86 \angle 36.86$ p.u.

Let $V = 0.96 \angle 0°$ p.u.



$E_G'' = 0.96\angle 0° - .866\angle 36.8 \times 0.3\angle 90°$
$= 0.73 \angle 14.50$

$E_m'' = 0.96\angle 0° - 0.866\angle 36.8 \times 0.2\angle 90°$
$= 1.07 \angle -7.42$



$$I_{sc} = I_{sc}' + I_{sc}''$$

$$\left(\frac{0.83\angle 14.54}{0.3\angle +90^\circ} + \frac{1.07\angle -7.4}{0.2\angle 90^\circ}\right)$$

$$= 7.99\angle -89.3$$

$$|I_{sc}| = 7.99 \times \frac{30\times10^6}{\sqrt{3}\times 13.2\times10^3}$$

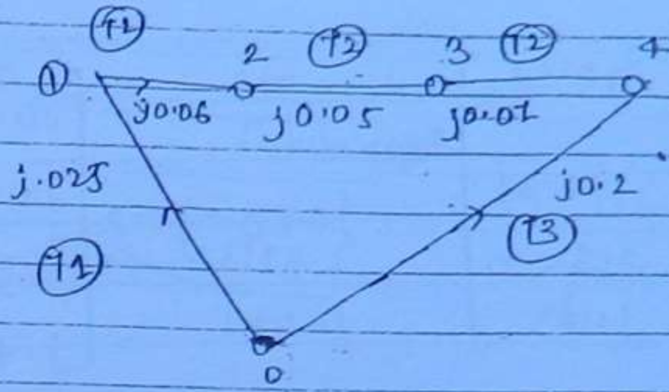
$$= 7.99 \times 10.48$$

$$I_{sc} = 83.73\,kA$$

Numerical:

A 50Hz alternator is rated 500MVA, 20KV with $X_d = 1$p.u, $X_d'' = 0.2$p.u. It supplies a pure resistive load of 400 MVA at 20kV. The load is directly connected across generator terminal when a symmetrical fault on load terminal the initial rms current is.

$$I_L = \frac{400\times10^6}{\sqrt{3}\times20\times10^3} = 11547.00\angle 0^\circ$$



Step 1

$Z_{bus} = (1)\ \boxed{j0.25}$

$$\frac{-1}{j0.36+j0.2}\begin{bmatrix} j0.25 \\ j.31 \\ j.36 \end{bmatrix}[j0$$

Zbus

	①	②
1	j0.25	j0.25
②	j0.25	j0.31

$(0.25+0.06)$

2

$Z_{kk} + Z_s$

Zbus.2	①	②	③
①	j0.25	j0.25	j0.25
②	j.025	j0.31	j.031
③	j.025	j0.31	j0.36

0.31
+.05
0.36

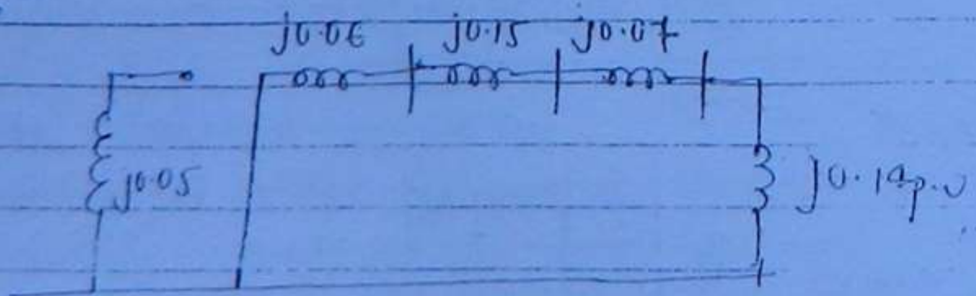
Zbus 2	①	②	③	4
①	j0.25	j0.25	j0.25	j0.25
②	j.025	j0.31	j.31	j.31
③	j.25	j0.31	j.36	j0.36
4	j.025	j.31	j.36	j0.36+j0.7

$$\begin{bmatrix} j0.25 & j0.25 & j0.25 & j0.25 \\ j0.25 & j0.31 & j0.31 & j0.31 \\ j0.25 & j0.31 & j.36 & j.36 \\ j0.25 & j0.31 & j.36 & j.43 \end{bmatrix} - \frac{1}{j0.43 + j0.2} \begin{bmatrix} j0.25 \\ j0.31 \\ j.36 \\ j.43 \end{bmatrix} \begin{bmatrix} j0.25 & j0.3 & j0 & j.\,\text{[illegible]} \end{bmatrix}$$

$$Z_{bus}(old) = \frac{1}{j0.63} \begin{bmatrix} -0.0625 & -0.0775 & -0.09 & -0.1075 \\ -0.0775 & -0.0961 & -0.1116 & -.1333 \\ -0.09 & -.1116 & -.1296 & -0.1548 \\ -0.1075 & -0.1333 & -0.1548 & -0.1849 \end{bmatrix}$$

$$Z_{bus}(new) = \begin{bmatrix} j0.15 & j0.12 & j0.107 & j0.079 \\ j0.1269 & j0.157 & j0.132 & j0.0984 \\ j0.107 & j0.132 & j0.154 & j0.114 \\ j0.076 & j0.098 & j0.114 & j0.136 \end{bmatrix}$$

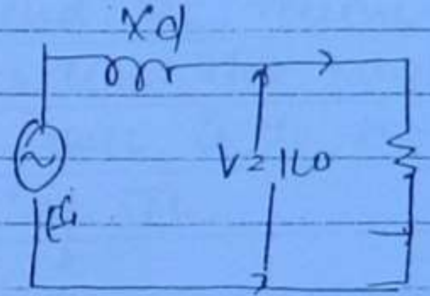
Zero sequence:-



$$I_{base} = \frac{850 \times 10^6}{\sqrt{3} \times 20 \times 10^3} \quad 14433.75\,A.$$

$$I_{pu} = \frac{11547}{14433} = 0.8\,p.u$$

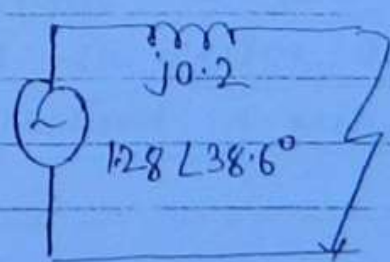
Befor fault:



Pre fault generate Emf $= 1\angle 0 + 0.8\angle 0 \times 1\angle 90$

$1.28\angle 38.65^\circ$ p.u.

During short ckt



$$I_{sc}'' = \frac{1.28}{0.2} = 6.4$$

$$I_{sc}'' = 6.4 \times 14433.75$$

$92.32\,kA$.

[redacted]

* Question :-

A 33KV single circuit 3ϕ T.L has the ABC parameter

$A = D = 1\angle 0°$

$B = 11.18\angle 63.43°$

the T.L is to deliver / 7.5MVA at 0.85 p.f lagging at the load end. the receiving end voltage is 32 KV line to line. How much active power and reactive power is to be dispatched from the sending end of T.L

Solution :-

\# the given data donot refer to load condenser method or source condenser method $A = D$.

\# the parameter B refers to the impedence of T.L which is connected in series. there fore the given data refers to nominal π method.

$V_R = 32 KV_{L-L}$

$P_S = \sqrt{3}\, V_{SL}\, I_{SL} \cos\phi_S$

$Q_S = \sqrt{3}\, V_{SL}\, I_{SL} \sin\phi_S$

$VA = \sqrt{3}\, V_{RL} I_{RL}$

$7.5 \times 10^6 = \sqrt{3} \times 32 \times 10^3 \times I$

$I_{RL} = 135.32 A$

$I_R = |I_R| \angle \phi_R$
$= 135.2 \angle -3$

$V_S = AV_R + BI_R$

$= (1\angle 0°)\left(\frac{32000}{\sqrt{3}}\right) + (11.18\angle 63.43°)(135.2\angle -31.7°)$

$= 19771.7\angle 2.34°.$

$V_{SL} = \sqrt{3} \times 19771.7 = 34.24 KV$

[redacted]

$AD - BC = 1$

$1 \times 1 - 11.8\angle 68.43 = 1$

$\Rightarrow \boxed{C = 0}$

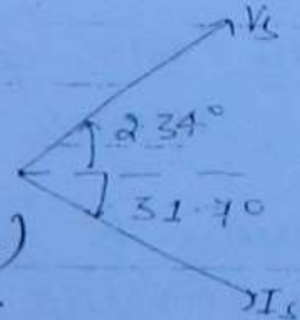
$\therefore \quad CV_R + DI_R = I_S$

$\Rightarrow \cancel{I_S = CV_R}$

$I_S = 0 \cdot V_R + (1\angle 0^\circ)(135.2\angle -31.7)$

$135.2\angle -31.7^\circ A$.

$$\boxed{I_S = 135.2\angle -31.7^\circ A}$$



$\phi_S = 2.34 + 31.7^\circ$

$P_S = \sqrt{3}\, V_{SL} \cdot I_{SL} \cos\phi_S$

$\sqrt{3}(34.24 \times 10^3)(135.2)(\cos 34.04)$

$P_S = \cancel{62}\ 6.64\ MW$

Reactive power $Q_S = \sqrt{3}\, V_{SL}\, I_{SL} \sin\phi_S$

$\sqrt{3}(34.24 \times 10^3)(135.2)(\sin 34.04^\circ$

$Q_S = 4.5\ MVAR$

Source condenser method is used to improve power factor of source

$$= \cancel{\begin{bmatrix} 1 & 1 \\ 1 & 3 \end{bmatrix} - \frac{1}{6}[1+1]}$$

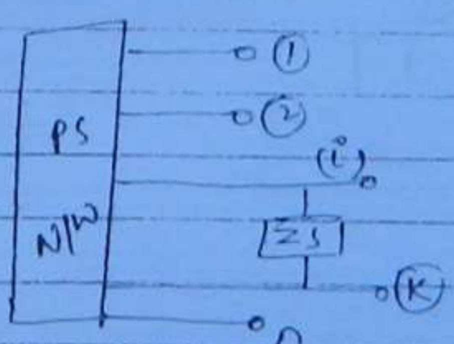
$$= \cancel{\begin{bmatrix} 1 & 1 \\ 1 & 3 \end{bmatrix} - \frac{7}{6}}$$

$$\begin{bmatrix} 1 & 1 \\ 31 & 3 \end{bmatrix} - \frac{1}{6}\begin{bmatrix} 1 & 3 \\ 3 & 9 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & 1 \\ 1 & 3 \end{bmatrix} - \begin{bmatrix} 1/6 & 1/2 \\ 1/2 & 3/2 \end{bmatrix} = \begin{bmatrix} 0.83 & 0.5 \\ 0.5 & \cancel{0.33}\,1.5 \end{bmatrix}$$

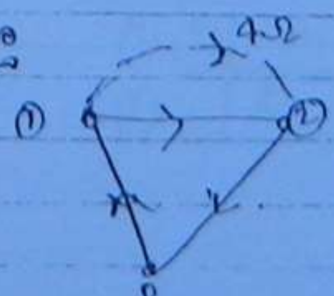
⇒ <u>Type 4 modification</u>:

An element with self impedance Z_s is added b/w old bus (i and k) (other than reference bus):



$$Z_{bus(new)} = \left[Z_{bus(old)} - \frac{1}{Z_s + Z_{ii} + Z_{kk} - 2Z_{ik}} \begin{bmatrix} Z_{1i} \\ \vdots \\ Z_{ni} \end{bmatrix} \times \begin{bmatrix} Z_{i1} - Z_{k1}, \ldots Z_{in} - Z_{kn} \end{bmatrix} \right]$$

Example:



$i = 1$

$k = 2$

$$Z_{bus(new)} = \begin{bmatrix} 0.83 & 0.5 \\ 0.5 & 1.5 \end{bmatrix} - \frac{1}{4 + Z_{11} + Z_{22} - 2Z_{12}}$$

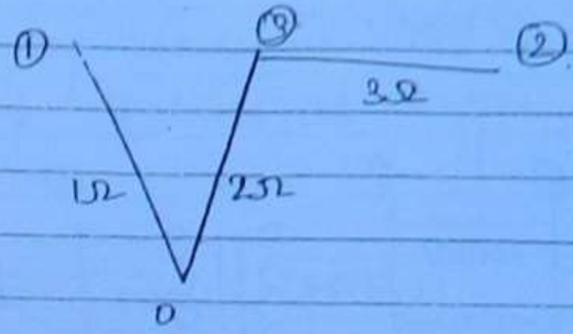
$$\begin{bmatrix} Z_{11} - Z_{12} \\ Z_{21} - Z_{22} \end{bmatrix} \begin{bmatrix} Z_{11} - Z_{21} & Z_{12} - Z_{22} \end{bmatrix}$$

$$\Rightarrow \begin{bmatrix} 0.83 & 0.5 \\ 0.5 & 1.5 \end{bmatrix} - \frac{1}{4 + 0.83 + 1.5 - 2 \times 0.5} \begin{bmatrix} 0.85 - 0.5 \\ 0.5 - 1.5 \end{bmatrix} \begin{bmatrix} 0.8 \\ 0. \end{bmatrix}$$

$$= \begin{bmatrix} 0.83 & 0.5 \\ 0.5 & 1.5 \end{bmatrix} - \frac{1}{5.3} \begin{bmatrix} 0.33 \\ 1 \end{bmatrix} \begin{bmatrix} 0.33 & 1 \end{bmatrix}$$

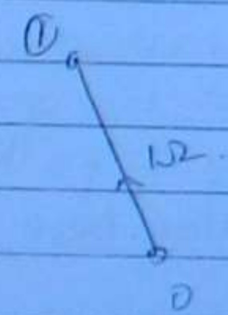
$$Z_{bus(new)} = \begin{bmatrix} 0.812 & 0.559 \\ 0.559 & 1.39 \end{bmatrix}$$

:- IES-Numerical:



Step 1 :-

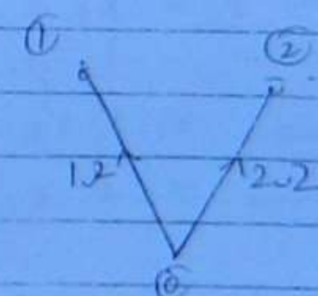
$$Z_{bus} = \begin{array}{c|c|} & ① \\ ① & 1\Omega \end{array}$$



Type I

Step 2 :

$$Z_{bus} = \begin{array}{c|c|c|} & ① & ③ \\ ① & 1\Omega & 0 \\ ③ & 0 & 3\Omega \end{array}$$

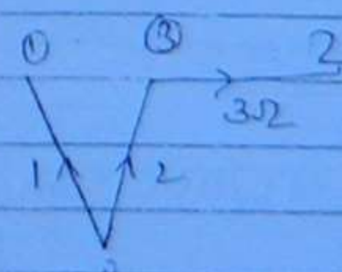


Type 1

Step 3 : $K = 3$

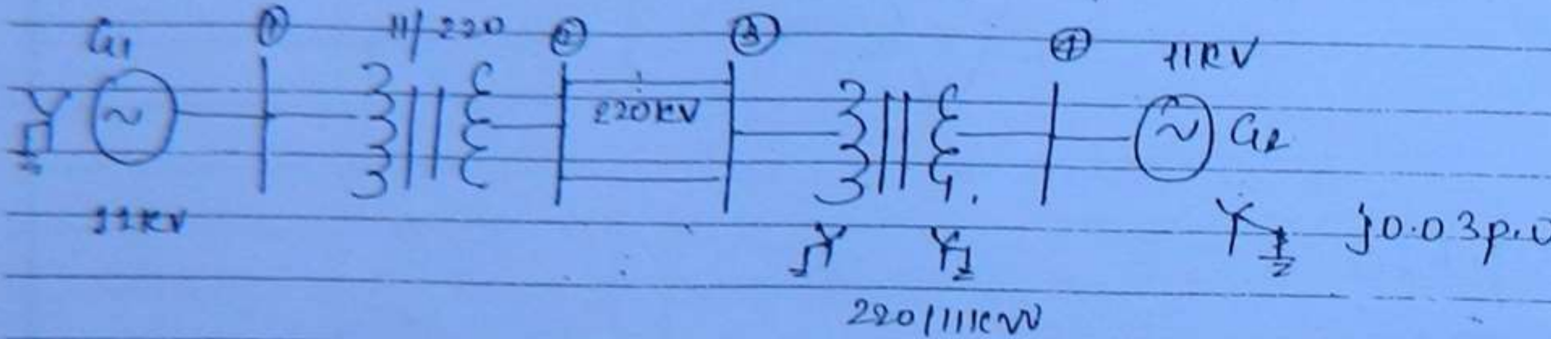
$q = 2$.

$$Z_{bus} = \begin{array}{c|c|c|c|} & ① & ③ & ② \\ ① & 1 & 0 & 0 \\ ③ & 0 & 2 & 2 \\ ② & 0 & 2 & 5 \end{array}$$



Type 2

Problem: for power s/m network shown form.
Z_1 bus, Z_2 bus, Z_0 bus.



Common base MVA = 100

$G_1 \rightarrow X_1 = X_2 = j0.25,\ X_0 = j0.05$ p.u
$G_2 \rightarrow X_1 = X_2 = j0.2;\ X_0 = j0.05$ p.u

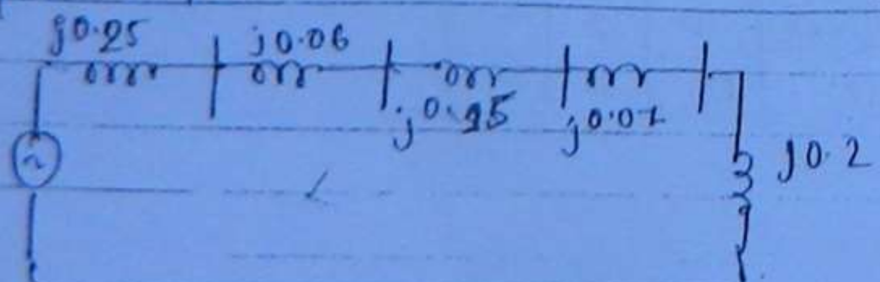
$T_1 \rightarrow X_1 = X_2 = X_0 = j0.06$ p.u
$T_2 \rightarrow X_1 = X_2 = X_0 = j0.07$ p.u

$L_1, L_2 \rightarrow X_1 = X_2 = X_0 = j0.3$.

Solution:

$\frac{0.03}{2}$

$\Rightarrow$ Positive sequence n/w

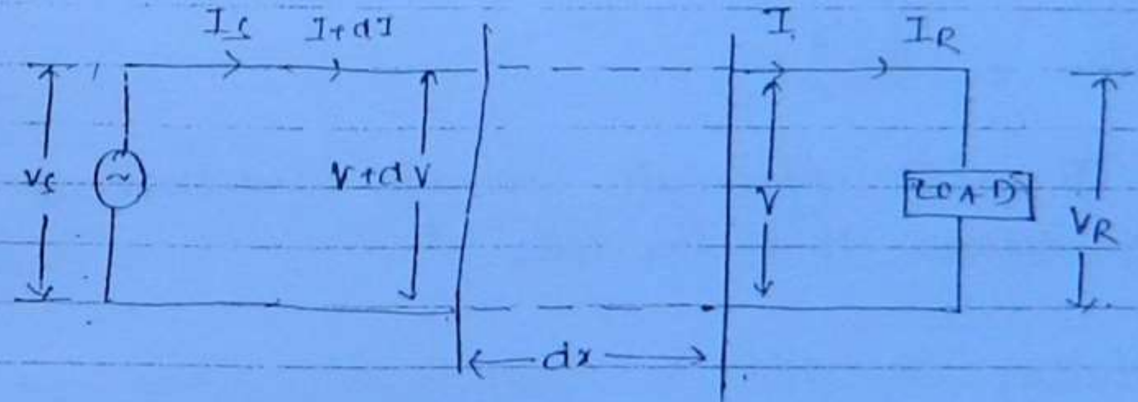


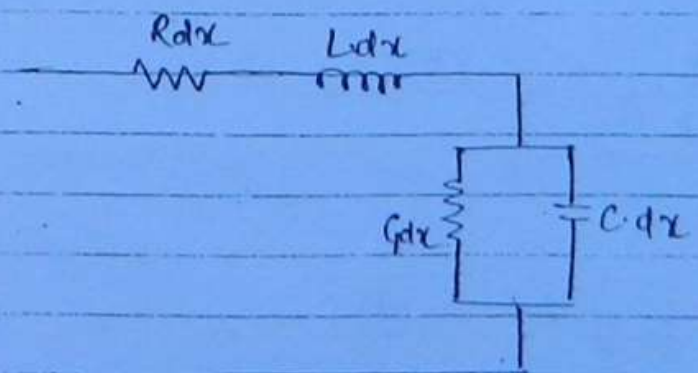
ZPB

The four methods of medium transmission line improve the p.f of line at different locatn:-

→ Long Transmission lines: (>150km)

In long transmission line capacitance is uniformly distributed through out the length of T.L. To determine the performance of long T.L consider a section (dx) of T.L.





z → impedence per unit length of T.L
y → shunt admittance per unit length of line.
l → total length of T.L.

$Z = z.l$ → series impedence for total length

$Y = y.l.$ → shunt admittance for total length of line

Analysis of Long Transmission line :-

$$dv = I.z\,dx.$$

$$\frac{dv}{dx} = I.z. \quad — ①$$

$$dI = V.y\,dx$$

$$\frac{dI}{dx} = V.y, \quad — ②$$

equation ① and ② represents voltage and current of the section dx of the line.

differentiating ① wrt x

$$\frac{d^2v}{dx^2} = \frac{dI}{dx}.z \quad — ③$$

Similarly

$$\frac{d^2v}{dx^2} = z.y.V \quad — ④$$

Equation 4 is second order differential equat^n.
the solution of equat^n ④ is

$$V = Ae^{\sqrt{yz}.x} + Be^{-\sqrt{yz}.x} \quad — ⑤$$

A and B are unknown constants. which

$\Rightarrow$

$$V_s = V_R\left\{A_1 + \frac{B_1(A_2 - A_1)}{B_1 + B_2}\right\} + \left(\frac{B_1 B_2}{B_1 + B_2}\right) I_R \quad \text{— (6)}$$

now.

$$I_s = I_{s1} + I_{s2}$$

$$I_s = C_1 V_{R_1} + D_1 I_{R_1} + C_2 V_R + D_2 I_{R_2}$$

$$I_s = [C_1 + C_2] V_R + D_1 I_{R_1} + D_2 [I_R - I_{R_1}]$$

$$I_s = [C_1 + C_2] V_R + [D_1 - D_2] I_{R1} + D_2 I_R \quad \text{— (7)}$$

substituting eq^n (5) in (7)

$$I_s = (C_1 + C_2) V_R + D_2 I_R + (D_1 + D_2)\left\{\frac{(A_2 - A_1) V_R + B_2 I_R}{B_1 + B_2}\right\}$$

$$\boxed{I_s = \left(C_1 + C_2) + \frac{(D_1 - D_2)(A_2 - A_1)}{B_1 + B_2}\right) V_R + \left(\frac{B_1 D_2 + B_2 D_1}{B_1 + B_2}\right) I_R}$$

Question:-

A 50Hz T.L is 500Km long. The parameter of the T.L

R = 0.1 Ω/Km ; X = 2mH/Km C = 0.01 μF/Km.

G=0. calculate the characteristic impedance and propogatⁿ constant of T.L

2π

$$Z_C = \sqrt{\frac{R+j\omega L}{G+j\omega C}} = \sqrt{0.1+jx}$$

in per phase.

$R = 0.1 \times 500 = 50\,\Omega$

$L = 2 \times 10^{-3} \times 500 = 1H.$

$C = 0.01 \times 10^{-6} \times 500 = 5 \times 10^{-6} F$

$2\pi 60 f = 2 \times 3.14 \times 50$

$\Rightarrow$

$$Z_C = \sqrt{\frac{50 + j \times 2 \times \pi \times 50 \times 1}{0 + j\,2 \times \pi \times 50 \times 5 \times 10^{-6}}} = \sqrt{\frac{Z \angle \phi}{Y \angle \phi}}$$

$$= \sqrt{\frac{317.96 \angle 80.95^\circ}{1570 \angle 90^\circ}} \quad 450.1 \angle -4.5^\circ$$

$\gamma = \sqrt{ZY} = \sqrt{} = \gamma \quad 0.707 \angle 85.47$

Questⁿ:

2) A 66kV, 3-ϕ, 50Hz, 150 km long T.L is open circuited at the receiving end, each conductor has resistance of $0.125\,\Omega/\text{Km}$ and inductive reactance of $0.5\,\Omega/\text{Km}$ and capacitive admittance to the neutral is $B_c = 4\times10^{-6}$ S/km.

1) Draw the nominal π equivalent ckt and indicate the value of each parameter.
2) Calculate the receiving end voltage if the sending end voltage is 66kV.

Solutⁿ

1) total impedence per phase $Z/\phi = R/\phi + jX/\phi$

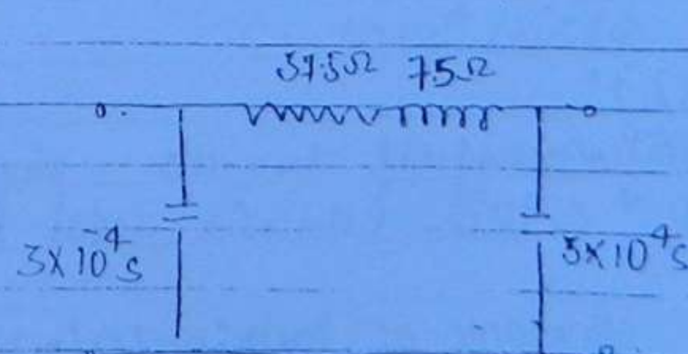
$$= \left(\frac{0.25\,\Omega}{\text{Km}} \times 150 + j\,\frac{0.5\,\Omega}{\text{Km}} \times 150\text{k}\right)$$

$$Z/\phi = (37.5 + j75)\,\Omega$$

$$Y/\phi = G/\phi + jB/\phi$$

$$0 + j\,\frac{4\times10^{-6}\,\text{S}}{\text{Km}} \times 150$$

$$Y/\phi = j6\times10^{-4}\,\text{S}.$$



2) $I_R = 0$

$$\Rightarrow V_s = AV_R + BI_R.$$

$$V_s = A \cdot V_{R0}$$

$$V_{R0} = \frac{V_s}{A} = \frac{V_s}{1 + \frac{YZ}{2}}$$

$$V_{R0} \Rightarrow \frac{66 \times 10^3}{1 + \frac{(37.5 + j75)(j6 \times 10^{-4})}{2}}$$

$$\boxed{V_{R0} = 67.5 \angle -0.66^\circ kV}$$

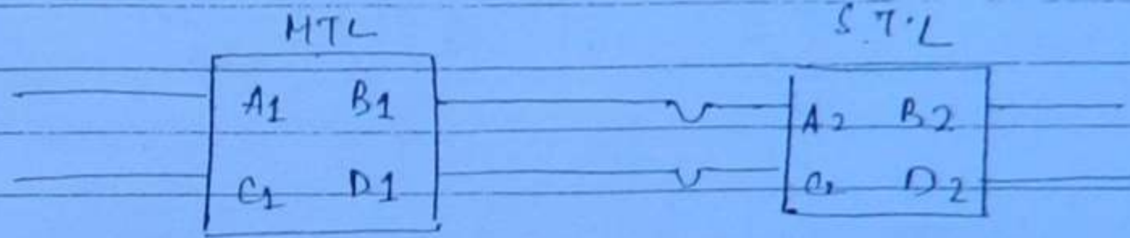
Questn

Two identical 3-ϕ T.L are connected in parallel to supply a total load of 100 MW at 132 kV and 0.8 p.f (lag) at the receiving end. The ABCD parameter of each T.L are as follows

$$A = D = 0.98 \angle 1^\circ$$
$$B = 100 \angle 75^\circ \Omega$$
$$C = 5 \times 10^{-4} \angle 90^\circ$$

Determine the ABCD constants of combined n/w

6) A medium line $\bar{c}$ parameters ABCD is extended by connecting a short-line of impedance Z connected in series. The overall ABCD parameters of the series combination will be.



$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1+\frac{YZ}{2} & Z\left(1+\frac{YZ}{4}\right) \\ Y & 1+\frac{YZ}{2} \end{bmatrix} \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} \left(1+\frac{YZ}{2}\right) & Z\left(1+\frac{YZ}{2}\right)+Z\left(1+\frac{YZ}{4}\right) \\ Y & YZ+1+\frac{YZ}{2} \end{bmatrix}$$

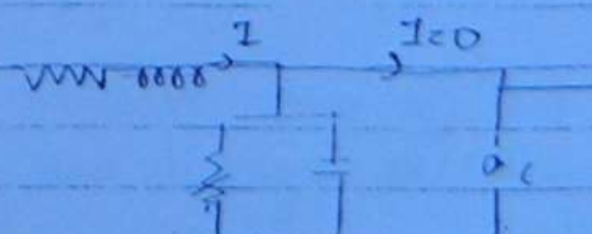
7) A 220kV, 20km long 3ϕ T.L has the following ABCD constant

$A = D = 0.96\angle 3^\circ$

$B = 55\angle 65^\circ \Omega/\phi$

$C = 5\times10^{-4}\angle 80^\circ S/\phi$

The charging current per phase when receiving end is open circuited is.



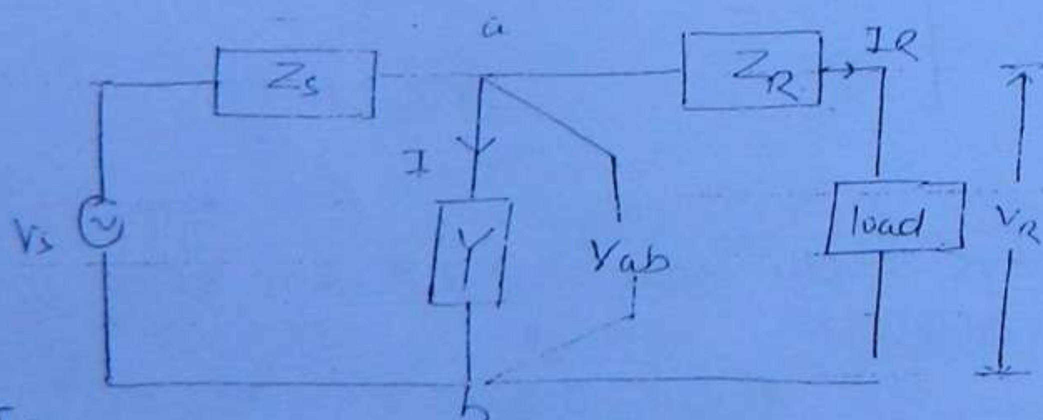
$I_s = CV_R + DI_R$

$I_R = 0 \Rightarrow I_s = CV_R$

$5\times10^{-5}\times\left(\frac{220\times10^{3}}{\sqrt{3}}\right) = \frac{11}{\sqrt{3}}$ A.

NOMINAL T AND π NETWORK FOR LONG T.L.

condition 1: T network.

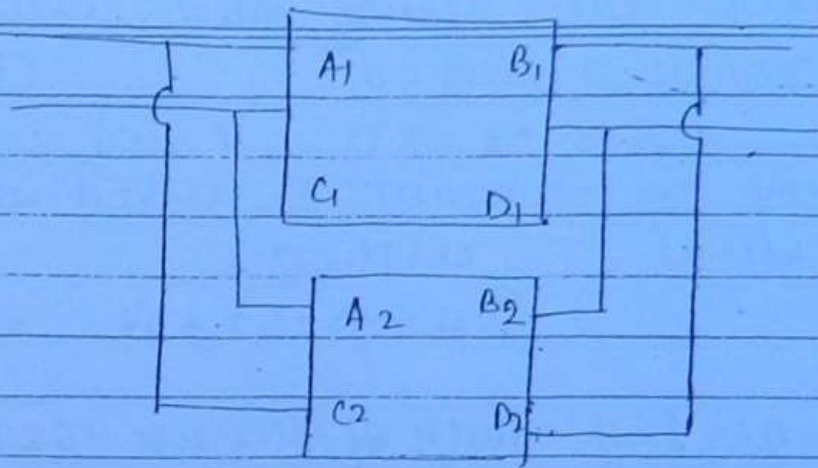


$V_{ab} = V_R + Z_R I_R$

$I = YV_{ab} = Y(V_R + Z_R I_R) = YV_R + YZ_R \cdot I_R$

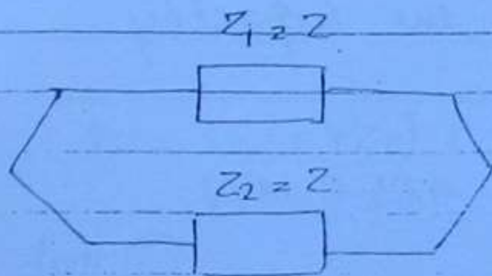
$I_S = I + I_R = (YV_R + YZ_R I_R) + I_R$

$I_S = YV_R + I_R(1 + YZ_R)$ — (1)

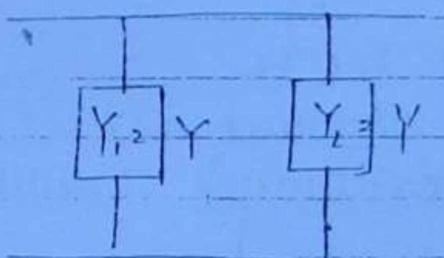


$A_0 = A_1 = A_2$

$D_0 = D_1 = D_2$



$B_0 = Z/2 = \frac{B}{2} = \frac{100\angle 75}{2} = 50\angle 75$



$C_0 = Y_1 + Y_2 = 2Y = 2C = 2(5\times10^{-4}\angle 90^\circ)$

$10\times10^{-4}\angle 90^\circ S$

Objective :-

1) The surge impedence of 50km long TL is 50Ω so for a length of 25km, the surge impedence is

→ surge impedence is independent of length

2) For long T.L for a particular receiving end voltage when the sending end voltage is calculated

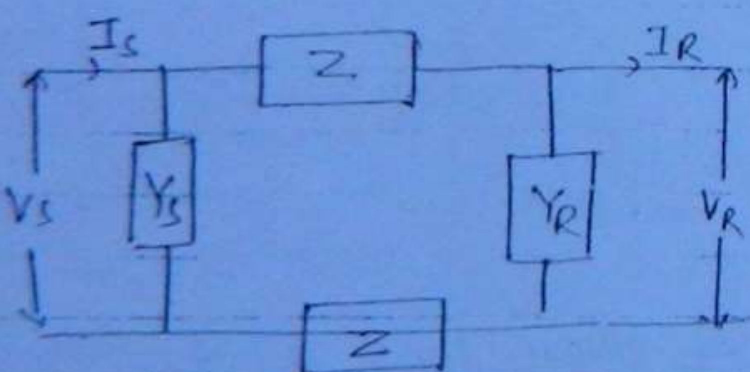
it is more than the actual value when calculated by nominal π method.

As voltage drop in nominal π method is more than nominal T method

) the voltages is at both ends of T.L are 132 kV and its reactance is 40Ω the capacity of line is.

$$\frac{\cancel{132}^{33} \times 132}{\cancel{40}} \Rightarrow 435.6 \text{ MW}$$

) the equivalent π n/w is given, if the T.L is short T.L then A, B, C, D constant are -



$A = 1$
$B = 2$
$C = 0$
$D = 1$

for any short T.L we get same value

5) to increase the power transferred, the surge impedance must be decreases

from (1)

$$\boxed{C = Y, \quad D = 1 + Y \cdot Z_R}.$$

$V_S = V_R + I_S Z_S + I_R Z_R.$

$V_S = V_R + \{ Y V_R + I_R (1 + Y Z_R) \} Z_S + I_R Z_R.$

$V_S = (1 + Y Z_S) + I_R (Z_S + Y Z_S Z_R + Z_R)$ —— (2)

from (2)

$$\boxed{A = 1 + Y Z_S, \quad B = Z_S + Z_R + Y Z_S Z_R}$$

condition 2: Symmetrical. T-n/w

$Z_S \rightarrow \frac{1}{2} Z_T, \quad Z_R = \frac{1}{2} Z_T; \quad Y = Y_T.$

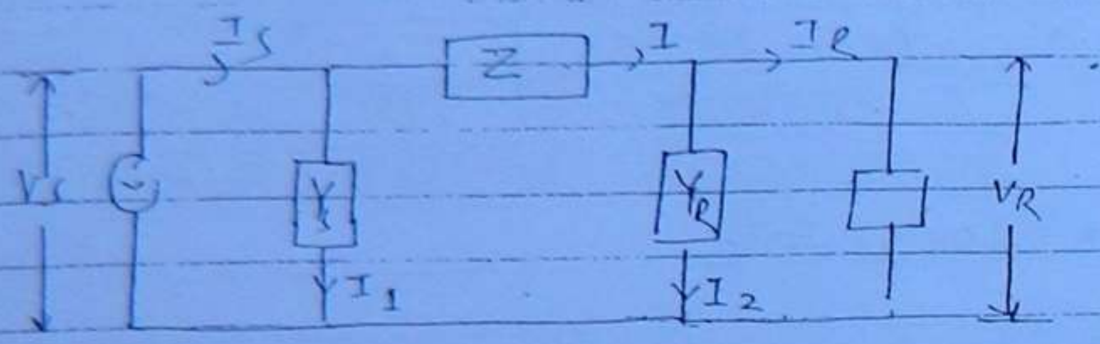
$A = 1 + Y Z_S = 1 + \frac{Y_T Z_T}{2}$

$D = 1 + Y Z_R = 1 + \frac{Y_T Z_T}{2}$

$B = Z_S + Z_R + Y Z_S Z_R = \frac{1}{2} Z_T + \frac{1}{2} Z_T + Y_T \frac{Z_T}{2} \frac{Z_T}{2}$

$C = Y = Y_T$

Condition 4: Nominal π network:-



$$I_1 = Y_s V_s \text{ ------- } (1)$$

$$I_2 = Y_R . V_R \text{ ------- } (2)$$

$$I = I_R + I_2 \text{ ------- } (3)$$

$$I_R + Y_R \cdot V_R \text{ ------- } (3)$$

$$I_s = I_1 + I$$

$$Y_s V_s + (I_R + V_R Y_R) \text{ --- } (4)$$

now

$$V_s = V_R + IZ$$

$$V_R + (I_R + Y_R V_R) Z$$

$$V_R + I_R Z + V_R Y_R Z$$

$$V_s = V_R (1 + Z Y_R) + Z I_R \text{ -- } (5)$$

from eqn 5

$$\boxed{\begin{aligned} A &= 1 + ZY_R \\ B &= Z \end{aligned}}$$

substituting ⑤ → ④

$$I_S = Y_S \{ V_R(1 + ZY_R) + ZI_R \} + I_R + Y_R V_R$$

$$= V_R (Y_S + ZY_S Y_R + Y_R) + I_R(1 + ZY_S)$$

$$\therefore \boxed{\begin{aligned} C &= Y_S + Y_S + ZY_S Y_R \\ D &= 1 + ZY_S \end{aligned}}$$

symmetrical π - n/w :-

$$Z = Z_\pi , \quad Y_S = \frac{Y_\pi}{2} , \quad Y_R = \frac{Y_\pi}{2}$$

$$\boxed{\begin{aligned} A &= 1 + Z, Y_R = 1 + Z_\pi \cdot \frac{Y_\pi}{2} \\ B &= Z = Z_\pi \end{aligned}}$$

$$C = Y_S + Y_R + ZY_S Y_R$$

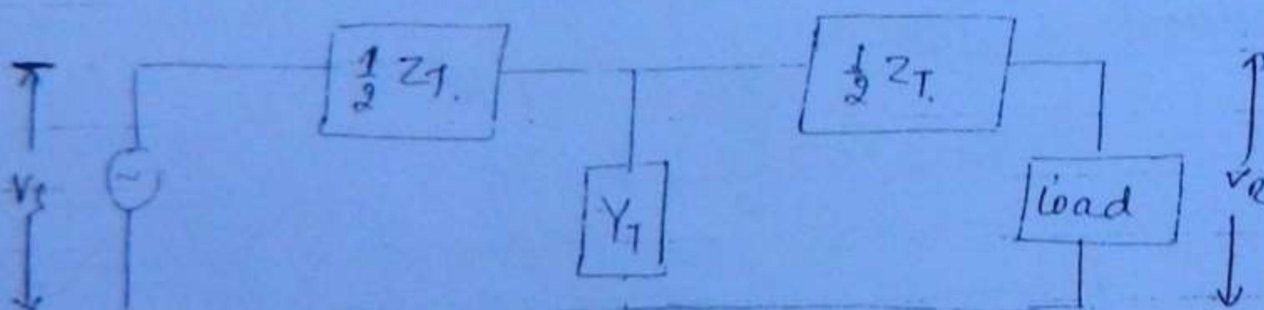
$$\frac{Y_\pi}{2} + \frac{Y_\pi}{2} + Z_\pi \frac{Y_\pi}{2} \frac{Y_\pi}{2}$$

$$\boxed{C = Y_\pi + \frac{Z_\pi Y_\pi^2}{4}}$$

$$D = 1 + ZY_S = 1 + Z_\pi \frac{Y_\pi}{2}$$

	T	π
A	$1+YZ_S$	$1+Y_R Z$
B	$Z_S+Z_R+Z_S Z_R Y$	Z
C	Y	$Y_S+Y_R+Y_S Y_R Z$
D	$1+YZ_R$	$1+Y_S Z$

EQUIVALENT T- NETWORK OF LTL :



$$A = D = 1 + \frac{Y_T \cdot Z_T}{2}$$

$$C = Y_T$$

$$B = Z_T\left(1 + \frac{Y_T Z_T}{4}\right)$$

$$\frac{1}{2} Z_T = ?$$

$$1 + \frac{Z_T Y_T}{2} = A$$

$$\Rightarrow \frac{Z_T Y_T}{2} = A - 1$$

$$\Rightarrow \frac{Z_T Y_T}{2} = \cosh \gamma x - 1$$

$$\frac{Z_T}{2} = \frac{\cosh \gamma x - 1}{Y_T}$$

$$\frac{Z_T}{2} = \frac{\cosh\gamma x - 1}{C} = \frac{\cosh\gamma x - 1}{\frac{1}{Z_c}\sinh\gamma x} = Z_c\frac{(\cosh\gamma x - 1)}{\sinh\gamma x\ x}$$

$$\Rightarrow Z_c \frac{2\sinh^2\gamma x/2}{2\sinh\gamma x/2\ \cosh\gamma x/2}$$

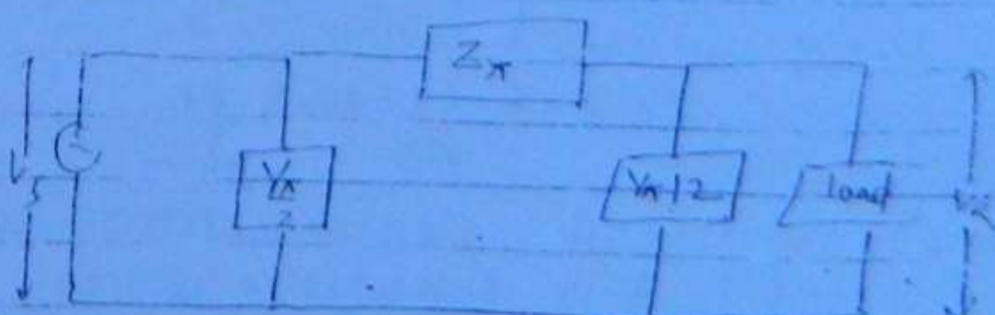
$$\frac{Z_T}{2} = Z_c \tanh\frac{\alpha x}{2}$$

we know that $Z_c = \sqrt{\frac{Z}{Y}} \Rightarrow \sqrt{\frac{Z \cdot Z}{ZY}} = \frac{Z}{\gamma}$.

$$= \frac{Z \cdot x}{\gamma \cdot x} = \frac{\text{total series impedence } (Z)}{\gamma x}.$$

$$\boxed{\frac{Z_T}{2} = \frac{Z}{2}\left(\frac{\tanh\gamma x/2}{\frac{\gamma x}{2}}\right)} \quad (1)$$

EQUIVALENT π N/W :



$$A = D = 1 + \frac{1}{2} Y_\pi Z_\pi$$

$$B = Z_\pi$$

$$C = Y_\pi \left\{ 1 + \frac{Y_\pi Z_\pi}{2} \right\}$$

To find :- $Z_\pi = ?$

$$\frac{Y_\pi}{2} = ?$$

$$1 + \frac{1}{2} Y_\pi Z_\pi = A$$

$$\frac{1}{2} Y_\pi Z_\pi = A - 1$$

$$\frac{Y_\pi}{2} = \frac{A-1}{B}$$

$$\frac{Y_\pi}{2} = \frac{\cosh \gamma x - 1}{Z_c \sinh \gamma x}$$

$$\frac{Y_\pi}{2} = \frac{1}{Z_c} \frac{2 \sinh^2 \gamma x/2}{2 \sinh \frac{\gamma x}{2} \cosh \gamma x/2}$$

$$\frac{Y_\pi}{2} = \frac{1}{Z_c} \tanh \frac{\gamma x}{2}$$

$$Z_c = \sqrt{\frac{Z}{Y}} = \sqrt{\frac{Z\cdot Y}{Y\cdot Y}} = \frac{\gamma}{Y}$$

$$\cancel{Y x} \quad \frac{\gamma \cdot x}{Y \cdot x} = \frac{\gamma \cdot x}{Y} = \frac{\gamma x/2}{Y/2}$$

$$\frac{Y_\pi}{2} = \frac{1}{\gamma x/2 \,/\, Y/2} \tanh\frac{\gamma x}{2}.$$

$$\boxed{\frac{Y_\pi}{2} = \frac{Y}{2}\left(\frac{\tanh\frac{\gamma x}{2}}{\gamma x/2}\right).}$$

CONCEPT OF TRAVELLING WAVES:

• Voltage and current travels in the form of waves from sending end to the receiving end of T.L in form of waves

S.E x———x R.E

V_1 V_2

S.E → R.E is called Incident wave

V, I ⟹ $V = Z_c I$

• Voltage wave and current wave travels gradually from sending end to receiving end.

- The voltage wave and current wave travelling from sending end to receiving end through T.L are reflected back in T.L when $Z_L \neq Z_c$

- The voltage wave and current wave reflected back into T.L are known as reflected voltage wave V' and reflected current I'

$$\boxed{I' = -\frac{V'}{Z_c}}$$ (∵ -ve as reflected wave). !

- The voltage wave and current wave travelling through the load are known as transmitted or refracted voltage wave (V'') and current wave (I'')

$$\boxed{I'' = \frac{V''}{Z_L}}$$

- If reflection do not occur when Z_L equal to Z_c.

$$\boxed{Z_L = Z_c}$$

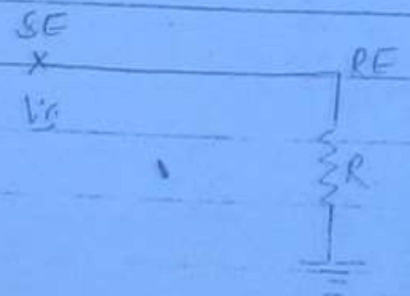
$$\boxed{\begin{array}{l} V'' = V + V' \\ I'' = I + I' \end{array}}$$

[redacted]

Travelling waves:

Condition 1: 'R'

Receiving end of T.L terminated by resistance



$$V'' = V + V' \qquad I'' = I + I'$$

$$I = V/Z_c \qquad I' = -V'/Z_c \qquad I'' = V''/R$$

$$V'' \rightarrow V, \quad V' \rightarrow V$$

Expressing transmitted voltage V'' in terms of incident voltage 'V' and transmitted current I'' in terms of in terms of incident current I.

$$\Rightarrow \quad V''/R = \frac{+V}{Z_c} + \left(\frac{-V'}{Z_c}\right)$$

replacing V' by $(V''-V)$

$$V''/R = \left(\frac{+V}{Z_c}\right) - \left(\frac{V''-V}{Z_c}\right)$$

$$V''\left[\frac{1}{R} + \frac{1}{Z_c}\right] = \frac{2V}{Z_c}$$

$$\boxed{V'' = V \cdot \left[\frac{2R}{R+Z_c}\right]} \quad \text{---- (1)}$$

- transmitted voltage co-efficient $\boxed{\tau_v = \frac{V''}{V} = \frac{2R}{R+Z_c}}$.

Similarly from eqn (I)

$$I''\cancel{R} = IZ_c\left(\frac{2\cancel{R}}{R+Z_c}\right)$$

$$\boxed{I'' = I\left(\frac{2Z_c}{R+Z_c}\right)}.$$

- transmitted current co-efficient

$$\boxed{\tau_i = \frac{I''}{I} = \frac{2Z_c}{R+Z_c}}.$$

Expressing reflected voltage (V') in terms of incident voltage (V) and reflected current (I') in terms of incident current I).

$$\frac{V''}{R} = \frac{+V}{Z_c} + \frac{(-V')}{Z_c}$$

$$\frac{V+V'}{R} = \frac{+V}{Z_c} + \frac{(-V')}{Z_c}$$

$$V\left[\frac{1}{R} - \frac{1}{Z_c}\right] = -V\left[\frac{1}{R} + \frac{1}{Z_c}\right]$$

$$\cancel{Z_c+R} \quad V\left[\frac{Z_c - R}{\cancel{R Z_c}}\right] = -V'\left[\frac{R+Z_c}{\cancel{R Z_c}}\right] \quad \text{---} \; (2)$$

- reflection coefficient of voltage $\boxed{\rho_v = \frac{V'}{V} = \frac{R-Z_c}{R+Z_c}}$.

similarly using eqn (2)

$$V' = V\left(\frac{R-Z_c}{R+Z_c}\right)$$

$$-I'\cancel{Z_c} = I\cancel{Z_c}\left(\frac{R-Z_c}{R+Z_c}\right)$$

- reflection coefficient of current $\boxed{\rho_i = \frac{I'}{I} = \frac{Z_c-R}{Z_c+R}}$

$$\boxed{\begin{aligned} \tau_V &= \frac{2R}{Z_c+R} \\ \tau_I &= \frac{2Z_c}{Z_c+R} \\ \rho_V &= \frac{R-Z_c}{Z_c+R} \\ \rho_{I\,(c)} &= \frac{Z_c-R}{Z_c+R} \end{aligned}}$$

Condition 2: Receiving end of T.L terminated by underground cable with impedance (Z_1).

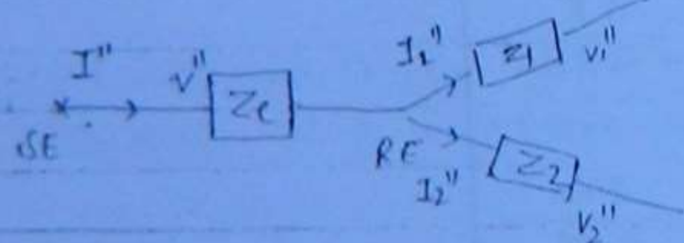
- $\tau_v = \dfrac{2Z_1}{Z_c + \cancel{R} Z_1}$ → replace R by Z_1.

- $\tau_I = \dfrac{2Z_c}{Z_c + Z_1}$

- $\rho_v = \dfrac{Z_1 - Z_c}{Z_c + Z_1}$

- $\rho_I = \dfrac{Z_c - Z_1}{Z_c + Z_1}$.

Condition 3: Receiving end of T.L line forming a T junc^n.



+ Z_1, Z_2 connected in parallel.

$$V_1'' = V_2'' = V''$$

$$I'' = I_1'' + I_2''$$

$$\Rightarrow I'' = I + I'$$

$$\Rightarrow I_1'' + I_2'' = I + I'$$

Expressing Transmitted voltage (V'') in terms of incident voltage (V), and transmitted current (I'') in terms of incident current (I):-

$$I_1'' + I_2'' = I + I'$$

$$\Rightarrow \frac{V_1''}{Z_1} + \frac{V_2''}{Z_2} = \frac{V}{Z_c} + \left(\frac{-V'}{Z_c}\right)$$

$$\Rightarrow \frac{V''}{Z_1} + \frac{V''}{Z_c} = \frac{V}{Z_c} - \frac{V'}{Z_c}$$

$$\Rightarrow V''\left(\frac{1}{Z_1} + \frac{1}{Z_c}\right) = \frac{V}{Z_c} - \frac{V'}{Z_c}$$

$$\Rightarrow V''\left[\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_c}\right] = \frac{2V}{Z_c}$$

$$V'' = \frac{V(2/Z_c)}{\left[\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_c}\right]} \quad \text{------ (1)}$$

- Transmitted ~~reflection~~ coefficient of voltage $\boxed{\tau_V = \frac{V''}{V} = \frac{2/Z_c}{\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_c}}}$

now using equat^n (1)

$$I'' Z_1 = \frac{I \cancel{Z_c} (2/\cancel{Z_c})}{\left[\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_c}\right]}$$

• Transmitted coefficient of current $\boxed{\tau_I = \frac{I_1''}{I} = \frac{2/Z_1}{\frac{1}{Z_1}+\frac{1}{Z_2}+\frac{1}{Z_c}}}$.

$$\therefore \quad \boxed{\tau_{I_2''} = \frac{I_2''}{I} = \frac{2/Z_2}{\frac{1}{Z_1}+\frac{1}{Z_2}+\frac{1}{Z_c}}}$$

• Expressing reflected voltage in terms of incident voltage and reflected current in terms of incident current

$$I_1'' + I_2'' = I + I'$$

$$\Rightarrow \frac{V_1''}{Z_1} + \frac{V_2''}{Z_2} = \frac{V}{Z_c} + \left(\frac{-V'}{Z_c}\right)$$

$$\frac{V''}{Z_1} + \frac{V''}{Z_2} = \frac{V}{Z_c} - \frac{V'}{Z_c}$$

$$\Rightarrow V''\left(\frac{1}{Z_1}+\frac{1}{Z_2}\right) = \frac{V}{Z_c} - \frac{V'}{Z_c}$$

$$\Rightarrow (V+V')\left(\frac{1}{Z_1}+\frac{1}{Z_2}\right) = \frac{V}{Z_c} - \frac{V'}{Z_c}$$

$$\Rightarrow V'\left(\frac{1}{Z_1}+\frac{1}{Z_2}+\frac{1}{Z_c}\right) = \frac{V}{Z_c} - \frac{V}{Z_1} - \frac{V}{Z_2}$$

$$\Rightarrow V' = V \frac{\left(\frac{1}{Z_c} \mp \frac{1}{Z_1} - \frac{1}{Z_2}\right)}{\left(\frac{1}{Z_c} + \frac{1}{Z_1} + \frac{1}{Z_c}\right)} \quad - - - - (a)$$

• reflected coefficient of voltage $\boxed{\rho_v = \frac{V'}{V} = \left[\frac{1/Z_c - 1/Z_1 - 1/Z_2}{1/Z_c + 1/Z_1 + 1/Z_2}\right]}$

Similarly: from eqn (a)

$$-I' Z_c = I \cdot Z_c \frac{\left(1/Z_c - 1/Z_1 - 1/Z_2\right)}{\left(\frac{1}{Z_c} + \frac{1}{Z_1} + \frac{1}{Z_2}\right)}$$

$$\Rightarrow I' = I \frac{\left(1/Z_1 + \frac{1}{Z_2} - 1/Z_c\right)}{\left(\frac{1}{Z_c} + \frac{1}{Z_1} + \frac{1}{Z_2}\right)}$$

• reflected coefficient of current $\boxed{\rho_i = \frac{I'}{I} = \left[\frac{1/Z_1 + 1/Z_2 - 1/Z_c}{\frac{1}{Z_c} + \frac{1}{Z_1} + \frac{1}{Z_2}}\right]}$

$$\tau_v = \left(2/Z_c\right) / \left(1/Z_c + \frac{1}{Z_1} + 1/Z_2\right)$$

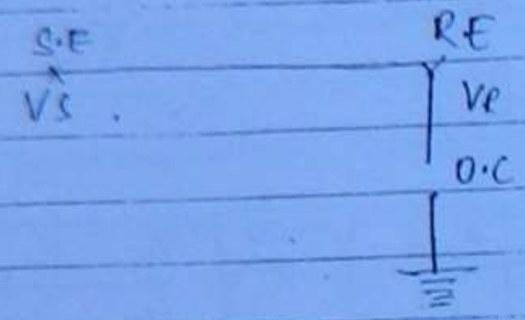
$$\tau_i = \left(2/Z_1 \text{ or } 2/Z_2\right) / \left(1/Z_c + 1/Z_1 + \frac{1}{Z_2}\right)$$

$$\rho_v = \left(\frac{1}{Z_c} - \frac{1}{Z_1} - \frac{1}{Z_2}\right) / \left(1/Z_c + 1/Z_1 + 1/Z_2\right)$$

$$= \left(\frac{1}{Z_1} + \frac{1}{Z_2} - \frac{1}{Z_c}\right) / \left(1/Z_c + 1/Z_1 + \frac{1}{Z_2}\right)$$

3rd

* Condition 4: Receiving end of T.L is open circuited.



$\frac{1}{2}LI^2$ $\quad$ $\frac{1}{2}CV^2$

$I = 0$

$\frac{1}{2}LI^2 = 0$

When the receiving end of T.L is open circuited $\boxed{(I=0)}$. Electromagnetic energy stored by inductor in magnetic field is equal. $\boxed{\frac{1}{2}LI^2 = 0}$. According to law of conservation of energy, energy cannot be destroyed but only can be converted from one form to another form. i.e. the entire electromagnetic energy is converted into electrostatic energy stored by capacitor in the electric field.

The increase in electrostatic energy increases the voltage. Let the voltage be increased by 'e' volts.

$$V \uparrow \rightarrow 'e' \text{ volts.}$$

so $\frac{1}{2}LI^2 = \frac{1}{2}Ce^2$

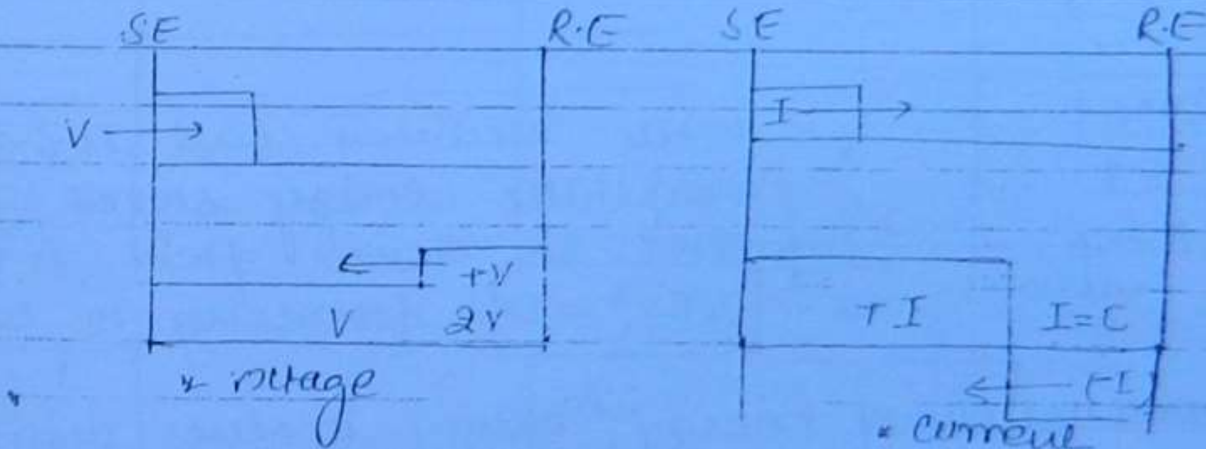
$$I^2 = e^2 / L/C$$

$$I^2 = e^2 / Z_c^2$$

$$= \quad e^2 = \underbrace{I^2}_{\text{incident current}} Z_c^2$$

$$\boxed{e = I \cdot Z_c = V.}$$

when the receiving end is open circuit the voltage is increased by 'V' when V is incident or voltage at sending end.



$$\boxed{\text{reflection coefficient } \rho_V = +V/V = 1}$$

← when recieving end is O.C

$$\boxed{\text{reflection coefficient } \rho_I = \frac{-I}{+I} = -1}$$

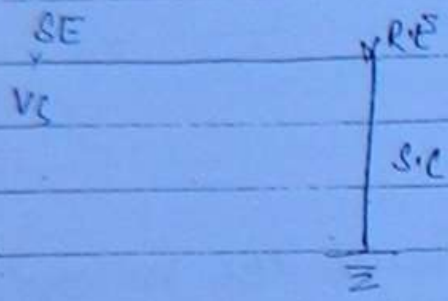
$$\tau_V = \frac{V''}{V} = \frac{V'+V}{V} = \frac{V+V}{V} = 2$$

$$\boxed{\tau_V = 2}$$

$$\tau_I = 0/I = 0$$

$$\boxed{\tau_I = 0}$$

Conditions: Receiving end to T.L Short-circuited.



$V = 0$

$$\frac{1}{2}LI^2, \quad \underset{\substack{\downarrow \\ 0}}{\frac{1}{2}CV^2} \rightarrow 0.$$

$\frac{1}{2}LI^2$.

EMF ↑
I ↑
i Amp

When receiving end is S.C $\boxed{V=0}$, electrostatic energy stored by capacitor in electric field is equal to $\boxed{\frac{1}{2}CV^2 = 0}$. According to law of conservation of energy, energy is never destroy but only is converted from one form to another form. i.e entire electro-static energy is converted into electromagnetic energy. As a result electromagnetic energy increases and current increase.

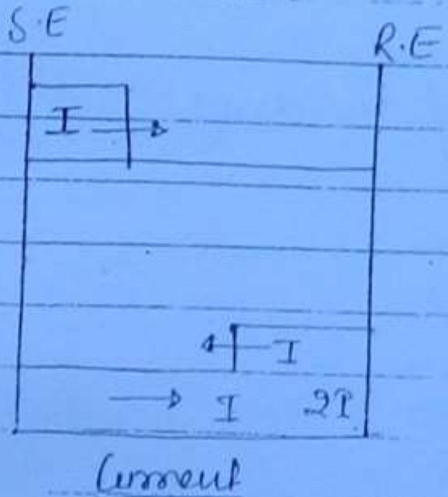
Let the current be increased by (i Amp)

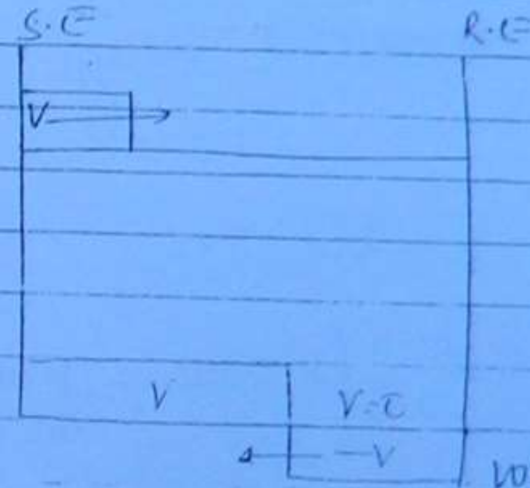
$$\frac{1}{2}Li^2 = \frac{1}{2}CV^2$$

$$\Rightarrow i^2 = \frac{V^2}{L/C} = \frac{V^2}{Z_c^2}$$

$$\boxed{i = \frac{V}{Z_c} = I}$$

The current i increases by I Amp, where I is incident current or current flowing from sending end to the receiving end of the T.L.





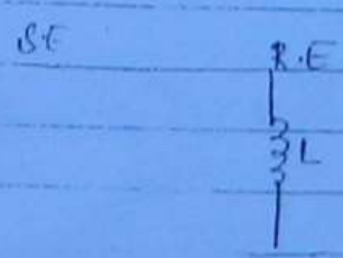
$$\rho_I = \frac{I}{I} = 1$$

$$\tau_I = \frac{2I}{I} = 2.$$

$$\rho_V = -V/V = -1$$

$$\tau_V = 0/V = 0$$

Condition 6: Receiving end of T.L is terminated by inductor 'L'



$$V'' = V + V'$$

$$I'' = I + I'$$

$$I = V/Z_c \quad ; \quad I' = -V'/Z_c$$

$$I'' = \frac{1}{L}\int V''(t)\,dt$$

Expressing transmitted voltage in terms of incident voltage V

$$I'' = I + I'$$

$$\Rightarrow \frac{1}{L}\int V''(t)\,dt = \frac{V}{Z_c} + \frac{(-V')}{Z_c}$$

$$\Rightarrow \frac{1}{L}\int V''(t)\,dt = \frac{V}{Z_c} - \left(\frac{V''-V}{Z_c}\right)$$

$$\Rightarrow \frac{1}{L}\int V''(t)\,dt = \frac{2V}{Z_c} - \frac{V''}{Z_c}$$

$$\Rightarrow \frac{1}{L}\int V''(t)\,dt + \frac{V''}{Z_c} = \frac{2V}{Z_c}$$

Applying Laplace Transform.

$$\frac{1}{L}\left\{\frac{V''(s)}{s}\right\} + \frac{V''(s)}{Z_c} = \frac{2V}{sZ_c}.$$

$$V''(s)\left[\frac{1}{sL} + \frac{1}{Z_c}\right] = \frac{2V}{sZ_c}.$$

$$\Rightarrow V''(s) \cdot \left\{ \frac{sL + Z_c}{\cancel{s} L Z_c} \right\} = \frac{2V}{\cancel{s} \cancel{Z_c}}.$$

$$V''(s) = \frac{2VL}{sL + Z_c}.$$

dividing by L.

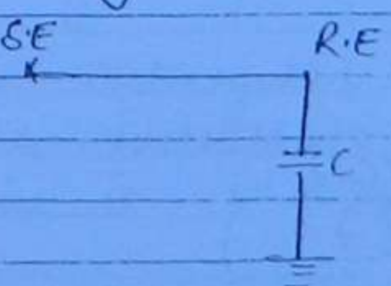
$$V''(s) = \frac{2V}{s + \frac{Z_c}{L}}.$$

Applying inverse laplace transform.

$$\Rightarrow \boxed{V''(t) = 2V \cdot e^{-Z_c/L \cdot t}}$$

when T.L is terminated by inductor the ~~incident~~ transmitted voltage decreases exponentially due to presence of inductor.

Condition 7: Receiving end of T.L terminated by capacitance



$V'' = V + V'$

$I'' = I + I'$

$I = V/Z_c \; ; \; I' = -V'/Z_c.$

$$I'' = \frac{C\, dV''(t)}{dt}$$

$$I + I' = \frac{C\, dV''(t)}{dt}$$

$$\frac{V}{Z_c} - \frac{V'}{Z_c} = C\frac{dV'(t)}{dt} \Rightarrow C\frac{dV''(t)}{dt} + \frac{V''(t)}{Z_c} = \frac{2V}{Z_c}.$$

applying Laplace Transform

$$\frac{V(s)}{Z_c} - \frac{V'(s)}{Z_c} = \frac{C}{S}$$

$$\Rightarrow C\left\{sV''(s)\right\} + \frac{V''(s)}{Z_c} = \frac{2V}{sZ_c}$$

$$\Rightarrow V''(s)\left\{Cs + \frac{1}{Z_c}\right\} = \frac{2V}{sZ_c}.$$

$$\Rightarrow V''(s)\left\{\frac{sCZ_c+1}{Z_c}\right\} = \frac{2V}{sZ_c}$$

$$\Rightarrow V''(s) = \frac{2V}{s(sCZ_c+1)}$$

dividing by CZ_c

$$V''(s) = \frac{2V/CZ_c}{s\left(s+\frac{1}{CZ_c}\right)}$$

using partial fraction

$$\therefore A \cdot \frac{1}{CZ_c} = \frac{2V}{CZ_c}$$

$$A = 2V.$$

's' : $A + B = 0$

$B = -A = -2V$

$$V''(s) = \frac{2V}{S} - \frac{2V}{S+\frac{1}{CZ}}$$

Applying inverse laplace Transform:-

$$V''(t) = 2V - 2V \cdot e^{-1/CZ \cdot t}$$

$$\boxed{V''(t) = 2V\left\{1 - e^{-1/CZ \cdot t}\right\} \text{ volt}}$$

due to discharging effect.

when T.L terminated by capacitor is decrease exponentially

Questn:

An inductance of 800mH connect two sectn of T.L each having surge impedence of 350Ω. a 500

A 500kV, 2usec rectangular surge travels along the line towards the inductance. The maxm value of transmitted wave is. $V'' = 2Ve^{-Z_c/L \, t}$

$$V'' = 2 \times 500 \times e^{-\left(\frac{350}{800 \times 10^{-6}}\right)\left(2 \times 10^{-6}\right)}$$

$$V'' = 416.86 \text{ kV}$$

4) A 500KV, 2μsec rectangular wave surge on T.L having surge impedence of 350Ω approaches a generating statn at which the concentrated earth capacitance is 3000pF the max^m value of the transmitted wave is

$$V$$

$$V'' = 2V\left(1 - e^{-t/Z_c C}\right).$$

$$V'' = 2\times 5000\left[1 - e^{-\left(2\times 10^{-6}/350\times 3000\times 10^{-12}\right)}\right]$$

$$V'' = 850\,KV.$$

5) A voltage surge of 60KV travelling in a line of natural impedence 500Ω, arrives at a junc^n with two T.L of impedence, 650Ω, 250Ω. the surge voltages and current transmitted into each branch of line or ar:

$$Z_c = 500\Omega$$

$$Z_1 = 650, \quad Z_2 = 250.$$

$$V'' = V\left(\frac{2/Z_c}{\frac{1}{Z_1}+\frac{1}{Z_2}+\frac{1}{Z_1}}\right)$$

$$V'' = 31.24\,KV$$

$$I_1'' = \frac{V_1''}{Z_1} = \frac{31.84\times10^3}{650} = 48.97 \text{ Amp.}$$

$$I_2'' = V_2''/Z_2 \quad \frac{31.84\times10^3}{250} = 127.4 \text{ Amp}$$

4) A voltage surge of 15KV travels along a cable. towards a juncⁿ with an over-head T.L. The inductance and capacitance of overhead T.L cable are 0.3mH, 0.4uF. The inductance and capacitance of over head T.L are 1.5mH, and 0.12 uF. The increase in voltage at the juncⁿ due to surge is?

$$Z_{c\,cable} = \sqrt{\frac{L}{C}} = \sqrt{\frac{0.3\times10^{-3}}{0.4\times10^{-6}}} = 27.38\,\Omega$$

$$Z_{c\,T.L} = \sqrt{\frac{1.5\times10^{-3}}{0.12\times10^{-6}}} = 353\,\Omega$$

$$V'' = \frac{2R}{Z_c+R} \Rightarrow \frac{2Z_{cable}}{Z_c+Z_{c\,cab}}$$ as surge travel through cable

$$\frac{2\times27.38}{353+27.38}\cdot 15\times10^3 = \cancel{2.948kV}$$

~~2159.4V~~

27.84 kV

A - 3ϕ overhead conductors in equilateral configuratn the core characteristic impedance is 500Ω. What should be load impedance such that reflections do not occur in T.L.

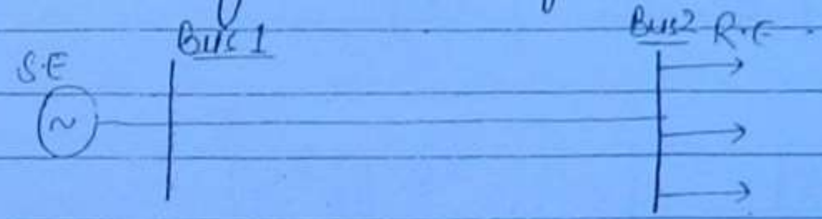
• TELEGRAPHER | WAVE EQUATION :

$$\frac{\partial^2 e}{\partial x^2} = RGe + (RC + LG)\frac{\partial e}{\partial t} + LC\frac{\partial^2 e}{\partial t^2}$$

$$\frac{\partial^2 i}{\partial x^2} = RGi + (RC + LG)\frac{\partial i}{\partial t} + LC\frac{\partial^2 i}{\partial t^2}$$

POWER CIRCLE DIAGRAMS:

Consider the single line diagram of 3ϕ T.L



V_s, I_s $\qquad\qquad$ V_R, I_R

$S_s = P_s + jQ_s$ $\qquad\qquad$ $S_R = P_R + jQ_R$

Bus 1 $\longrightarrow$ SEB $\qquad\qquad$ Bus2 $\longrightarrow$ REB

In single line diagram bus 1 is fed by generating statn and bus2 feeds the load connected at receiving end.

Expressing I_R and I_s in terms of V_R and V_s.

$$I_s = CV_R + DI_R.$$

$$I_R = \frac{I_s}{D} - \frac{CV_R}{D}$$

from the two port n/w model.

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix}$$

$$\Rightarrow \quad V_s = AV_r + BI_r \quad ----- (1)$$

$$I_s = CV_r + DI_r \quad ----- (2)$$

$$\begin{bmatrix} V_r \\ I_r \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}^{-1} \begin{bmatrix} V_s \\ I_s \end{bmatrix}$$

$$= \begin{bmatrix} V_r \\ I_r \end{bmatrix} = \frac{1}{AD-BC} \begin{bmatrix} D & -B \\ -C & A \end{bmatrix} \begin{bmatrix} V_s \\ I_s \end{bmatrix}$$

$$\begin{bmatrix} V_r \\ I_r \end{bmatrix} = \begin{bmatrix} D & -B \\ -C & A \end{bmatrix} \begin{bmatrix} V_s \\ I_s \end{bmatrix}$$

$$V_r = DV_s - BI_s \quad --- (3)$$

$$\cancel{V} \cdot I_r = -CV_s + AI_s \quad --- (4)$$

The equatn (3) and (4) gives relation b/w recieving end values and secending end value.

~~sub~~ $2 \rightarrow 4$

$$I_r = -CV_s + A\{CV_r + DI_r\}$$

$$I_r[1-AD] = -CV_s + ACV_r$$

$$I_r \overline{B\cancel{C}} = -\cancel{C}V_s + A\cancel{C}V_r$$

$$\left\{P_s - \frac{|D||V_s|^2}{|B|}\cos(\beta-\Delta)\right\}^2 + \left\{Q_s - \frac{|D||V_s|^2}{|B|}\sin(\beta-\Delta)\right\}^2 = \left\{\frac{|V_s||V_R|}{|B|}\right\}^2 \quad \text{--- (15)}$$

represent the equatⁿ of circle.

$$x \rightarrow \frac{|D||V_s|^2 \cos(\beta-\Delta)}{|B|}$$

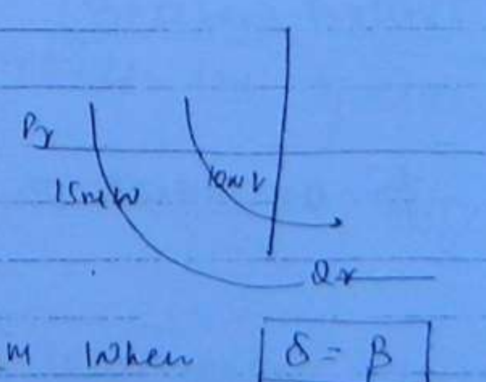
$$y \rightarrow \frac{|D||V_s|^2 \sin(\beta-\Delta)}{|B|}$$

$$\text{radius} \rightarrow \frac{|V_s||V_r|}{|B|}$$

Question:-

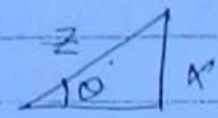
When the sending end voltage and receiving end voltage of T.L are constant the real power at the receiving end of the T.L is Maxᵐ for the condition

$$P_r + \frac{|A||V_r|^2}{|B|}\cos(\beta-\alpha) = \frac{|V_s||V_r|}{|B|}\cos(\beta-\delta)$$



P_r is maxᵐ when $\boxed{\delta = \beta}$

2) The power circle equation of short T.L are.



For S.T.L

$A = 1\angle 0^\circ \quad |A|\angle\alpha \quad \alpha = 0^\circ \quad |A| = 1$

$B = Z \quad |B|\angle\beta \quad \beta = \theta \cdot \quad |B| = Z$

$C = 0$

$D = 1\angle 0^\circ \quad |D|\angle\Delta \quad \Delta = 0^\circ \quad |D| = 1.$

now equatn

$$10 \rightarrow P_r + \frac{1.|V_r|^2 \cos(\theta)}{Z} = \frac{|V_r||V_s|}{Z} \cos(\theta - \delta)$$

$$11 \rightarrow Q_r + \frac{|V_r|^2 \sin\theta}{Z} = \frac{|V_r||V_s|}{Z} \sin(\theta - \delta),$$

$$13 \rightarrow P_s - \frac{1.|V_s|^2 \cos(\theta)}{Z} = -\frac{|V_r||V_s|}{Z} \cos(\theta + \delta)$$

$$14 \rightarrow Q_s - \frac{1.|V_s|^2 \sin\theta}{Z} = -\frac{|V_r||V_s|}{Z} \sin(\theta + \delta).$$

) The power circle equatn for an ideal short T.L is

$$S_r = \frac{|V_r||V_s|}{|B|} \angle \beta - \delta - \frac{|A||V_r|^2}{|B|} \angle \beta - \alpha \quad \text{---- (9)}$$

As $S_r = P_r + jQ_r$

$$P_r = \frac{|V_r||V_s|}{|B|} \cos(\beta - \delta) - \frac{|A||V_r|^2}{|B|} \cos(\beta - \alpha)$$

$$\Rightarrow \quad P_r + \frac{|A||V_r|^2}{|B|} \cos(\beta - \alpha) = \frac{|V_s||V_r|}{|B|} \cos(\beta - \delta) \quad \text{--- (10)}$$

Similarly:

$$Q_r = \frac{|V_r||V_s|}{|B|} \sin(\beta - \delta) - \frac{|A||V_r|^2}{|B|} \sin(\beta - \alpha)$$

$$Q_r + \frac{|A||V_r|^2}{|B|} \sin(\beta - \alpha) = \frac{|V_r||V_s|}{|B|} \sin(\beta - \delta) \quad \text{--- (11)}$$

$(10)^2 + (11)^2$.

$$\left\{P_r + \frac{|A||V_r|^2}{|B|} \cos(\beta - \alpha)\right\}^2 + \left\{Q_r + \frac{|A||V_r|^2}{|B|} \sin(\beta - \alpha)\right\} = \left\{\frac{|V_s||V_r|}{|B|}\right\}^2 \quad \text{--- (12)}$$

...uation (12) represents the equation of circle with ...r coordinate

$$x\text{-coordinate} = -\frac{|A||V_r|^2}{B} \cos(\beta - \alpha)$$

$$Y\text{-coordinate} = -\frac{|A||V_r|^2}{|B|} \sin(\beta - \alpha)$$

$$\text{radius} = \frac{|V_s||V_r|}{|B|}.$$

The complex power per phase at the sending end of T.L:-

$$S_s = V_s I_s^*$$

$$\Rightarrow S_s = V_s \angle \delta \left\{ \frac{|D||V_s|}{|B|} \angle \beta - \Delta - \delta - \frac{|V_r|}{|B|} \angle \beta \right\}.$$

$$P_s + jQ_s = \frac{|D||V_s|^2}{|B|} \angle \beta - \Delta - \frac{|V_r||V_s|}{|B|} \angle \beta + \Delta.$$

$$P_s = \frac{|D||V_s|^2}{|B|} \cos(\beta - \Delta) - \frac{|V_r||V_s|}{|B|} \cos(\beta + \Delta)$$

$$\frac{|V_r||V_s|}{|B|} \cos(\beta + \Delta) = P_s - \frac{|D||V_s|^2}{|B|} \cos(\beta - \Delta) \quad \text{----} (13)$$

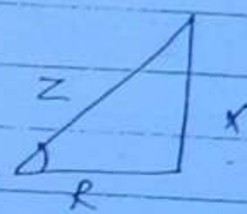
Similarly

$$\frac{|V_s||V_s|}{\beta} \sin(\beta + \Delta) = Q_s - \frac{|D||V_s|^2}{|B|} \sin(\beta - \Delta) \quad \text{----} (14)$$

$(13)^2 + (14)^2$

As ideal so no losses, resistance is neglected
$\theta \to 90^\circ$.

$\tan^{-1}\left(\frac{X}{R}\right) = 90^\circ$.



$10 \to P_r + 0 = \frac{|V_s||V_r|\sin\delta}{Z}$

$11 \to Q_r + \frac{|V_r|^2}{Z} = \frac{|V_r||V_s|\cos\delta}{Z}$

$13 \to P_s - 0 = \frac{|V_r||V_s|\sin\delta}{Z}$

$14 \to Q_s - \frac{|V_s|^2}{Z} = -\frac{|V_r||V_s|\cos\delta}{Z}$

4) For a system to operate under static conditions load angle δ must be.

$P_r = \frac{V_s \cdot V_r \sin\delta}{X}$ δ must lie b/w 0 - 90°.

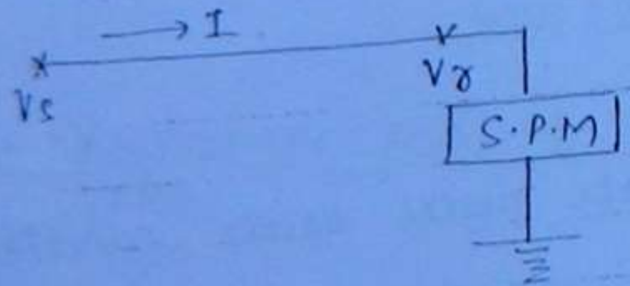
5) When sending end voltage and receiving end voltage are increased by 10% the max^m active power transferred is?

$$P_{r_{max}} = \frac{|1.1 V_s||1.1 V_r|}{X} \sin\delta$$

$$\boxed{P_{r_{max}} = 1.21 \frac{V_s V_r}{X} \sin\delta}$$

CONSTANT VOLTAGE TRANSMISSION

- For a constant voltage transmission specially designed synchronous motors known as synchronous phase modifiers are installed at the receiving end which maintains constant voltage drop along T.L



Synchronous phase modifier can take either lagging or leading current from the T.L by altering the excitation. ~~Synchro~~

- Synchronous m/r are installed in combination $\bar{c}$ g/r stat^n to improve the power factor at the load end of T.L

During the peak hours T.L requires lagging VAR at the receiving end.

During half peak hours T.L require leading VAR at the receiving end to prevent the voltage drop

SPM delivers lagging VAR when excitatⁿ is increased and delivers leading VAR when excitatⁿ is decreased

Questions:

1) A 200 km, 3ϕ 50Hz. T.L has following data

$$A = D = 0.938 \angle 1.2^\circ$$
$$B = 131.2 \angle 72.3^\circ \Omega$$
$$C = 0.001 \angle 90^\circ \ S.$$

The sending end voltage is 250kV, determine

1) Receiving end voltage V_R when load is disconnected

2) T.L charging current

3) Maxᵐ power that can be transmitted at the receiving end voltage of 220kV and the corresponding load reactive power required at the receiving end.

$$V_s = AV_r + BI_r.$$

when load disconnected $I_R = 0$, $V_r \rightarrow V_{R0}$

$V_s = V_{RO}/A = \dfrac{230/\sqrt{3}}{0.938 \angle 1.2^{\circ}}$

$141.57 \angle -1.2^{\circ}$ KV

re $V_{S\,L-L} =$ ~~2.~~ $245.20 \angle -1.2$ KV

) charging current, current through capacitor when receiving end is O.C.

~~2.~~ $I_S = CV_R + DI_R$

$I_R = 0$

$I_{charging} = I_S = CV_R$

$(0.001 \angle 90^{\circ})(141.57 \angle -1.2^{\circ})$

$I_{charging}$ $\underline{141.57 \angle 88.8^{\circ}}$

(c) $P_r = \dfrac{|V_s||V_r| \cos(\beta - \delta)}{|B|} - \dfrac{|A||V_r|^2 \cos(\beta - \alpha)}{|B|}$

P_r is max $\beta = \delta$.

$P_{r\,max} = \dfrac{|V_s||V_r|}{B} - \dfrac{|A||V_r|^2 \cos(\beta - \alpha)}{|B|}$

$$P_{rmax} = \frac{|132.79||141.57|}{131.2} - \frac{|141.57|^2|0.938|}{131.2}\cos(72.3-1.2^\circ)$$

$P_{rmax} = 91.2MW.$

→ Reactive power. $Q_{rmax} = \beta = \delta$

$$Q_r = -\frac{|A||V_r|^2}{|B|}\sin(72.3-1.2^\circ)$$

$Q_r = -9.$

Disadvantage :-

→ On connecting SPM, the short-circuit current of s/m is increased

Question!-

A 3-φ T.L has resistance per phase of 5Ω and inductive reactance of 1CΩ/phase. Determine the load, which line which the line will be supplying at 132 kV at 0.8 p.f lagging. The sending voltage is 140KV. If a CPM is connected in parallel with load to improve the powerfactor upto 0.95lagging. determine the leading MVAR supplied by synchronous phase modifier. the receiving end voltage and load are constant. Assume A BCD parameters of short T.L soln

for a short T.L

$$A = 1,\ \alpha = 0$$

$$B = Z = \sqrt{R^2 + X^2}$$

$$= \sqrt{5^2 + 15^2} = 15.81\,\Omega$$

$$\beta = \tan^{-1}\left(\frac{X}{R}\right) = \tan^{-1}\left(\frac{15}{5}\right) = 71.6^\circ$$

step: Receiving end circle diagram

$$\text{radius} = \frac{|V_S||V_R|}{|B|} = \frac{132 \times 140}{15.81} = 1168.8\,\text{MVA}$$

horizontal coordinate

$$-\frac{|A||V_R|^2}{B}\cos(\beta - \alpha)$$

$$= -\frac{|1||132|}{|15.81|}\cos(71.6 - 0)$$

$$= -347.8\ \text{MW}.$$

vertical coordinate

$$-\frac{|A||V_R|^2}{B}\sin(\beta - \alpha)$$

$$= -1045.6\ \text{MVAR}.$$

Step 2: select power scale.

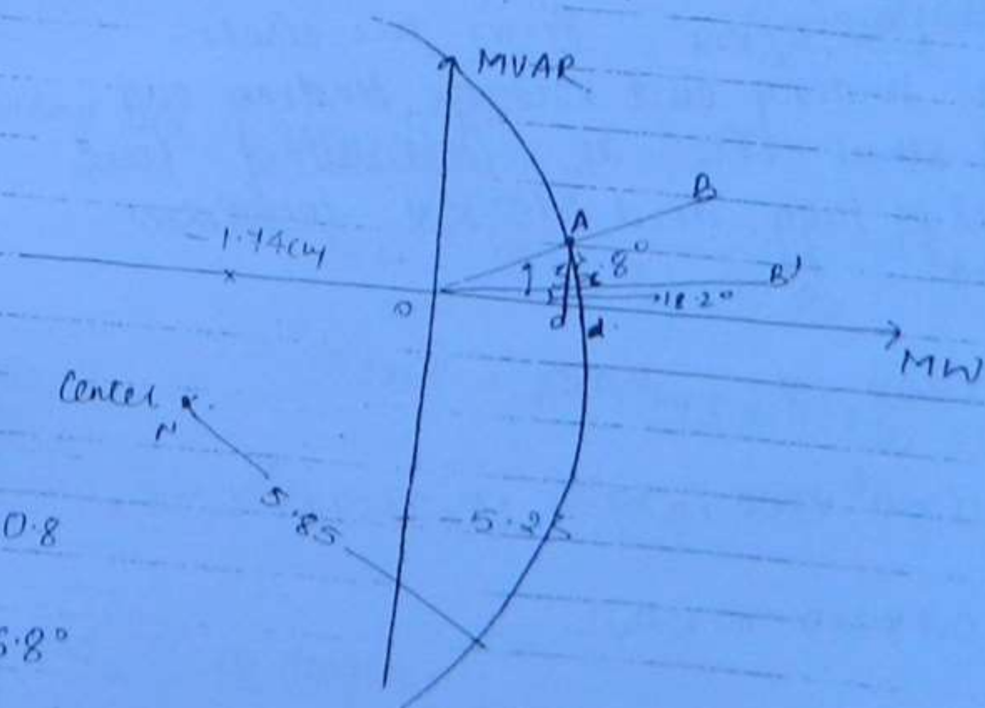
$$1\,cm = 200\,MW = 200\,MVA = 200\,MVAR$$

radius $= \frac{1168.8}{200}$ $5.85\,cm$.

Horizontal co-ordinate $= \frac{-347.8}{200} = -1.74\,cm$

vertical co-ordinate $= -\frac{1045.6}{200} = -5.25\,cm$.

Step 3: construct^n of circle diagram at receiving end.



$\cos\phi_R = 0.8$

$\phi_R = 36.8°$

$\cos^{-1} 0.95$

$\phi = 18.2°$

To increase the P.f from 0.8 lagging to 0.95 lagging synchronous phase modifier has to supply leading MVAR.

MVAR (leading) supplied by synchronous phase modifier is = ~~b~~ ac

$= 0.1 \text{ cm}$

$= 0.1 \times 200$

$= 20 \text{ MVAR}.$

when T.L is supplying at 132 KV and 0.8 p.f. The power supplied is

$OD = 0.3 \text{ cm}.$

$= 200 \times 0.3$

$60 \text{ MW}.$

) Draw the receiving end and sending end power circle diagram of 300 km. T.L with resistance ~~0.0~~ 0.4Ω/km and $Y = 5.15^{-6} \angle 90°$ S/km. from the circle diagram determine sending end voltage, sending end current and p.f. when T.L is delivering load of 192 MW at 0.8 p.f lagg. and 275 KV consider nominal π method.

$R/\phi = 0.08 \times 300 \Rightarrow 24\Omega$

$Y = 5.15 \times 10^{-6} \times 300 \angle 90° = 1.5,545 \times 10^{-3} \angle 90° S$

$X/\phi = 0.4 \times 300 = 120\Omega$

$Z/\phi = R/\phi + jX/\phi$

$= 24 + j120$

To find A, B, C, D constant using nominal π method.

$$A = 1 + \frac{YZ}{2} = 1 + \frac{1.543\angle 90 (24 + j120)}{2} = 0.9075\angle$$

$$B = Z = 24 + j120 = 122.38\angle 78.69\,\Omega$$

$C = Y$ not required

$$D = 0.9075\angle 1.17$$

$|A| = |D| = 0.9075$

$\alpha = 1.170$

$|B| = 122.38$

$\beta = 78.69$

Receiving end current $I_r = ?$

$$MW = \sqrt{3} V_{RL} I_{RL} \cos\phi_R$$

$$192\times10^6 = \sqrt{3} \times 275\times10^3 \times I_{RL} \times 0.8$$

$$I_{RL} = I_R = 504\,A$$

Receiving end circle diagram

$$\text{Horizontal} = \frac{|A||V_R|^2}{|B|} \cos(\beta - \alpha)$$

$$= 0.9075 \times 275 \cos(78.69$$

vertical co-ordinate

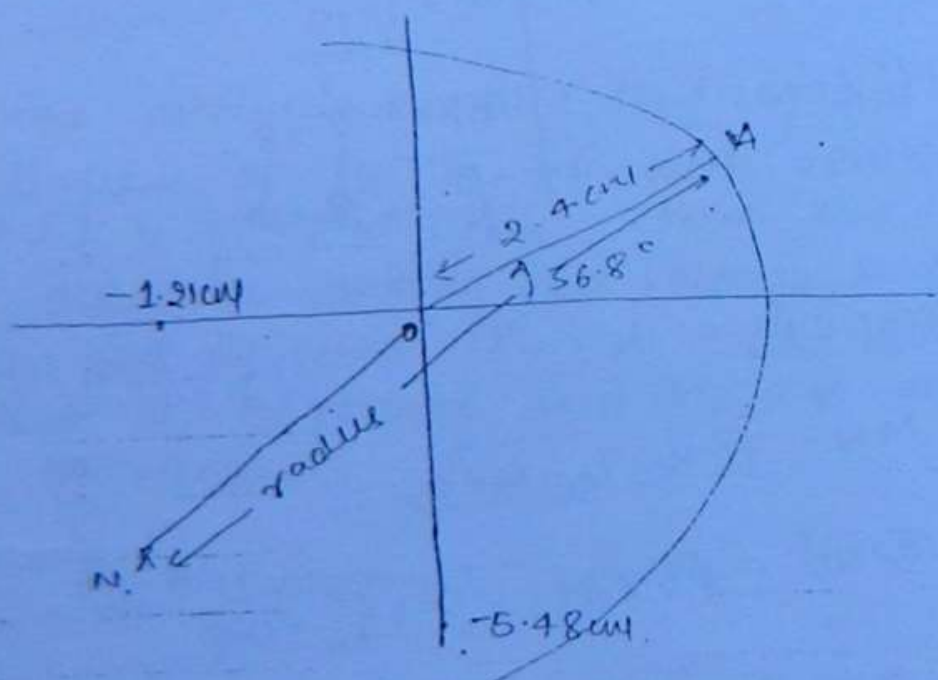
$$-\frac{|A||V_R|^2 \sin(\beta-\alpha)}{|B|}$$

$$= -548\ \text{MVAR}$$

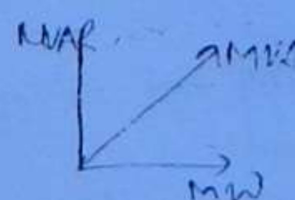
Power Scale:

$$1\,cm = 100\,MW = 100\,MVAR$$

$$= -1.21\,cm$$
$$= -5.48\,cm.$$



volt Ampere at the receiving end at the T.L



$$V_A = \sqrt{3} \cdot V_{RL} \cdot I_{RL}$$
$$240\,MVA$$

let $1\,cm = 100\,MVA \Rightarrow VA = 2.4\,cm$

radius of the circle is equal to $MP \Rightarrow 7.6\,cm$.

$= 7.6 \times 100 = 760\,MVA$.

The Resultant VA $760 = \frac{V_s V_r}{B}$.

$$760 = \frac{V_s \cdot 275}{122.38}$$

$$V_s = 338\,KV.$$

2) Sending end circle diagram:-

$$\text{Horizontal} = \frac{|D|}{|B|}|V_s|^2 \cos(\beta - \Delta)$$

$$= 183\,MW$$

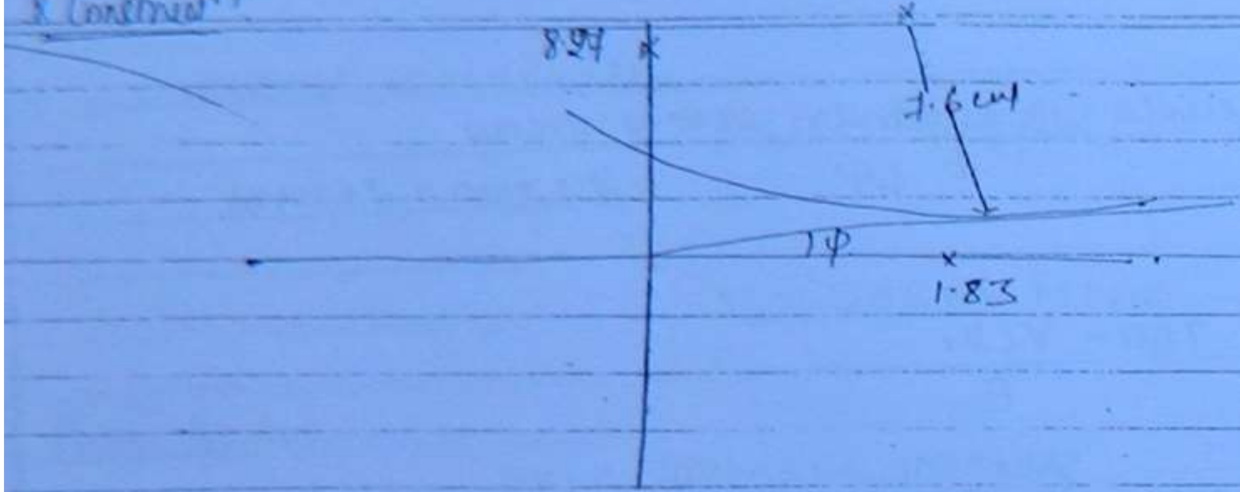
$$\text{vertical coordinate} = \frac{|D|}{|B|}|V_s|^2 \sin(\beta - \Delta)$$

$$827\,MVAR$$

$$\text{radius} \quad \frac{|V_s||V_r|}{|B|} = 760\,MVA$$

$1\,\text{pu} = 100\,\text{MW} = 100\,\text{MVAR} = 100\,\text{MVA}$

x Construction:



$\phi_s(\text{graph}) = 15^\circ$

$\cos(\phi_s) = \cos 15^\circ = 0.966$.

→ sending end current

$$VA = \sqrt{3}\, V_{SL} I_{SL} \cos\phi_S$$

$$240 \times 10^6 = \sqrt{3} \times 33 \times 10^3 \times I_{SL} \times 0.966$$

$$\boxed{I_{SL} = 410\,A}$$

ECONOMIC ASPECT OF GENERATING STATIONS

1) Connected load:-

The sum of kW rating of all the equipments connected to a system.

2) Maximum Demand:

The highest load existing on the S/M in a given duration.

3) Average load:

It is the mean of loads connected to system at different durations.

4) Demand factor:

Maximum demand by connected load. It is always ≤ 1.

5) load factor:-

Average load by maxm demand. always ≤ 1.

6).

$$\boxed{\text{load factor} = \frac{(\text{Energy generated for 24 hr})/24}{\text{Maximum demand}}}$$

6) load duration curve:

It gives the no of hours loads are existing on the system

Qustn

A residential consumer has electrical equipment as follows.

10 lamps each 60 Watts

2) 2 heater, each 1000 watts

The Max^m demand is 1000 W. The consumer uses 8 lamps for 5 hr in a day and 2 heaters for 3hr/day. Calculate

1) Connected load
2) demand factor
3) energy consumed per day
4) Avg load
5) load factor.

Solution

$\cancel{(8 \times 5 \times 60) + (2 \times 1000)}$

1) Connected load

$(10 \times 60) + (2 \times 1000)$

$= 2600\,W$

2) demand factor $= \dfrac{\text{Max demand}}{\text{Connected load}}$

$= \dfrac{1000}{2600} = 0.38$

3) Energy consumed per day $= (8 \times 5 \times 60) + (2 \times 1000 \times 3)$

$= 8400\,W$

$= 8.4\,kWh$

4). Average load = $\frac{\text{Total EG}}{\text{No of hour}} = \frac{8400}{24} = 350W$.

5) Load factor = $\frac{A.L}{\text{Max demand}} = \frac{350}{1000} = 0.35$.

7) DIVERSITY FACTOR

sum of the individual maxm demand by maxm demand existing on s/m.

$$D.f = \frac{\Sigma(I.M.D)}{M.D \text{ of } s/m} > 1.$$

8) Co-incident factor:

$$C.F = \frac{1}{\text{Diversity Factor}}$$

9) Plant capacity factor:

$$\frac{\text{Actual energy generated}}{\text{Max}^m \text{ energy that can be generate}}$$

10) Reserve capacity:

Plant capacity − Maxm demand

11) Operation factor:

$$\frac{\text{No. of hours generating stat}^n \text{ is in operat}^n}{\text{Max}^m \text{ no of hours generating stat}^n \text{ can be operated}}$$

12) Utilization factor / Plant use factor:-

$$\frac{\text{Energy generated in KWh}}{\text{Plant capacity} \times \text{no of hours in operat}^n}$$

3) Firm power: The minimum power available at any time instance.

4) Cold Reserve: The reserve generating capacity available for service but not in operation

5) HOT Reserve: The reserve generating capacity which in operat^n but not in service.

6) Spining Reserve: the generating capacity connected to the bus and ready to take the load is known as spining reserve.

Question:

1) The maxm demand on G/r station is 80 MW. The plant capacity factor and Plant utilizatn factor are 0.5, 0.8 respectively. Determine

1) Load factor
2) Average load
3) No. of units Generated per day
4) Plant capacity
5) Reserve capacity

2) A G/r statn operates at maxm demand of 100 MW. load factor 0.65, plant capacity factor is ~~equa~~ 0.5 Plant use factor 0.75. Calculate

1) Average loads
2) No of units Generated
3) Plant capacity
4) Reserve capacity
5) Maxm energy that can be generated by power statn
6) No of hours the generating statn operates.

CORONA

→ Electrical power transmission takes place through power conductor

→ the power conductor is in the atmosphere.

→ the ionization of air surrounding the power conductor is known as corona

→ If the electric field intensity around the power conductor is grtr than the dielectric strength of air then corona occurs otherwise corona donot occur.

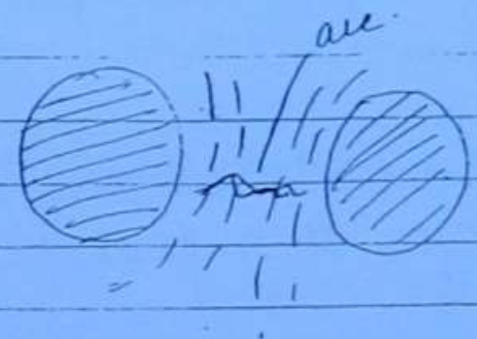
→ corona can be eliminated by

1) decreasing electric field intensity
2) Increasing dielectric strength of air
3)

→ Due to radioactivity no of free electrons around the power conductor results in high electric field intensity

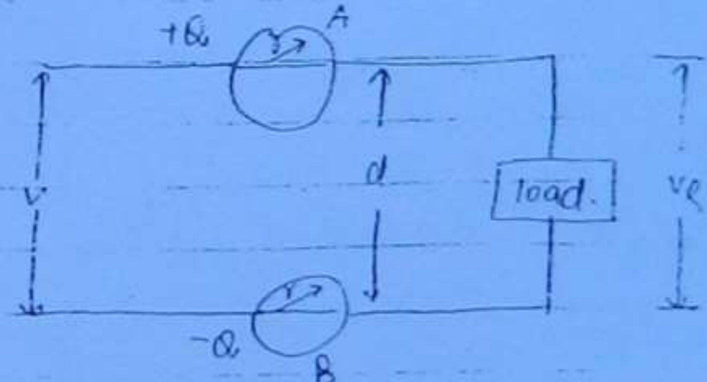
→ for EHV T.L where the operating voltage is greater 275 KV the free electrons travel at a higher velocity such that Dielectric strength of air is neglected

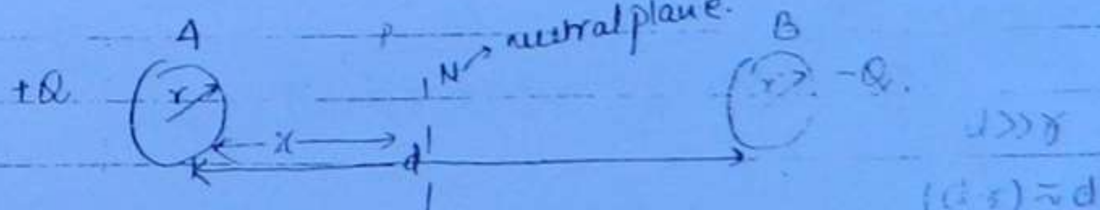
→ When corona occurs due to two power conductors arc is formed in the air resulting in line to line fault.



Ex

CRITICAL DISTRUCTIVE VOLTAGE





- Consider a 1-φ T.L
- Let 'r' be the radius of the conductor 'd' be the distance between the conductor
- The distance between the conductor (d-r) ≈ d
- Let 'Q' be the charge per unit length of conductor
- Consider a neutral plane at middle of two conductors
- Potential of conductor 'A' w.r.t to neutral plane is (V/2)

Potential of conductor 'B' w.r.t neutral plane $(-V/2)$ (negative as the charge is -ve).

consider a point 'P' at a distance 'x' from center of conductor 'A'.

to determine electric field intensity at a point 'P' consider a unit positive charge at a point 'P'

the electric field due to conductor 'A' is repulsive

Electric field intensity at the point 'P' due to conductor 'A'

$$E_{x_A} = \frac{Q}{2\pi \varepsilon_0 \varepsilon_r x} = \frac{Q}{2\pi \varepsilon_0 x} \quad --- (1) \quad \because \varepsilon_r = 1 \text{ (air)}$$

$$E_{x_B} = \frac{Q}{2\pi \varepsilon_0 \varepsilon_r (d-x)} = \frac{Q}{2\pi \varepsilon_0 (d-x)} \quad --- (2)$$

- Electric field intensity at the point P due to conductor 'B' is eqn (2)
- Total electric field intensity b/w the two conductors

$$E_x = E_{x_A} + E_{x_B}$$

$$\boxed{E_x = \frac{Q}{2\pi\epsilon_0}\left[\frac{1}{x} + \frac{1}{\cancel{x+d}\; d-x}\right]}$$ --- electrical field intensity

- Potential difference between the two conductors.

$$V = \int_{r}^{d-r} E_x \cdot dx$$

$$= \int_{r}^{d-r} \frac{Q}{2\pi\epsilon_0}\left\{\frac{1}{x} + \frac{1}{d-x}\right\} dx$$

$$V = \frac{Q}{2\pi\epsilon_0}\left[\left\{\ln x\right\}_{r}^{d-r} - \left\{\ln(d-x)\right\}_{r}^{d-r}\right]$$

$$V = \frac{Q}{2\pi\epsilon_0}\left[\ln\left(\frac{d-r}{r}\right) - \ln\left(\frac{r}{d-r}\right)\right]$$

$$V = \frac{Q}{2\pi\epsilon_0}\left\{2\ln\left(\frac{d-r}{r}\right)\right\}$$

$$\boxed{V = \frac{Q}{\pi\epsilon_0}\left\{\ln\left(\frac{d-r}{r}\right)\right\}}$$ potential difference

$$\boxed{V = \frac{Q}{\pi\epsilon_0}\ln\frac{d}{r}}$$ $\because (d-r) = d$

- When the potential difference between two conductor is gr8 than dielectric strength of a, the corona takes place.

The 'gradient' at a point located at a distance x from the center of the conductor

$$E_x = \frac{Q}{2\pi\epsilon_0}\left[\frac{1}{x} + \frac{1}{d-x}\right]$$

$$= \frac{Q}{2\pi\epsilon_0}\left\{\frac{d-x+x}{x(d-x)}\right\}$$

$$\boxed{E_x = \frac{Q}{2\pi\epsilon_0}\left[\frac{d}{x(d-x)}\right]} \quad \text{------} \quad 3.4.$$

substituting (3) in (4) value $Q = \frac{\pi\epsilon_0 V}{\ln(d/r)}$

$$E_x = \frac{\pi\epsilon_0 V}{\ln(d/r)} \cdot \frac{1}{2\pi\epsilon_0}\left\{\frac{d}{x(d-x)}\right\}$$

$$\boxed{E_x = \frac{V}{2\ln(d/x)}\left\{\frac{d}{x(d-x)}\right\}}$$

- In above equatn, these voltage ($V/2$) represents the potential of conductor A w.r.t neutral plane.

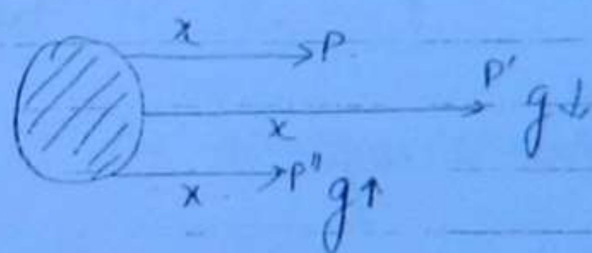
So,

$$E_x = \frac{V'}{\ln(d/r)}\left\{\frac{d}{x(d-x)}\right\}$$

Here $V \rightarrow$ line voltage.

$V' \rightarrow$ phase voltage.

$$\boxed{g \propto \frac{1}{x}}$$



- When $\boxed{x = r}$ gradient is max^m.

The max^m gradient

$$g_{max} = \frac{V'}{\ln(d/r)}\left[\frac{d}{r(d-r)}\right]$$

$(d-r) \simeq d$

$$g_{max} = \frac{V'}{\ln(d/r)}\left[\frac{1}{r}\right]$$

$$\boxed{g_{max} = \frac{V'}{r\ln\left(\frac{d}{r}\right)}} \quad \text{--- --- --- 5.}$$

Critical destructive voltage

g_{max} is measure of critical destruptive voltage.

Defination :-

The voltage at which complete destruption of the dielectric takes place around power conductor. In general the critical destruptive voltage is represented by

$$\boxed{V' = g_{max} \cdot r \ln(d/r)}$$

V' is phase voltage

- Since the power conductor is in air the critical destruptive voltage

$$\boxed{V' = V_d = \gamma_0 \cdot r \cdot \ln\left(\frac{d}{r}\right)} \qquad g_{max} \rightarrow \gamma_0 \rightarrow g_0.$$

γ_0 is dielectric strength in kV/cm/peak value.

$$\boxed{\gamma_0 \rightarrow 30\,kV/cm/peak \ \text{at NTP}}$$

where P → 76cm of Hg & 25°C

In Numericals

$$\gamma_0 \rightarrow \frac{30}{\sqrt{2}}\ kV/cm/rms$$

$$\boxed{\gamma_0 \rightarrow 21.1\ kV/cm/rms}$$

- At any other temp and pressure

$$\boxed{\gamma_0' = \gamma_0 \cdot \delta}$$

$\delta \rightarrow$ air density correctⁿ factor $= \dfrac{3.92h}{273+t}$

$h \rightarrow$ actual pressure in cm of Hg.
$t \rightarrow$ actual temp in °C.

$\delta << 1$ (always) → for ~~at other~~ other than NTP.

- For any value of temperature and pressure ($\gamma_0' < \gamma_0$).
- At any other temp and pressure.

~~Vd =~~

$$\boxed{V_d = (\gamma_0 \cdot \delta) \cdot r \cdot \ln(d/r)}$$

$$\boxed{V_d = (21.1\,\delta)\, r \ln(d/r)} \text{ kV/rms.}$$

- The critical disruptive voltage is directly related air density correctⁿ factor.
- Critical disruptive voltage depends on surface of conductor
'm' gives informatⁿ regarding surface of conductor

1) $m = 1$ ⟶ for smooth/solid conductor

2) $m = 0.93$ to 0.98 ⟶ for rough surface (stranded conductor).

3) $M = 0.83$ to 0.87 ⟶ Cable upto 7-strands

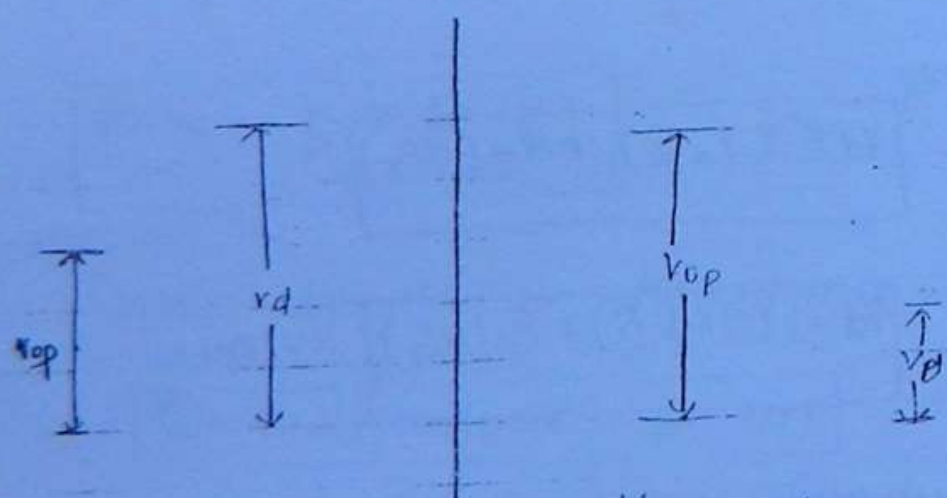
4). $M = 0.9$ ⟶ cable > 7 strands.

So,

$$\boxed{V_d = (8 (\gamma_{0.8})(M)(r)\ln(d/r).}$$

$$\boxed{V_d = (21.18) \cdot M \, r \ln(d/r).}$$

Example:



$V_{op} < V_d$ corona do not occur.

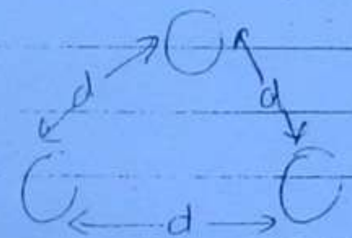
$V_{op} > V_d$ Corona occurs.

Electric field intensity must be more so operating voltage must be more > Vd

- In terms of GMD.

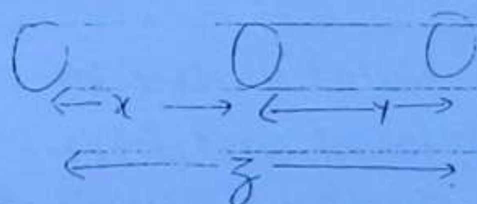
$$V_d = 21.18\, m \cdot r \ln\left(\frac{GMD}{r}\right)$$

1) GMD = d for symmetrical N/W



GMD = $(x \cdot y \cdot z)^{1/3}$

2) GMD = $(x \cdot y \cdot z)^{1/3}$ unsymmetrical N/W.



OBSERVATION OF CORONA:-

1) Hissing noise
2) ozone gas
3) Increase in radius of conductor

VISUAL CRITICAL DISRUPTIVE VOLTAGE:-

When electric field intensity is very high arc is formed b/w the two conductor i.e. corona is visualized.

- The electric field intensity required to visualize the corona is known as visual critical disruptive voltage.

-

$$\boxed{V_v = \gamma_v\, m \cdot r \ln\left(\frac{d}{r}\right)}$$

where $\boxed{\gamma_v = (21 \cdot 1\, \delta)\left(1 + \frac{0.5}{\sqrt{\delta r}}\right)}$

- $\boxed{V_v > V_d}$.

Corona Loss :-

When corona is initiated due to ionization of A, the air near surface of conductor increases the temp along the surface of conductor resulting in power loss known as corona loss.

Corona loss

$$= 244 \times 10^{-5}\left(\frac{f+25}{\delta}\right)\sqrt{\frac{r}{d}}\left\{(V_{ph} - V_d)^2\right\} \text{ kW/km/ph}$$

* HVDC is prefered as corona loss decreased by $\frac{1}{3}$.

FACTORS EFFECTING CORONA :-

(1) Electrical factors :-

1) Supply frequency :-

- For DC s/m $f=0$, corona loss $\propto (f+25) \propto (25)$
- for AC s/m $P_{loss} \propto (f+25)$.

At normal frequency

$P_{DC} \propto 25$

$P_{AC} \propto (f+25) \propto (75)$

** $\boxed{P_{AC} = 3P_{DC}}$

Questn

at $f = 50Hz$, $P_{50Hz} = 1.2$ kW/km/ph,

at $f = 60Hz$, $P_{60Hz} = ?$

Soln

$P_{50Hz} \propto (f+25) \propto (50+25)$

$\Rightarrow 1.2 \propto (75)$ —— (1)

$P_{60Hz} \propto (f+25) \propto (60+25)$

$P_{60Hz} \propto (85)$ - - - (2)

$\frac{P_{60Hz}}{1.2} = \frac{85}{75}$

$$\boxed{P_{60Hz} = 1.36\ kW/km/ph}$$

2). for 400 kV ac line P_{loss} 3 kW/km/phase

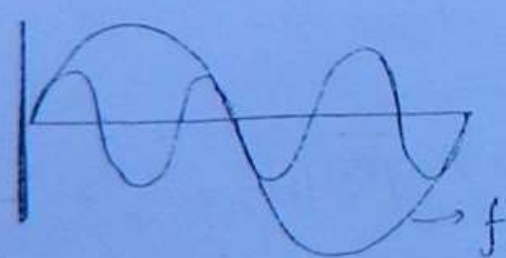
for 400 kV DC line

$P_{DC} = ?$

Sol^n

∴ for any kV $P_{DC} = \frac{1}{3} P_{ac} = 1\ kW/km/ph.$

2.) SUPPLY WAVEFORM :-



$P_{AC} \propto (f + 25)$

- $P_{AC} \propto (f + 25)$
- $\boxed{P_{AC} \propto (f + 3f + 25)}$ ---- with 3rd harmonic

f = 50 Hz

1) $P_{AC} \propto (50 + 25) = 75$

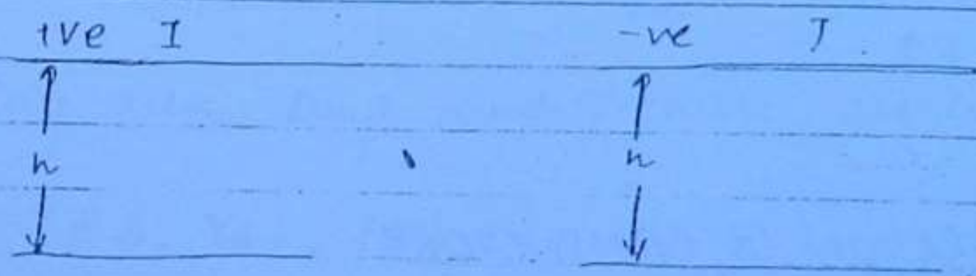
2: $P_{AC} \propto (50 + 150 + 125) = 225$ ... 3rd

3: $P_{AC} \propto (50 + 250 + 25) \propto 325$ ... 5th

Harmonic increases the corona loss

3). POLARITY OF CONDUCTOR :-

- A conductor can have positive polarity and negative polarity.



$P_{loss} \uparrow$ $P_{loss} \downarrow$

- In positive polarity conductor mobility of conductor is high corona loss increases:

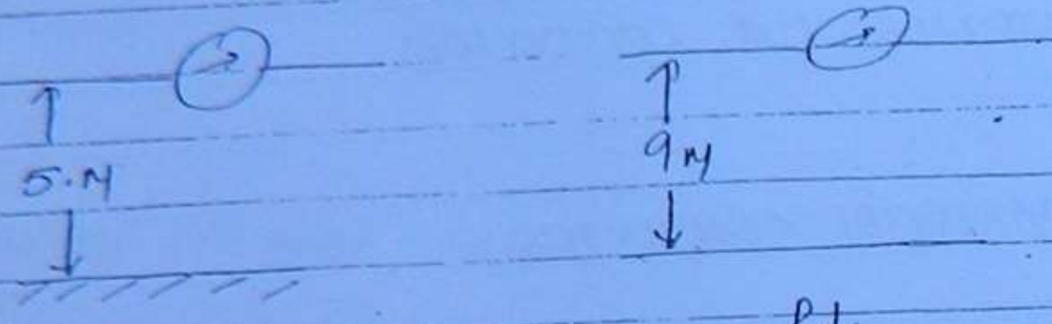
4) DISTANCE B/W CONDUCTORS

$$\boxed{P \propto 1/\sqrt{d}}$$

$d \uparrow , P \downarrow$

$d \downarrow , P \uparrow$

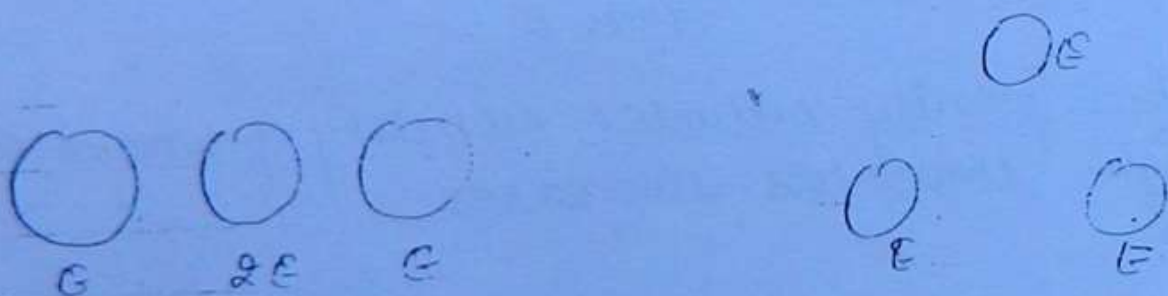
- At higher distance corona loss decreases



$P\uparrow$ $\qquad$ $P\downarrow$

(EFI ↓, so
is ionisation ↓.
as a result $P\uparrow$

5) CONFIGURATION OF CONDUCTORS



$P\uparrow$ $\qquad$ $P\downarrow$

If T.L is unsymmetrically located middle conductor has high corona loss due to high electric field.
For symmetrical n/w each conductor experience same corona loss.

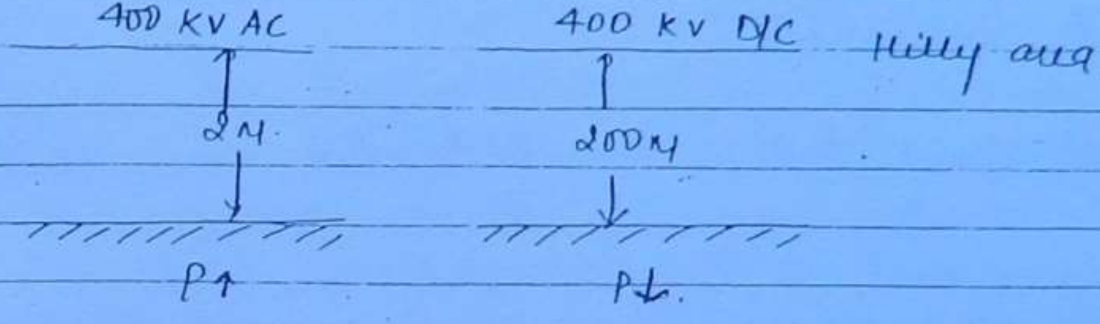
(B) Atmospheric factors:
1) temperature and pressure

- As $\delta\uparrow$ $V_d\uparrow$, $P\downarrow$

→ Temperature and pressure ⇒ P↓
→ deposition of ice → P↑

Questn:-

For the given 400KV ac line.



• ∧ hilly area temp and pressure are less. (δ↓)

(δ↓, Vd↓, P↑)

2) Diposition of ice/snow on surface of conductor.

M↓, Vd↓ and P↑

C) FACTORS RELATED TO SIZE OF CONDUCTORS:-

• Corona can be decrease by selecting a conductor of small radius.

• If r↓, Vd↓, corona ↑, so while selecting radius of conductor disruptive voltage Vd and corona loss P must be considered.

• For Bundled conductors self GMD increases.

- Select 'r' such that $V_d \uparrow$ and $P \downarrow$

D) PROFILE OF CONDUCTOR :-

- Select d/r ratio such that ~~Vd↓~~ $V_d \uparrow$, $P \downarrow$

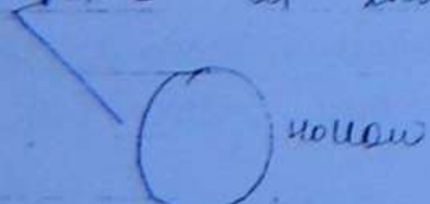
DISADVANTAGE OF CORONA

- Corona losses occur.
- It cause radio-interference with communication line.

METHODS TO REDUCE CORONA LOSS

- Use large size conductor.
- By use hollow conductor ∴ corona loss is decreased.

$\mu = 1$ at there is no skin effect.



- Using Bundled conductors. In a bundled conductor d/r ratio is more. Vd ↑, corona loss decreases.

Questn

Find the corona characteristics of a 3-φ 220KV T.L, 200KM. long consisting of 3×100mm² stranded conductor equally spaced 3m apart. The air temp is 32°C and altitude is 3000m corresponding to pressure of 715 mm of Hg. The frequency of s/m is 50Hz, Irregularity factor is 0.88 for the critical disruptive voltage and 0.75 for visual critical voltage.

Soln

d = 3m

• $\pi r^2 = \frac{100}{4}$

$r = \sqrt{\frac{100}{3.14}} = 5.64\,mm = 5.64 \times 10^{-3} m$

• $\ln(d/r) = \ln\left(\frac{3000m}{5.64}\right) = 6.28 = 12.98.158$

$\sqrt{r/d} = 0.043.$

air density correctn factor $\delta = \frac{3.92\,h}{273 + t}$

$\delta = \frac{3.92 \times 715}{273 + 32^\circ} = 3.38\ 0.918$

$V_d = 21.1\,\delta m_0 r \ln(d/r)$

$= 21.1 \times 0.918 \times 0.88 \times 5.64 \times 10^{-3} \times 6.28$

Critical disruptive voltage.

$$= 21.1 \times \delta \times M_v \times \ln(d/r)$$
$$= 0.515 \text{ KV/m}.$$

Corona Loss.

$$P_{loss} = 24 \times 10^{-5} \left(\frac{f+25}{\delta}\right) \sqrt{\frac{r}{d}} \left\{ (V_{ph} - V_d)^2 \right\}$$

$$= 24 \times 10^{-5} \left(\frac{75}{0.918}\right) \times 0.043 \times \left\{ \frac{220}{\sqrt{3}} - 0.604 \right)^2$$

$$= 13.47 \text{ KV/km/ph}$$

A 3-ϕ T.L as conductors each of radius 20mm and is arranged in form of equilateral Δle. Assuming the climatic conditions are good, air density factor 0.9 and irregularity factor 0.93. find the max^m. spacing b/w the conductors if critical desruption voltage do not exceed 250KV b/w the line. the breakdown strength is 35KV/cm (max^m)

$V_d \rightarrow 250 \text{KV}$
$M = 0.95$
$\delta = 0.9$
$r = 20 \times 10^{-3}$.

$$V_d = 21.1 r \ln(d/r)$$

8

critical disruptive voltage $\frac{35}{\sqrt{2}}$ kV/rms.

$$\frac{35}{\sqrt{2}} = 21.1 \times 0.9 \times 0.93 \times \ln(d/2.0) \times 70$$

$$\ln(d/r) = 1.4$$

$$d/r = e^{1.4}$$

$$d = 4.05 \times 2$$

$$= 8.110 \text{ cm}.$$

$$V_d = (24.75)\, m \cdot \delta \cdot r \cdot \ln(d/r) \quad \text{kV/cm}.$$

$$250/\sqrt{3} = (24.75)(0.95 \times 0.9 \times 2 r \ln d/r)$$

$$d/r = 32.46$$

$$d = 32.46 \times 2$$

$$= 64.92 \text{ cm}.$$

5) find the corona characteristic of ~~[illegible]~~ 110 kV T.L, 50Hz 3-ϕ T.L, 200km long consisting of 3 conductors 0.8cm diameter, stranded copper conductor 2.8m arranged in Δ. temp is 28°C, barometric pressure is 75cm. $m = 0.84$ and for visual corona $m_v = 0.75$. and for general corona $m_v = 0.8$.

$f = 50\,Hz$

$r = 0.4\,cm$

$t = 28°C$

$l = 75\,km$

$N = 0.84$

$N_r = 0.75$

$d = 2.8\,m.$

$\sqrt{r/d} = \sqrt{\frac{0.4}{0.28}} = 1.19\,cm.$

$V_d = \ln\left(\frac{d}{r}\right) = \ln\left(\frac{2.8}{0.4}\right) = 4.24.$

$V_d = 21.1 \cdot \delta \cdot 0.4 \times 0.84 \ln\left(\frac{28}{0.4}\right)$

$\delta = \frac{3.92 \times 75}{273 + 28} = 0.976$

$V_d = 21.1 \times 0.976 \times 0.4 \times 0.84 \times 4.24$

$= 29.3\,kV/cm/ph$

critical disruptive voltage

$21.1 \times 0.976 \times 0.75 \times 4.24$

$= 65.42\,kV/cm/ph.$

$P = 241 \times 10^{-5} \times \left(\frac{50+25}{0.976}\right) \times \sqrt{1.19} \times \left\{\frac{110}{\sqrt{3}} - 29.3\right\}^2$

$= 25.67$

INSULATOR

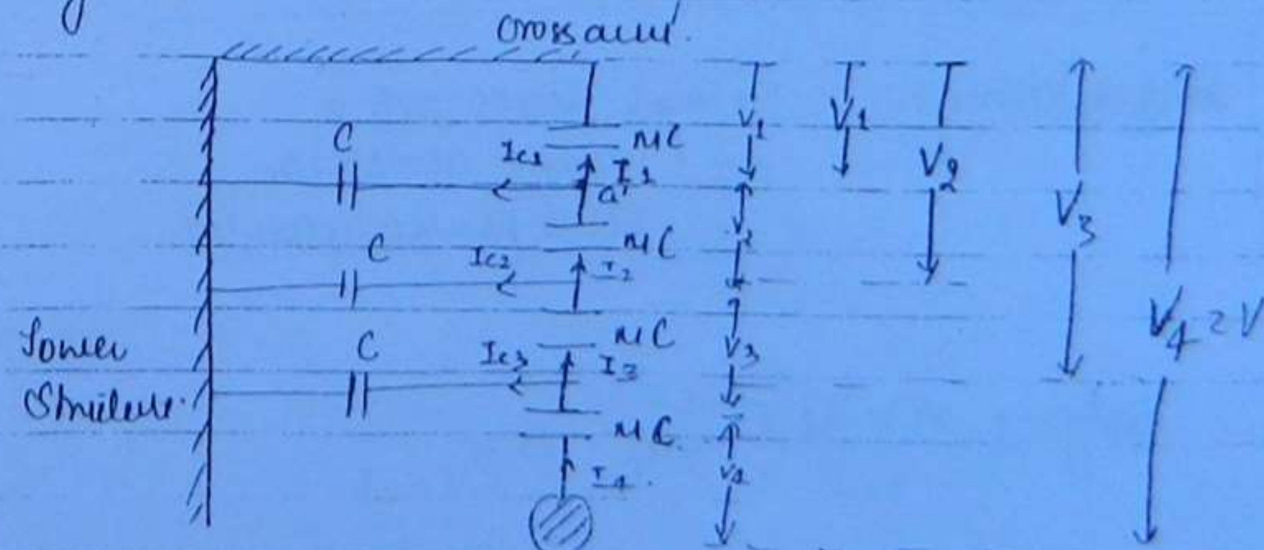
- Insulator provide insulation to the power conductor from the ground.
- Material used:

  1) Porcelain (20% Si, 30% Feldspar + 50% clay) [15 - 17 KV]

  2) Toughened glass [37 KV]

POTENTIAL DISTRIBUTION OVER STRING OF SUPPRESSION INSULA

- An insulator disc can withstand voltages upto 33 KV, the power transmission takes place at 132 KV. Therefore several insulator disc are connected in the form of string to transmit the bulk power.



- As the current is flowing from power conductor to the top insulator the disc at the bottom experience more stress. This is due to the capacitances formed b/w the metal part of insulator and tower structure.

- The capacitance b/w metal part of the insulator and tower structure can be neglected by increasing the distance b/w the conductors. As a result the cross arm increases which increases the cost of s/m.

- Therefore voltage distribution across string is not uniform due to the capacitances b/w metal part of insulator and tower structure.

- 'C' is the capacitance to the ground and. $mC \rightarrow$ mutual capacitance.

- To determine whether the distribution of voltage across insulators is uniform or not. Calculate the string efficiency.

$$\boxed{\text{string efficiency} = \frac{\text{voltage across string}}{n \times \text{voltage across disc near power conductor}}}$$

Applying KCL at 'a'

$$\sum I_{in} = \sum I_{out}$$

$$I_2 = I_1 + I_{c1}$$

$V_2 \omega(MC) \cancel{V_2} = V_1 \omega(MC) + V_1(\omega C)$

$\Rightarrow V_2 \cancel{\omega}.M\cancel{C} = V_1 \cancel{\omega C}(M+1)$

$$\boxed{V_2 = V_1\left(\frac{1+M}{M}\right)} \quad \text{------} \quad (1)$$

- applying at 'b'.

$$I_3 = I_{C_2} + I_2$$

$$V_3 \omega(MC) = (V_1+V_2)\omega C + V_2 \omega(MC)$$

$$\cancel{\boxed{V_3 = V_2\left(\frac{M+1}{M}\right)}} \quad \text{------} \quad (2)$$

$$V_3 M = V_2 M + V_1 + V_2,$$

$$V_3 . M = V_1 + V_2(1+M)$$

$$V_3 = \frac{V_1}{M} + V_2\left(\frac{1+M}{M}\right)$$

substituting (1)

$$V_3 = V_1\left[\frac{1}{M} + \frac{(1+M)^2}{M^2}\right]$$

$$V_3 = V_1\left[\frac{M+(1+M)^2}{M^2}\right]$$

$$\boxed{V_3 = V_1 \left\{ \frac{M^2 + 3m + 1}{M^2} \right\}} \quad \text{- - - - - (2)}$$

apply KCL at "C"

$$\Sigma I_{in} = \Sigma I_{out}$$

$$I_4 = I_3 + I_{C3}$$

$$V_4 \cancel{\omega} MC = V_3 \cancel{\omega}(MC) + (V_1 + V_2 + V_3)\cancel{\omega C}$$

$$V_4 = \frac{V_1}{M} + \frac{V_2}{M} + V_3\left(\frac{1+M}{M}\right)$$

$$\boxed{V_4 = V_1 \left\{ \frac{M^2 + 3M + 1}{M^2} + \frac{3M^2 + 4M + 1}{m^3} \right\} - (3)}$$

Let $M = 5$

$$V_2 = V_1\left(\frac{1+M}{M}\right) = V_1\left(\frac{1+5}{5}\right) = 1.2V_1$$

$$V_3 = V_1\left(\frac{M^3 + 3M + 1}{M^2}\right) = V_1\left(\frac{125 + 15 + 1}{25}\right) = \frac{41V_1}{25} = 1.64V_1$$

$$V_4 = 2.408V_1$$

$$\boxed{V_1 < V_2 < V_3 < V_4}$$

• string efficiency $= \frac{V_1 + V_2 + V_3 + V_4}{4 \times V_4} \times 100.$

$$= \frac{V_1 + 1.2V_1 + 1.64V_1 + 2.408V_1}{4 \times 2.408 V_1}$$

$$= \cancel{6.408}\ 54.4\%.$$

Important

$I_4 = I_3 + I_{3C}$

$I_n = I_{(n-1)} + I_{(n-1)C}.$

$V_{n+1}(\omega mC) = V_n(\omega mC) + V_n(\omega C)$

$$\boxed{V_{n+1} = \frac{V_n}{m} + V_n.}$$

METHOD OF EQUALIZING THE POTENTIAL:

• 1) Selection of m:

One of the methods to equalise the potential drop across insulator disc in the string is have higher value of m, which requires longer cross arm thereby increasing the cost of the s/m.

•2) Capacitance grading:

In capacitance grading different insulator disc of different rating must be selected

- The disc near the cross-arm must have low capacitance or high capacitive reactance.

- The disc near the cross-arm should have minimum capacitance or maxm capacitive reactance and as we approach to the disc near the power conductor capacitance must be maximum or capacitive reactance must be minimum.

- The ground capacitances are of equal value and mutual capacitances are different.

$$I_{n+1} = I_n + I_{cn} \quad \cdots (1)$$

$$\boxed{I_{n+1} = V\cdot[\omega M C_{n+1}]}$$

$$I_{c_3} = 3V\cdot\omega C$$

$$\boxed{I_n = V(\omega M C_n)}$$

$$V_1 = V_2 = V_3 = V_4 = V.$$

So equ^n

$$V[\omega M C_{n+1}] = V(\omega M C_n) + nV\omega C.$$

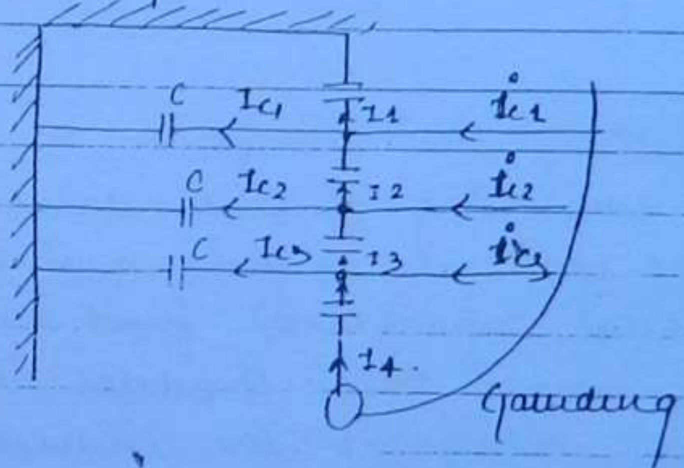
$$\boxed{C_{n+1} = C_n + \frac{nC_n}{M}}$$

DISADVANTAGES:-

1) different capacitances are required which require additional investment
2) This method is useful except for very high voltage line

iii) STATIC SHIELDING:

- In the static shielding the current flowing from metal part of the insulator to the tower structure are cancelled by passing the same current towards the metal part of insulator



- Equal potential across each insulator disc is obtained by means of Gaurd ring. which operates at different potentials thereby injecting different currents
- Gaurd-ring can neutralize the capacitive ground currents

$$\boxed{I_{n+1} = I_n}$$

$$\boxed{i_{cn} = I_{cn}}$$

- By using gaurd ring the capacitance of nth disc can be determined

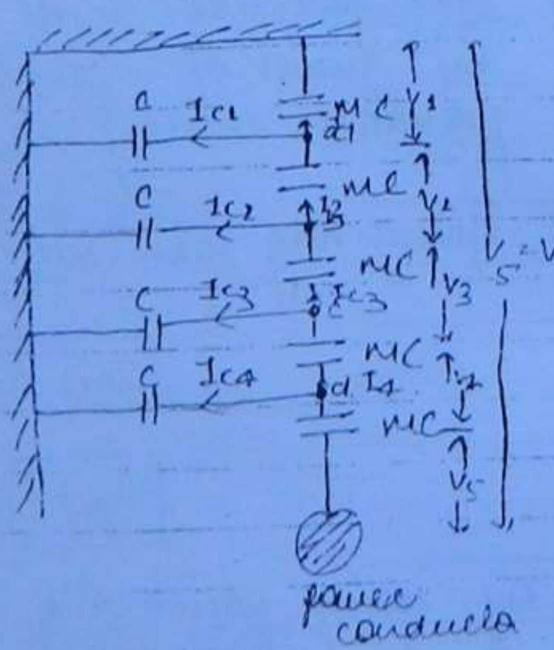
$$\boxed{C_n = \frac{n}{K-n} \cdot C}$$

• $K \rightarrow$ total no of disc
• $n \rightarrow$ no of disc upto which gaurd ring can be utilized.

Dated
9' Oct 2010

Question:

In transmission cover consisting of 5 insulator disc the string capacitance b/w each unit and earth is 1/6 times the mutual capacitance. find the voltage distribution across each insulator in the string as percentage of voltage of the conductor to the earth.



Solutⁿ

→ M always grt 1

• Pin to earth capacitance = C
Mutual capacitance

$MC = 6C$

$\therefore \boxed{M = 6}$

$I_5 = I_4 + I_{c4}$

$$V_5 \times \omega m C = V_4 \omega m C + V_4 \omega C.$$

$$= \quad V_5 \cdot m = V_4 m + V_4$$

$$\boxed{V_5 = V_4 + \frac{V_4}{m}} \quad \text{-----} \quad (1)$$

Imp formula

for $n = 4$ $\quad$ $V_{n+1} = V_n + \dfrac{V_n}{m}$

n is no of insulator from top cover the structure.

• ($n = 1$) $\quad$ $V_{n+1} = V_1 + \dfrac{V_1}{m}$

$$V_2 = V_1 + \frac{V_1}{m} \qquad \text{as } \boxed{V_1 = V_1}$$

$$V_2 = V_1\left(1 + \frac{1}{6}\right)$$

$$\boxed{V_2 = V_1 \cdot 7/6} \quad \text{----} \quad (2)$$

• ($n = 2$) $\quad$ $V_3 = V_2 + \dfrac{V_2}{m}$

$$V_3 = V_2 + \frac{V_1 + V_2}{m}$$

$$V_3 = \frac{V_1}{m} + V_2\left(1 + \frac{1}{6}\right)$$

substitute value of V_2 from (2)

$$V_3 = \frac{V_1}{6} + V_1\left(7/6\right)\left(7/6\right)$$

$$\boxed{V_3 = V_1\left(\frac{55}{36}\right)}$$

$n=3$: $V_4 = V_3 + \frac{V_3}{N}$

$$V_4 = V_3 + \frac{V_1+V_2+V_3}{N}$$

$$V_4 = V_3\left(1+\frac{1}{N}\right) + \frac{V_1+V_2}{N}$$

$$V_4 = \frac{55\,V_1}{36}\cdot\frac{7}{6} + \frac{V_1}{6} + \frac{87\,V_1}{6\cdot 6}$$

$$\frac{385}{216}V_1 + \frac{V_1}{6} + \frac{7\,V_1}{36}$$

$$\boxed{V_4 = \frac{463\,V_1}{216}}$$

$n=4$

$$V_5 = V_4 + \frac{V_4}{N}$$

$$V_5 = \frac{463}{216}V_1 + \frac{V_1+V_2+V_3+V_4}{N}$$

$$V_5 = \cancel{\frac{463}{216}V_1} + \frac{V_1}{N} + \frac{7\,V_1}{6\cdot 6} + \frac{5}{3}\,\frac{V_1}{6} + \frac{463}{216}\cdot\frac{7}{6}V_1$$

$$\frac{V_1}{6} + \frac{7\,V_1}{36} + \frac{55\,V_1}{216} + \frac{\text{[illegible]}\,3\times 7\,V_1}{1296}$$

$$\boxed{V_5 = 311\,V_1}$$

voltage across string

$$V = V_1 + V_2 + V_3 + V_4 + V_5$$

$$= V_1\left(1 + \frac{7}{6} + \frac{55}{36} + \frac{463}{216} + 3.11\right)$$

$$V = V_1 \times 8.94.$$

%age of V

- $V_1 = \frac{V}{8.93} \times 100 = 11.16\%\ V.$

$V_2 = \frac{7}{6} \times 11.6\%$ of V

- $V_2 = 13.03\%$ of V

$V_3 = \frac{55}{36} \times 11.16$ of V

- $V_3 = 17.050\%$ of V

- $V_4 = \frac{463}{216} \times 11.16$ of $= 25.92\%$ of V.

$V_5 = 3.11 \times 11.16$ of V

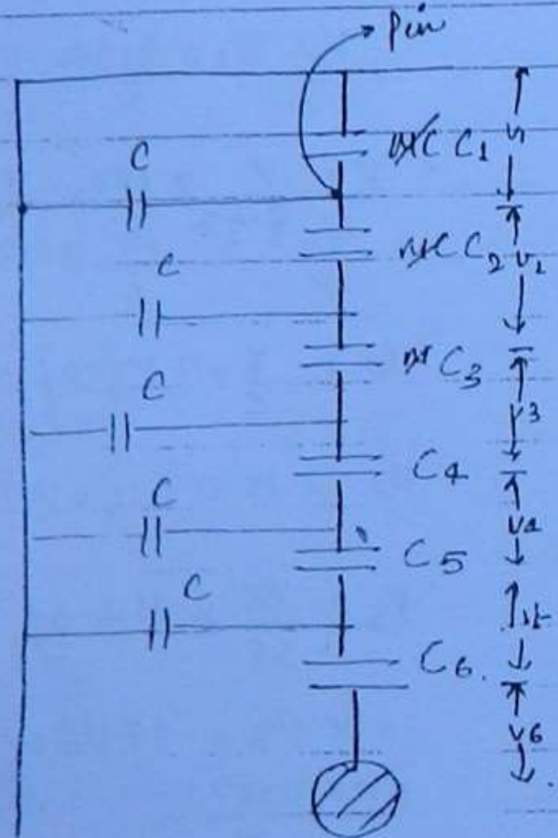
- $V_5 = 34.74\%$ of V

string efficiency $= \frac{V}{n \times V_5}$

$$\eta_{string} = \frac{V}{5 \times 34.7\,V} \times 100 = 57.63\%\ \text{Ans}$$

2) A string of 6 suspension insulators is to be graded to obtain uniform distributⁿ of voltage across the string if the pin to earth capacitance is equal to C and the self capacitance of the top insulator is 10C, find the mutual capacitance in ~~ten~~ ~~terms~~ of C.

** insulators are to be graded so no equal value of capacitance, so do notatⁿ from top to bottom



Generalize formula

$$C_{n+1} = \frac{C_n + nC_0}{N}$$

when grading of capacitor are asked then default value of $\boxed{(N=1)}$ alway taken

+ Pin to earth capacitance = C

+ Capacitance of top insulator disc $C_1 = 10C$

since capacitance across each disc is not same $\boxed{N \neq 10}$,

$\therefore \quad C_{n+1} = n+1C$

1). $n = 1$

$$C_2 = C_1 + C$$

$$\boxed{C_2 = 11C}$$

2) $n = 2$.

$$C_3 = C_2 + 2C$$

$$C_3 = 11C + 2C$$

$$\boxed{C_3 = 13C}$$

3) $n = 3$

$$C_4 = C_3 + 3C$$

$$C_4 = 13C + 3C$$

$$\boxed{C_4 = 16C}$$

4) $n = 4$

$$C_5 = C_4 + 4C$$

$$16C + 4C$$

$$\boxed{C_5 = 20C}$$

5) $n = 5$

$$C_6 = C_5 + 5C$$

$$\boxed{C_6 = 25C}$$

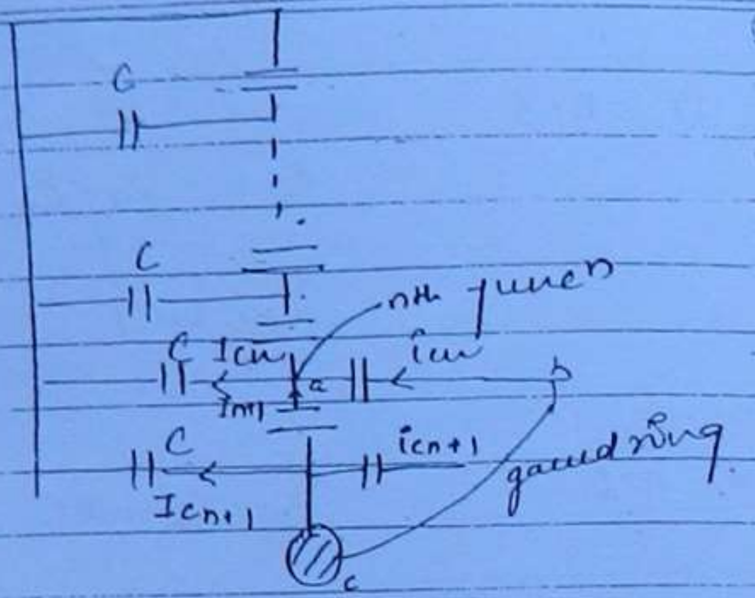
3) A string of 4 suspension insulators is to be fitted with a gaurd ring / grading ring if the pin to earth capacitance is equal to C find the values of line to pin capacitances that gives uniform voltage distributn over the string.

at n^{th} junc^n.

$I_{cn} = i_{cn}$ (as per guard ring)

as voltage is uniform.

$$\boxed{I_{cn} = nV.\omega C} \quad -(1)$$



* voltage across ab is similar to voltage across cb.
as voltage across ca is know as $(K-n)V$.

so eq^n (1)

$$\boxed{n.V(\omega C) = (K-n)V(\omega C_n)} \quad --- (2)$$

* the current flowing through capacitance C_n connected b/w line and pin ca is $\boxed{i_{cn} = (K-n)V\omega C_n}$

where K is total no. of disc in string
n is junc^n to which current i_{cn} is flowing or no. of insulator disc from top of cross arm.

$$C_n = \left(\frac{n}{K-n}\right)C.$$

$$C_2 = \left(\frac{6.1}{5}\right)$$

$$C_3 = \frac{?}{?}C.$$

$$n_3 = \frac{3}{4}C = C_3$$

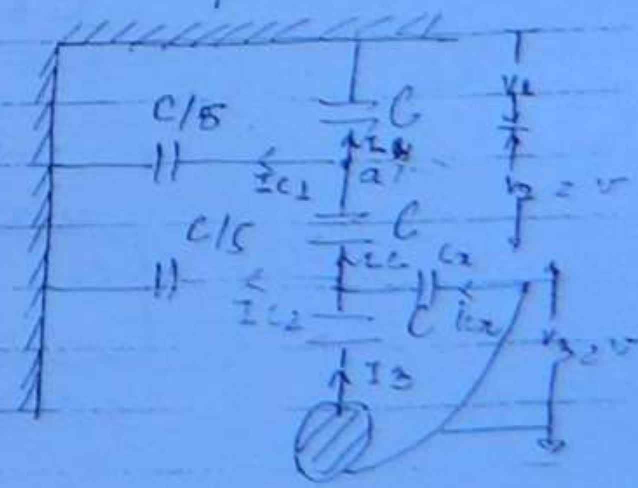
$$n_4 = \frac{4C}{3} = C_4$$

$$n_5 = \frac{5C}{2} = C_5$$

$$n_6 = 6C = C_6.$$

4) In a T.L each conductor is at 20KV and is supported by a string of 3 suspension insulators the air capacitance b/w each capacitor pin junctⁿ an tower is 1/5 times the capacitance C of each insulator disc. A gaurd ring effective only over the line end insulator is fitted so that the voltage of the two unit near the line end are equal. Calculate

1) voltage on the line end unit
2) the value of capacitance C_x required.



Solutⁿ $V_2 = V_3$ (given)

as.
When gaurd ring is connected to the insulator disc at the bottom end of the line.

$$\boxed{i_{c_2} = i_x}$$

$$= (v_1+v_2)\frac{\omega C}{5} = v\ \omega C_x$$

$$= (v_1+v)\frac{\omega C}{5} = v\omega C_x$$

$$v_1 . \frac{\omega C}{5} = v\left(C_x - \frac{C}{5}\right)$$

$$\Rightarrow \boxed{C_x = \left(\frac{v_1+v}{v}\right)\times\frac{C}{5}} \quad \text{- - - . (1)}$$

Applying KCL at 'a'

$$I_1 + I_{C_1} = I_2$$

$$\Rightarrow \omega C . v_2 = v_1 . \omega C + v_1 . \frac{C\omega}{5}$$

$$\boxed{v_2 = \frac{6}{5} . v_1} \text{ —— (2)}$$

substituting on (1)

$$C_x = \left(\frac{v_1}{v} + 1\right)\times\frac{C}{5}$$

$$C_x = \left(\frac{5v_1}{6v_1} + 1\right)\times\frac{C}{5}$$

$$C_x = \frac{11}{5}\times\frac{C}{5} =$$

$$\boxed{C_x = \frac{11}{30}C}$$

→ voltage across line end unit $V_2 = V_3 = V =$

$$V_1 + V_2 + V_3 = 20$$

$$V_1 + 2V = 20$$

$$V_1 + 2 \times \frac{6}{5} V_1 = 20$$

$$\frac{5+12}{5} V_1 = 20$$

$$\frac{17}{5} V_1 = 20$$

$$V_1 = \frac{100}{17}$$

$$\text{So } V = \frac{6}{5} \times \frac{\overset{20}{\cancel{100}}}{17} = \frac{120}{17} \text{ kV}$$

$$\boxed{V = 7.05 \text{ kV}}$$

Types of Insulator

1) Pin insulator:- (upto 25 kV)

- A pin insulator operate upto 25kV
- multipin insulators operate upto 55kV
- vertile configuratn.

2) Suspension Insulators (upto 11 kV)

- suspension insulator operates upto 11 kV.

- No. of disc required to transmit power through a conductor at 132 KV is
  (vertical configurat^n) $\boxed{132/11 = 12 \text{ disc.}}$

) Strain insulator: (mechanically strong).

strain insulator is mechanically strong, it is used when T.L direct^n is changed. or when T.L is laid across a river or at the dead end. of
(vertical configurat^n)

-) Shackle Insulator:-

shackle insulators are used for low tension lines, distribution services.
shackle insulator can be arranged either horizontally or vertically.

- Material used of insulators:

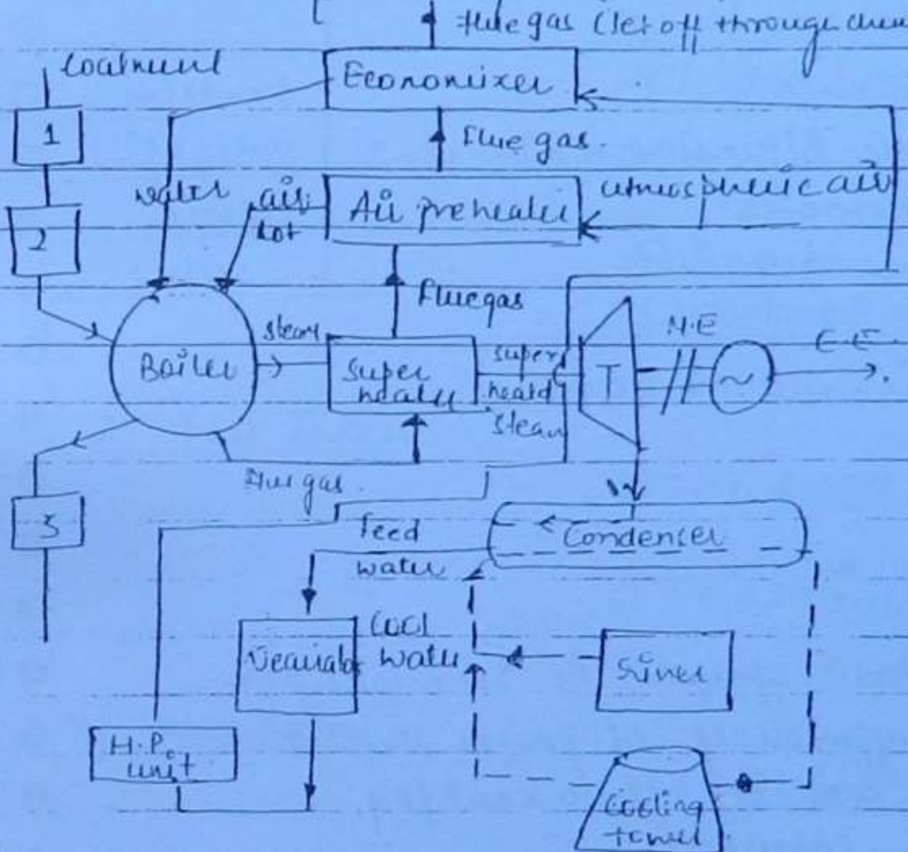
-) Synthetic Resin:-
used in the region where rainfall is more.
(17% costlier)

2) Steatite:
used in region where snowfall is more.
(24% costlier)

GENERATING STATIONS

1) **Thermal Generating Station:**

1) Coal storage yard
2) Coal handling yard
3) Ash storage yard



i) Coal Handling plant:

coal mines $\xrightarrow{\text{rail / road}}$ coal storage yard $\xrightarrow{\text{coal}}$ Pulverized mill $\xrightarrow{\text{coal powder}}$ Boiler

Coal storage yard:
- coal is cover (protect for rain)
- coal is exposed to sun (~~protect~~ Increase caloric value)

Wet coal decreases the efficiency of boiler.

Any thermal statⁿ efficiency - 25-30%

- Types of coal used.

1.) Peat
2) Lignite
3) Bituminous
4) Semi-Bituminous (Indian).
5) Anthracite
6) Super-Anthracite.

Ascending order of Calorific value.

- Coal in powdered form is STEAM COAL.

Question 1

A thermal power statⁿ spends Rs 10.6 lakh/yr for utilization of coal. The efficiency of power statⁿ is 30%. The calorific value of coal is 5000 kcal/kg. The cost of coal is Rs 50/ton. Calculate

1) Quantity of coal consumed per year
2) The heat input/heat of combustion
3) Heat output
4) electrical energy generated per year.
5) Avg load on g/r statⁿ.

Solⁿ

cost = 10.6 lakh/yr

$\eta = 30\%$

C.V = 5000 k cal/kg

cost/ton = Rs 50/ton

1) coal consumed per year ?

$$= \frac{\text{cost of coal / yr}}{\text{cost of coal / ton}}$$

$$= \frac{10.6 \times 10^5}{50} =$$

$= 21200$ tone/year. Ans

2) heat input

$$= 5000 \times 21200 \times 1000$$

$$= 1.06 \times 10^{10} \text{ kcal / year.}$$

3) Heat output

$$= 0.30 \times 1.06 \times 10^{10}$$

$$= 3.18 \times 10^{9} \text{ kcal / year}$$

4) electrical energy generated per year. (kWh)

$\Rightarrow$ heat o/p $= 3.18 \times 10^9$ kcal/yr

1 kWh = 860 kcal

$$= \frac{3.18 \times 10^9}{860} = 3.69 \times 10^6 \text{ kWh}$$

5) Average load.

$$= \frac{\text{Energy gen/year}}{\text{no. of hour/year}}$$

$$= \frac{3.69 \times 10^6}{365 \times 24} \quad \cancel{0.422 \text{ kW}} \quad 0.42 \text{ MW}$$

(i) BOILER:- → Water Tube Boiler
→ Fire tube Boiler

• Water tube Boiler	• Fire tube Boiler
• ~~hot water~~ hot gases inside tube ← water hot gases	• water hot gases (inside tube) water
• Explosion donot occur	• Explosion occurs when temp of hot gases exceeds specific temp
• 17 kg/cm^2 (Pressure)	• 85 kg/cm^3 (Pressure)
• 100 °C	• 600 °C.

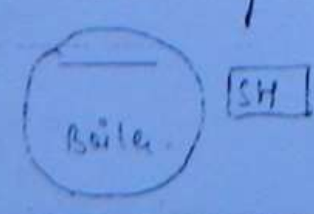
(ii) SUPER HEATER:

In the super heater the temperature of steam is increase by ~~increasing~~ absorbing heat of flue gases.

• Radiant Super heater

• 

• Convection Super heater

• 

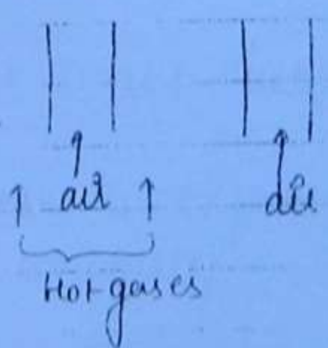
- more efficient
- less efficient

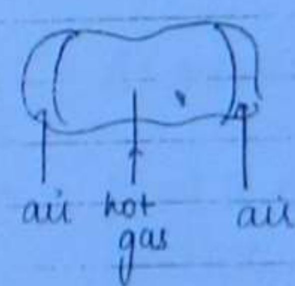
IV) AIR PREHEATER:

In air preheater the atmospheric air absorbs the heat of flue gases and hot air is send to the boiler for effective combustion.

Recuperative

Regenerative

- 

- 

- More efficient
- less efficient
- explosion donot occur
- explosion may occur when temp hot gases increases

Questn:

A thermal power stathn having capacity 100MW utilizes coal of 6400 Kcal/kg. The efficiency of boiler is 50%. efficiency of turbine g/r is 90%. calculate
the no of unit g/r per hour at rated o/p.
2) overall efficiency 3) Heat output in. Kcal.

4) Heat input.
5) Coal utillized for generatn.

Solutn: capacity = 100 MW

power output = 100 MW

$= 100 \times 10^3$ kW

1) Unit generated/hour = $\frac{kWh}{h}$ = kW = 100×10^3 kW.

2) overall efficiency.

$\eta = \eta_T \times \eta_B$

0.3×0.9

$= 0.27$

$\eta_{total} = 27\%$

3). Heat output in kcal.

1 kWh = 860 kcal.

$100 \times 10^3 \longrightarrow 100 \times 10^3 \times 860$

$= 86 \times 10^6$ kcal/hr.

• The heat output is the kcal. of the coal burnt during combustion per hour = 86×10^6 k.cal.

4) Heat I/p = $\frac{86 \cdot 10^6}{0.3} = 2.86 \times 10^6$ kcal/hr

5) coal utilized for generation $= \dfrac{2.8 \times 10^6 \text{ Kcal/hr}}{6400}$

$= 437.446.87$ kg/hr

V) TURBINE:

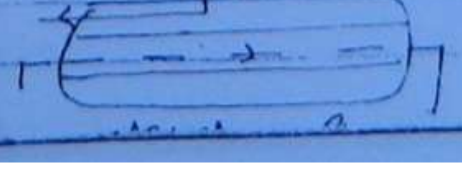
- In turbine work is done by expansion of the steam.
- Turbine converts super-heated steam into mechanical energy.

# IMPULSE TURBINE	# REACTION TURBINE
• Steam is expanded completely	• Steam is expanded partially.
• Pressure on moving plates is constant	• Pressure on moving plates is not constant
•	

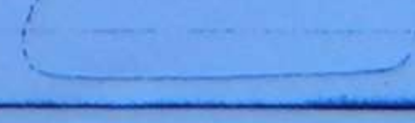
VI) CONDENSER :-

- Exhaust steam is converted into feed water
- condenser is the equipment operating at the lowest pressure.

SURFACE



JET

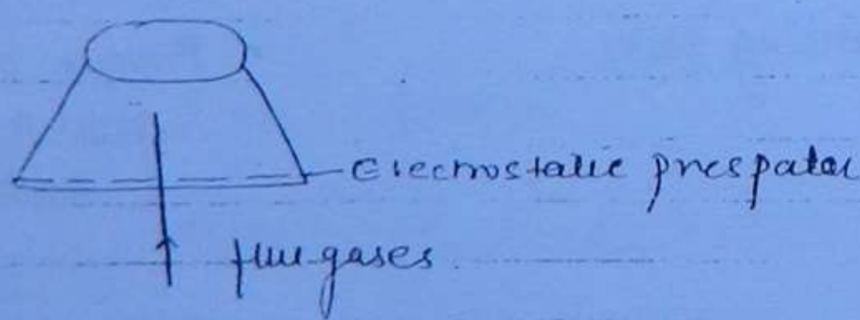


• cool water flow through tube and exhaust steam passes outside the tube.	• cool water and exhaust steam come in contact with each other
• less efficiency.	• more efficient

(vii) ECONOMISER:-

Converts feed water into water at higher temp by extracting the heat from flue gases.

(viii) CHIMNEY:-



Electro-static precipitator removes the dust particles by operating at 30 KV

Induced draft fan forces the flue gases from the bottom surface to top surface

Quesⁿ

A thermal power statⁿ has efficiency 21%, 0.75 kg of coal is utilized to generate 1 KWh of energy calculate

k 1) Heat o/p
2) Calorific value of coal
3) Heat of combustion

Ans

$\eta = 21\%$.

coal = 0.75 kg.

Energy generated = 1 KWh.

1) Heat o/p

1 KWh = 860 Kcal/~~kg~~.

Heat output = 860 Kcal.

2) calorific value of coal

=

$1\,KWh \begin{cases} \rightarrow 860\,Kcal \\ \rightarrow 0.75 \end{cases}$

$= \dfrac{860\ Kcal}{0.75\ kg} = 1.14 \times 10^3\ Kcal/kg$

3) Heat I/p $= \dfrac{860}{0.21} = 4.1 \times 10^3\ Kcal$

7) A thermal power statⁿ utilizes 0.7 kg of coal to generate electrical energy of 1kWh. The calorific value of coal is 7421 kcal/kg. The efficiency of turbine generator set is 95% and g/r is 96%. Determine the thermal efficiency.

Solⁿ

$1 kWh \longrightarrow 860 \, kcal$

heat input C.V = ~~7421~~ CV × coal

$7421 \times 0.7 kg$

$= 5194.7 \, kal$

$\% \eta_T = \frac{860}{5194.7 \times 0.95 \times 0.6}$

$\eta_T = 0.18$

$\eta_T = 18\%$

~~HYDROELECTRIC~~

HYDRO ELECTRIC GENERATING STATIONS

• they are classified as below.

1) Generating capacity:
   a) Micro HEPS (0-5)
   b) Small " (5-100)
   c) Medium " (100-1000)
   d) large " (>1000 MW)

2) Based on Head of Water:
   From
   a) low head HEPS (0-70) Ex Propellor
   b) Medium HEPS (70-300) Kaplans
   c) High HEPS (>300) Peltons

5) Based on nature of load:
   a) Base load
   b) Peak load
   c) Pump storage Plant

4) Based on Quantity of water available:
   a) Run-off river plant $\bar{c}$ pondage
   b) Run-off river plant $\bar{c}$out pondage
   c) Reservoir plant.

5) Based on construction:
   a) Run off river plant $\bar{c}$ pondage
   b) Run off river plant $\bar{c}$out pondage
   c) Reservoir plant
   d) Diversion plant
   e) High head diversion Canal

POWER EQUATION: Bernoulis equation

$$\boxed{P = \frac{0.736}{75} Qwh \quad KW}$$

$Q \rightarrow$ water discharge $= m^3/sec$
$w \rightarrow$ density of water
$= 1000 kg/m^3$
$h \rightarrow$ head of water.

$$\boxed{P = \frac{736}{75} Q.w} \quad K.W$$

$$\boxed{P = 9.81 Qh} \; KW.$$

- Depending on η of generating statn power transmitted or O/P power.

$$\boxed{P_{tr} = 9.81 Qh \times \eta}$$

Question:
A hydroelectric power statn is supplied water from the ~~high~~ reservoir at a rate of $50 m^3/sec$. The head of water $h = 50 m$. Power developed by turbine-g/r set with 75% η is

$$P_{tr} = 9.81 \times 50 \times 50 \times 0.75$$

$$P_{tr} = 18.4 \; MW$$

Hydrological

HYDROGEN CYCLE :-

1.) Precipitation
2) Evoporation
3) Stream flow or Runoff (m^3/sec)

$$\boxed{\text{Runoff} = \text{Precipitat}^n - \text{Evoporation}}$$

Precipitatⁿ: the volume of water available (m^3) or water discharged from the river to HE generating statⁿ

Evoporation: the volume of water evoporated during its normal flow is evoporation

Run-off : the ~~to~~ volume of water available at HE g/r statn is known as run off

numericals : day-sec-metre - $1m^3/sec$ in day
month-sec metre → $1m^3/sec$ in month
year-sec metre → $1m^3/sec$ in year.

- $24 \times 60 \times 60 = 86400\ m^3/day$
- $30 \times 24 \times 60 \times 60 = 2.6 \times 10^6 m^3/month$
- $365 \times 30 \times 24 \times 60 \times 60$

Questn

A hydroelectric generating statn is operating at water head of 75m. A reservoir area is 200km^2 The average rainfall is 420 cm/year. 50% of water is lost due to evoporatn. the efficiency of turbine is 80%. efficiency of generator is 85%. the power generated is.

Avg rainfall = 420cm/year

volume of water stored in reservoir/year =

$$\text{Avg rainfall} \times 200 \times 10^6$$

$$= \cancel{0.420}\ 0.420 \times 200 \times (10^3)^2 \ m^3/\text{year}$$

$$= \cancel{88}\ 840 \times 10^6 \ m^3/\text{year}$$

Available water g/r stat = $0.7 \times 840 \times 10^6$

$$= 588 \times 10^6 \ m^3/\text{year}$$

volume of water discharge/sec = 18.64 m^3/sec

$$P_o = 9.81 \times 18.64 \times 75 \times (.8) \times (.85)$$

9.3MW

Ques A hydro-electric g/r station has the following data

1) operating head → 30m.
2) reservoir area → 400 km²
3) Avg rain/year → 125 cm/year
4) yield factor = 75% (available)
5) $\eta_{t} = 85\%$

6) $\eta_{Penstock} = 90\%$

7) $\eta_{a/r} = 95\%$

the power generated is ?

$$P_{tr} = \cancel{12.5}\ 12.5 \times 400 \times 10^6$$
$$= 5 \times 10^8 \, m^3/year.$$

$$\text{Available water} = \frac{5 \times 10^8}{365 \times 24 \times 60 \times 60}$$

$$Q = 11.89 \, m^3/sec$$

$$P_t = 11.89 \times 30 \times 9.81 \times \cancel{0.75} \times .85 \times .90 \times 0.95$$
$$=$$

can be obtained for voltage and current equat^n.

from eq^n (1)

$$\frac{1}{z}\frac{dV}{dx} = I$$

$$\Rightarrow I = \frac{1}{z}\left[\frac{d}{dx}\left\{Ae^{\sqrt{yz}\cdot x} + Be^{-\sqrt{yz}\cdot x}\right\}\right]$$

$$I = \frac{1}{z}\left[\sqrt{yz}\cdot Ae^{\sqrt{yz}\cdot x} - \sqrt{yz}\,e^{-\sqrt{yz}\cdot x}\right]$$

$$I = \sqrt{\frac{y}{z}}\left[Ae^{\sqrt{yz}\cdot x} - Be^{-\sqrt{yz}\cdot x}\right]$$

$$I = \frac{1}{\sqrt{z/y}}\left[Ae^{\sqrt{yz}\cdot x} - Be^{-\sqrt{yz}\cdot x}\right] \quad \text{— (6)}$$

Applying initial condition.
$V = V_R$, $I = I_R$ when $x = 0$

Now from equation (6) we get

$$I_R = \left[\frac{1}{\sqrt{z/y}}\left\{Ae^{0} - Be^{0}\right\}\right]$$

$$I_R = \frac{1}{\sqrt{z/y}}\left[A - B\right] \quad \text{— (7)}$$

Similarly:

$$V_R = A \cdot e^{\sqrt{yz} \cdot 0} + Be^{-\sqrt{yz} \cdot 0}$$

$$\Rightarrow V_R = A + B \quad - (8).$$

$\boxed{\gamma = \sqrt{yz}}$ → no unit = known as propagation constant (γ).

$\boxed{\gamma = (\alpha + j\beta)}$ α → attenuation constant

β → phase constant

$\sqrt{z/y}$ → characteristic impedance Z_c

$A + B = V_R$

$A - B = Z_c \cdot I_R$

$2A = V_R + Z_c I_R$.

$$\boxed{A = \frac{V_R + Z_c \cdot I_R}{2}}$$

$$\boxed{B = \frac{V_R - Z_c I_R}{2}}$$

substituting value of A, B.

$$V = \underbrace{\left(\frac{V_R + Z_c \cdot I_R}{2}\right)}_{\text{incident wave}} e^{\gamma x} + \underbrace{\left(\frac{V_R - Z_c I_R}{2}\right)}_{\text{reflected wave}} e^{-\gamma x} \quad \text{--- (9)}$$

$$= V_R\left(\frac{e^{\gamma x} + e^{-\gamma x}}{2}\right) + I_R Z_c \left(\frac{e^{\gamma x} - e^{-\gamma x}}{2}\right).$$

$$\boxed{V \Rightarrow V_R \cosh\gamma x + I_R Z_c \sinh\gamma x \quad \text{--- } 10}$$

Similarly:

$$I = \frac{1}{Z_c}\left\{\left(\frac{V_R + Z_c \cdot I_R}{2}\right) e^{\gamma x} - \left(\frac{V_R - Z_c I_R}{2}\right) e^{-\gamma x}\right]$$

$$\boxed{I = \frac{1}{Z_c}\left[V_R\left\{\cancel{V_R}\frac{e^{\gamma x} - e^{-\gamma x}}{2}\right\} + Z_c I_R \left\{\frac{e^{\gamma x} - e^{-\gamma x}}{2}\right\}\right]} \quad (11)$$

$$\boxed{I = \frac{1}{Z_c}\{\sinh\gamma x\} V_R + I_R\{\cosh\gamma x\} \quad \text{--- } (12)}$$

when $x = l$, $V = V_S$ $I = I_S$

$$\boxed{\begin{aligned} V_S &= V_R \cosh\gamma l + I_R Z_c \sinh\gamma l \quad \text{--- } (13) \\ I_S &= \frac{V_r}{Z_c} \sinh\gamma l + I_R \cosh\gamma l \quad \text{--- } (14) \end{aligned}}$$

$A = \cosh\gamma l = D$ — $B = Z_c \sinh\gamma l$; $C = \frac{1}{Z_c}\sinh\gamma l$.

Main points :-

Equation (9) is combination of incident voltage wave and reflected voltage wave.

Incident voltage V_a wave decreases from sending end to receiving end.

Reflected voltage wave increases from sending end to receiving end.

From equatn (11) current wave is combination of incident current and reflected current wave.

Incident current wave decreases from sending end to receiving end. so

Reflected current wave increases from a sending end to receiving end.

- Receiving end
- Reflected voltage
- Reflected current
- Reduced

ABCD Constants :-

1.) Power series

$$\cosh\gamma l = \left\{ 1 + \frac{(\gamma l)^2}{2!} + \frac{(\gamma l)^4}{4!} + \cdots \right\}$$

$$\gamma l = \sqrt{yz}\cdot l = \sqrt{(yl)(zl)} = \sqrt{YZ}$$

$$\cosh\gamma l = \left\{ 1 + \frac{(\sqrt{YZ})^2}{2!} + \frac{(\sqrt{YZ})^4}{4!} \cdots \right\}$$

$$= 1 + \frac{YZ}{2} + \frac{(YZ)^2}{24} + \cdots$$

$$\cosh\gamma l \cong 1 + \frac{YZ}{2}$$

$$\therefore \boxed{A = D = \cosh\gamma l = 1 + \frac{YZ}{2}}$$

$$\sinh\gamma l = \left\{ \gamma l + \frac{(\gamma l)^3}{3!} + \cdots \right\}$$

$$\left\{ \sqrt{YZ} + \frac{(\sqrt{YZ})^3}{6} + \cdots \right\}$$

$$\sqrt{YZ} \left\{ 1 + \frac{YZ}{6} + \cdots \right\}$$

$$B = Z_C \sinh\gamma l = \sqrt{\frac{Z}{Y}}\sqrt{YZ}\left\{ 1 + \frac{YZ}{6} \right\} \quad \boxed{B = Z\left\{ 1 + \frac{YZ}{6} \right\}}$$

$$C = \frac{1}{Z_C}\sinh\gamma l = \sqrt{\frac{Y}{Z}}\sqrt{YZ}\left\{ 1 + \frac{YZ}{6} \right\} \quad \boxed{C = Y\left\{ 1 + \frac{YZ}{6} \right\}}$$

$\therefore$

$$\boxed{\begin{aligned} A &= \cosh\gamma l = D \\ B &= Z_c \sinh\gamma l \\ C &= \frac{1}{Z_c}\sinh\gamma l \end{aligned}}$$

(2) <u>Complex exponential</u>:

$$\cosh\gamma l = \cosh(\alpha - j\beta)l = \cosh(\alpha l + j\beta l)$$

$$= \left\{ \frac{e^{(\alpha l + j\beta l)} + e^{-(\alpha l + j\beta l)}}{2} \right\}$$

$$= \frac{1}{2}\left\{ \cancel{e^{\alpha l}}\; e^{\alpha l} \cdot e^{j\beta l} + e^{-\alpha l} e^{-j\beta l} \right\}$$

$$\boxed{\cosh\gamma l = \frac{1}{2}\left[e^{\alpha l}\,\angle\beta l + e^{-\alpha l}\,\angle -\beta l \right\}}$$

$$\sinh\gamma l = \sinh(\alpha l + j\beta l)$$

$$= \left\{ \frac{e^{\gamma l + j\beta l} - e^{-(\gamma l + j\beta l)}}{2} \right\}$$

$$\boxed{\sinh \gamma l = \frac{1}{2} \left\{ e^{\gamma l} \angle \beta l - e^{-\gamma l} \angle -\beta l. \right\}}$$

	S.T.L	M.T.L T	M.T.L Π	L.T.L
A	1	$1 + \frac{YZ}{2}$	$1 + \frac{YZ}{2}$	$1 + \frac{YZ}{2}$
B	Z	$Z\left(1 + \frac{YZ}{4}\right)$	Z	$Z\left(1 + \frac{YZ}{6}\right)$
C	0	Y	$Y\left(1 + \frac{YZ}{4}\right)$	$Y\left(1 + \frac{YZ}{6}\right)$
D	1	$1 + \frac{YZ}{2}$	$1 + \frac{YZ}{2}$	$1 + \frac{YZ}{2}$

SURGE IMPEDENCE :-

the impedence of lossless Transmission line is known as surge impedence.
for a lossless T.L $\boxed{Z_C = Z_S}$

$$Z_C = \sqrt{\frac{Z}{Y}} = \sqrt{\frac{R+j\omega L}{G+jB_C}}$$ → characteristic impedence.

$R=0$; $G=0$

$$Z_S = \sqrt{\frac{j\omega L}{jB_C}} = \sqrt{\frac{j\omega L}{j\omega C}}$$

$$\boxed{Z_S = \sqrt{\frac{L}{C}}}$$

characteristic impedence of over overhead line is $400\,\Omega$
• underground cable is $40\,\Omega$

Flat line OR INFINITE LINE

A lossless transmission line terminated with its characteristic impendence it is knowns as flat line or infinite line. the phase angle of characteristic impedence of T.L is b/w
$0 - (-15^\circ)$

- Surge impedence loading / characteristic impedence loading

CIL and S.I.L refers to MW, MVA, MVAR of load connected at the receiving end of T.L, when the T.L donot have losses. SIL

$$\boxed{SIL = \frac{V_S V_R}{Z_s}}$$

If the T.L have losses

$$\boxed{CIL = \frac{V_S V_R}{Z_c}}$$

in terms of ABCD constant

$$\boxed{SIL/CIL = \frac{V_S V_R}{B}}$$

Relation b/w characteristic impedence, open-circuit impedence, short circuit impedence:

$V_S = AV_R + BI_R$

$I_S = CV_R + DI_R$

Receiving end is O.C

$I_R = 0$

$\Rightarrow V_S = A \cdot V_{RO} \Rightarrow A = V_S / V_{RO}$

$I_S = C \cdot V_{RO} \Rightarrow C = I_S / V_{RO}$

$$\boxed{A/C = V_S / I_S} \quad \text{— (1)}$$

Receiving end is S.C. $V_R = 0$.

$V_S = B I_R \Rightarrow B = V_S / I_R$

and $D = I_S / I_R$.

$$\boxed{B/D = \frac{V_S}{I_S}} \quad \text{——— (2)}$$

multiplying eq^n (1) and (2)

$$\frac{V_S}{I_S} = \sqrt{\frac{\cancel{A} \cdot B}{C \cdot \cancel{D}}} \qquad A = D$$

$$\boxed{\frac{V_S}{I_S} = \sqrt{\frac{B}{C}}}$$

S.E $\qquad Z_c \qquad$ R.E

$$\frac{V_s}{I_s} = Z_C \qquad\qquad \frac{V_R}{I_R} = Z_C$$

$$Z_c = \sqrt{\frac{B}{C}} = \sqrt{\frac{Z_{sc}}{Y_{oc}}}$$

$$\boxed{Z_C = \sqrt{Z_{sc} Z_{oc}}}$$

Question:

1) The surge impedence loading of 400KV T.L is

$$\frac{V_s \times V_R}{B} = \frac{V_s \cdot V_r}{Z_c} = \frac{400 \times 400}{400}$$

$$Z_s = 400MW.$$

2) Surge impedence loading of a 220KV of T.L is

$$\frac{\cancel{220} \times \cancel{220}}{\cancel{400}} = 121MW$$

A T.L can be loaded & more than surge impedence loading or less than surge impedence loading

Condition 1:-

Loading > S.I.L

1) Current increases.
2) load impedence (Z_L) < Z_c.
3) As $\frac{1}{2}Li^2 > \frac{1}{2}CV^2$, so the power factor is lagging

4) $V_R < V_S$

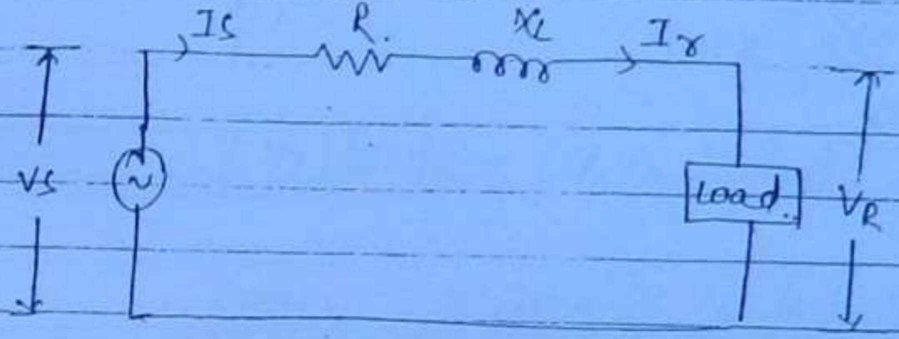
Condition 2:

Loading < S.I.L

1) Current decrease.
2) load impedence $(Z_L) > Z_S$
3) As $\frac{1}{2}Li^2 < \frac{1}{2}CV^2$, so the power factor is leading
4) $V_R > V_S$.

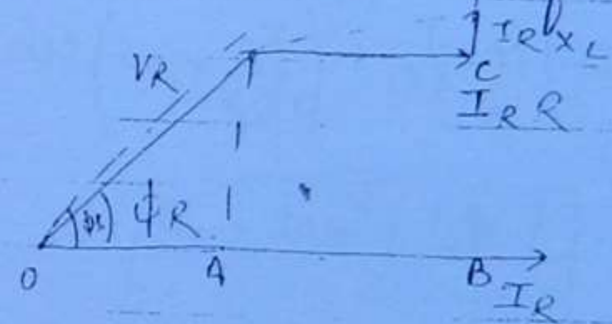
In general T.L is loaded more than surge impedence loading. Surge impedence also called Natural impedence.

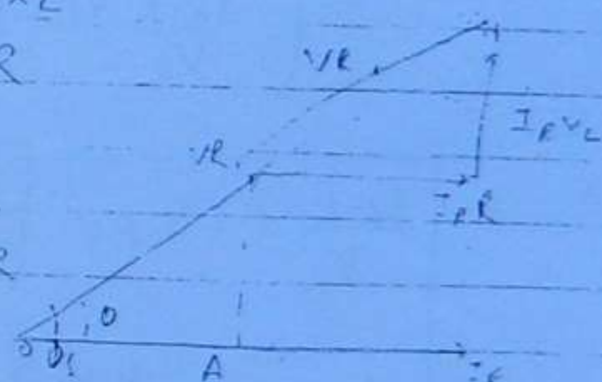
CONDITION FOR ZERO REGULATION OF T.L :-



Vs D

consider R.E current I_R as reference vector.





$$V_S^2 = OD^2 = OB^2 + BD^2$$

$$V_S^2 = (OA + AB)^2 + (BC + CD)^2$$

$$OB = V_S \cos\phi_S = OA + AB.$$

$$= V_R \cos\phi_R + I_R \cdot R \quad \text{--- (1)}$$

$$BD = V_S \sin\phi_S = BC + CD.$$

$$= V_R \sin\phi_R + I_R X_L \quad \text{--- (2)}$$

$(1)^2 + (2)^2$

$$V_S^2 = V_R^2 + I_R^2 (R^2 + X_L^2)$$

$$V_S - V_R \cong I_R R \cos\phi_R + I_R X \sin\phi_R .$$

$$\% E = \frac{V_C - V_R}{V_R} \times 100$$

$$\frac{I_R R \cos\phi_R + I_R X \sin\phi_R}{V_R} \times 100$$

$$= \left(\frac{I_R \cdot R}{V_R} \times 100 \right) \cos\phi_R + \left(\frac{I_R}{V_R} \times 100 \right) \sin\phi_R .$$

$$\boxed{\begin{array}{l} \dfrac{I_R R}{V_R} = V_R \text{ p.u} \\ \\ \dfrac{I_R \cdot R}{V_R} \times 100 = \% V_R . \end{array}}$$

$$\boxed{\% E = (\% V_R) \cos\phi_R + (\% V_R) \sin\phi_R .}$$

--- for lagging p.f

$$\boxed{\% E = (\% V_R) \cos\phi_R - (\% V_R) \sin\phi_R}$$

--- leading p.f.

#: • for zero voltage regulation power factor must be leading

$$\%E = 0$$

$$(\%V_r)\cos\phi_R - (\%V_x)\sin\phi_R = 0$$

$$\%V_r \cos\phi_r = \%V_x \sin\phi_r$$

$$R\cos\phi_R = X\sin\phi_R$$

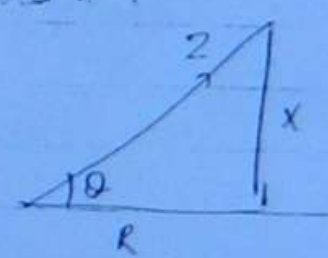
$$\tan\phi_R = R/x.$$

$$\boxed{\phi_R = \tan^{-1}(R/x)}$$

when phases are given b/w between R and x.

$$\cot\theta = R/x.$$

$$\therefore \tan\phi_R = \frac{R}{x} = \cot\theta.$$



$$Z = R+jx$$

$$\tan\phi_R = \tan(\pi/2 - \theta)$$

$$\boxed{\phi_R = \pi/2 - \theta}$$

4. Phase angle of load at which regulatⁿ is maximum

For lagging p.f, percentage regulatⁿ is maxᵐ.

$$\%E = (\%V_R)\cos\phi_R + (\%V_x)\sin\phi_R$$

$$\frac{d(\%E)}{d\phi_R} = (\%V_r)(-\sin\phi_R) + (\%V_x)\cos\phi_R.$$

$$\frac{d(\%E)}{d\phi_R} = 0 \Rightarrow (\%V_r)(-\sin\phi_R) + (\%V_x)\cos\phi_r = 0$$

$$\Rightarrow \left(\frac{I_R \cdot R}{V_R} \times 100\right)\sin\phi_R = \left(\frac{I_R}{V_R} \times 100\right)\cos\phi_R.$$

$$R\sin\phi_R = X\cos\phi_R$$

$$\boxed{\tan\phi_R = X/R}$$ regulatⁿ is maxᵐ

From the phase Δle $\tan\theta = X/R$

$$\tan\theta_R = X/R = \tan\theta$$

$$\boxed{\phi_R = \theta}$$

X is more than R.

For max^m ratio ↑ X/R

	Zero Regulation	Max^m Regulation
$\tan \phi_R$	R/X	X/R
ϕ_R	$\frac{\pi}{2} - \theta$	θ

When both zero

Zero Regulati^n = Max^m Regulation

when pf is 0.707 (lagging or leading)

as

$\tan \phi_R = R/X \ (=) \ \tan\phi_R = X/R$

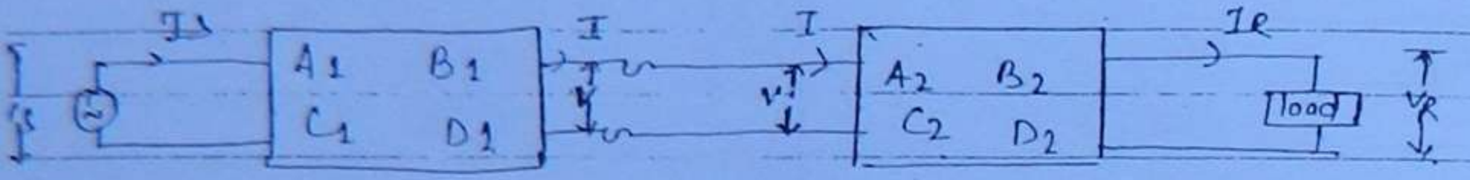
$\therefore \quad \boxed{X = R}$

$\phi_R = \tan^{-1}(1) = 45°$

$\boxed{\cos \phi_R = \cos(45) = 0.707}$

percentage regulation of T.L (practically) around 6-7%

T.L CONNECTED IN SERIES OR CASCADE OR TANDOM:



$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} V \\ I \end{bmatrix} \qquad \begin{bmatrix} V \\ I \end{bmatrix} = \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_2 \end{bmatrix} \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A_1 A_2 + B_1 C_2 & A_1 B_2 + B_1 D_2 \\ A_2 C_1 + D_1 C_2 & C_1 B_2 + D_1 D_2 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

for identical T.L

$A_1 = A_2 = A$

$B_1 = B_2 = B$

$C_1 = C_2 = C$

$D_1 = D_2 = D$

therefore.

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A^2+BC & AB+BD \\ AC+DC & BC+D^2 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}.$$

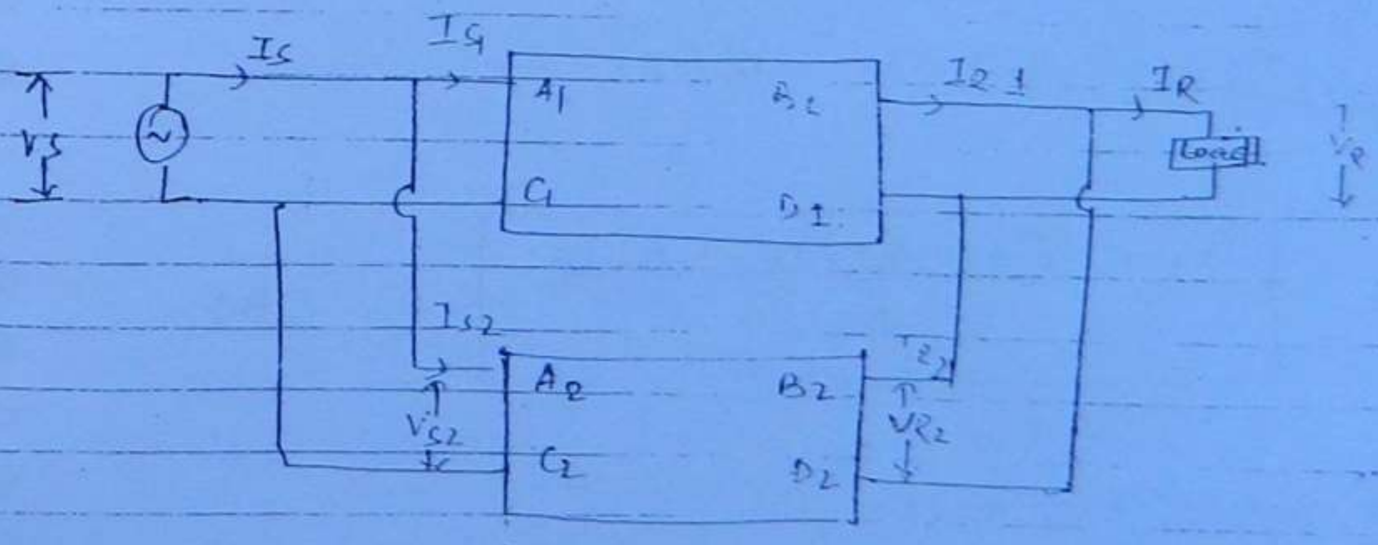
$$A \longrightarrow A_1A_2+B_1C_2 = A^2+BC$$

$$B \longrightarrow A_1B_2+B_1D_2 = AB+BD$$

$$C \longrightarrow A_2C_1+D_1C_2 = AC+DC$$

$$D \longrightarrow B_2C_1+D_1D_2 = BC+D^2.$$

T.L CONNECTED IN PARALLEL :-



$$I_s = I_{s1} + I_{s2}$$

$$I_R = I_{R1} + I_{R2}$$

POWER SYSTEM-1

$$V_c = V_{c_1} = V_{c_2}$$

$$V_{R_1} = V_R = V_{R_2}.$$

$$V_c = V_{S_1} = A_1 V_{R_1} + B_1 I_{R_1} = A_1 V_R + B_1 I_{R_1} \quad \text{——— (1)}$$

$$V_c = V_{S_2} = A_2 V_{R_2} + B_2 I_{R_2} = A_2 V_R + B_2 I_{R_2} \quad \text{——— (2)}$$

$$I_{S_1} = C_1 V_{R_1} + D_1 I_{R_1} = C_1 V_R + D_1 I_{R_1} \quad \text{— (3)}$$

$$I_{S_2} = C_2 V_{R_2} + D_2 I_{R_2} = C_2 V_R + D_2 I_{R_2} \quad \text{— (4)}$$

equating eqn (1) and (2)

$$A_1 V_R + B_1 I_{R_1} = A_2 V_R + B_2 I_{R_2}$$

$$\Rightarrow \quad B_1 I_{R_1} - B_2 I_{R_2} = V_R (A_2 - A_1)$$

$$\boxed{I_{R_1} = \frac{(A_2 - A_1) V_R + B_2 I_R}{B_1 + B_2}} \quad \text{- - - (5)}$$

Substituting eqn (5) in (1)

$$V_S = \cancel{A_1 V_R}\; A_1 V_R + B_1 \left\{ \frac{(A_2 - A_1) V_R + B_2 I_R}{B_1 + B_2} \right\}$$