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-: HAND WRITTEN NOTES:-

OF

ELECTRICAL ENGINEERING

-: SUBJECT:-

POWER SYSTEM - I

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

→ Section 4: (Most Imp)

- Per unit System Analysis.
- Concept of symmetrical components in power system.
- Evaluation 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

#

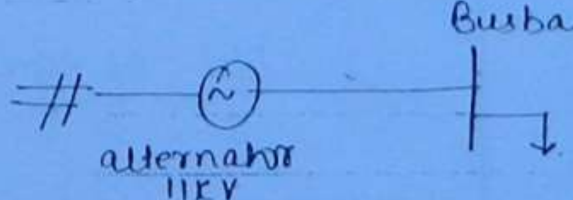
→ The performance of a power system network consisting of several power system equipments like: a

* 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.

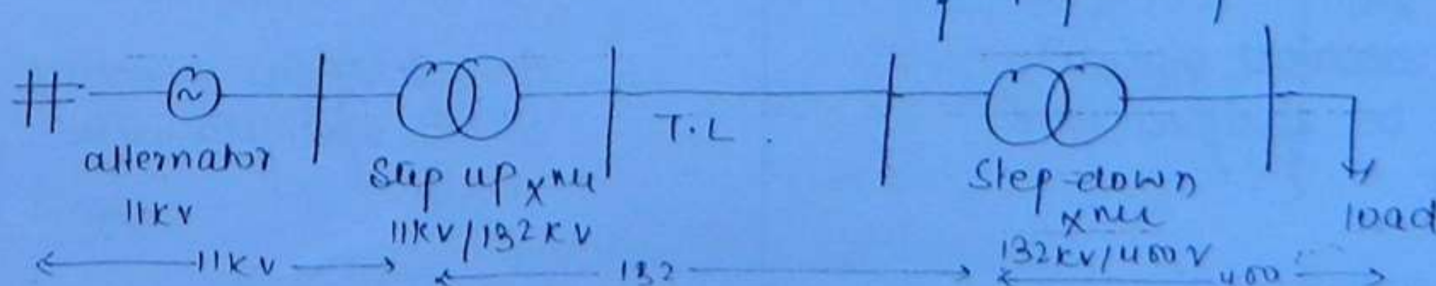
→ Before 1980 the performance of a power system network is obtained by using ABSOLUTE SYSTEM.

#- 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	=	$\dfrac{\text{Actual value of an electrical quantity exp in c}}{\text{Base value of same electrical quantity expd in on}}$

→ 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	$PU_3 = 135/100 = 1.35$	$PU_3 = \infty$	

As resistance is negligible to reactance 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 resistance 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 :-

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

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

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

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 $\qquad$ $\downarrow$ 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
$KV_{old} = 11K$	$KV_{new} = 13.2KV$

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

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

uestn:-

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

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

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

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

uestion:-

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

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

$$KV_b(new) = 2\,KV_b(old)$$

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

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

Question:

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

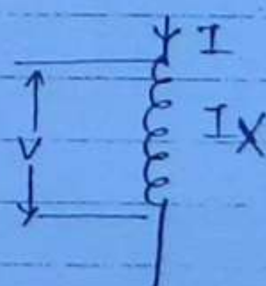
Default perunit

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

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

* 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:

$$\boxed{\left.\begin{aligned}\%X &= 100 \cdot X_{pu} \\ \%X &= 100 \cdot \frac{IX}{V}\end{aligned}\right\}} \quad -(6):$$

substitude (3) in equation (6).

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

$$\boxed{\%X_{\cancel{p}} = 100 \cdot X_{in\,\Omega}\left(\frac{MVA\ base}{KV_b^2}\right)} \quad -(7)$$

from equation (6).

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

now $$\boxed{X\ in\ \Omega = \frac{\%X}{100} \cdot \frac{V}{I}} \quad -(8).$$

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

$$X_b = V_b/I_b$$

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

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

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

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

* 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

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

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

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

* Short circuit current And short ckt MVA :

$$I_{sc} = \frac{V_{in\ volt}}{X_{in\ \Omega}}$$

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

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

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

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

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

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)

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

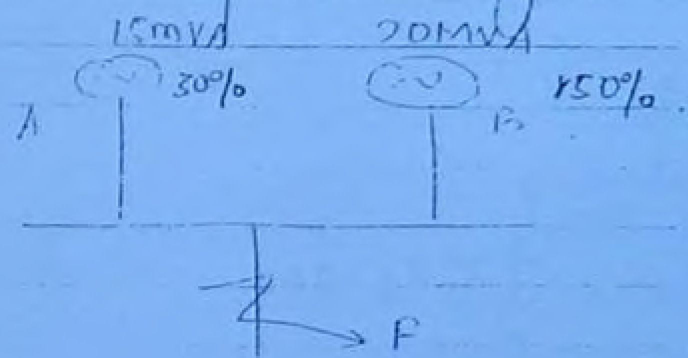
$$MVA_{sc} = \frac{100}{\% X} MVA$$

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

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

$$30\% \longrightarrow 15\text{MVA}$$

$$X_A\% \longrightarrow 35\text{ MAV}$$

∵ more value will be found as ∝ proptn

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

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

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

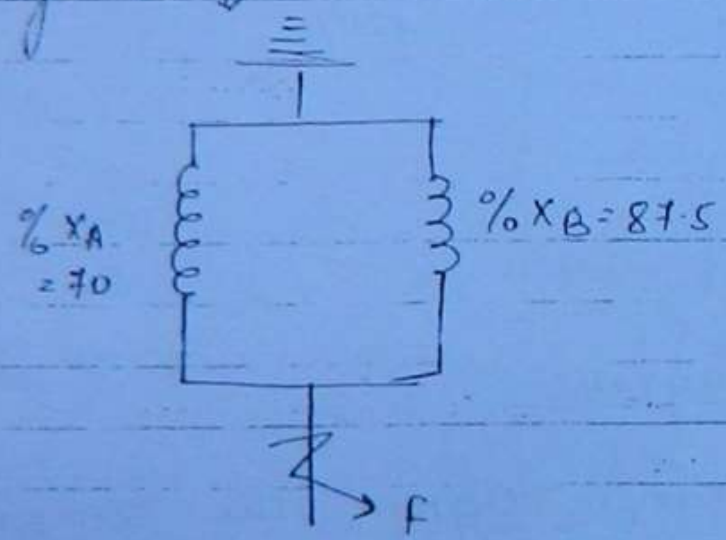
$\% X_B$ w.r.t Base 35 MVA

15% —— base 20 MVA

$$X_B\% = \frac{35 \times 15}{20_2}3 = 87.5\%$$

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

Reactance Diagram :

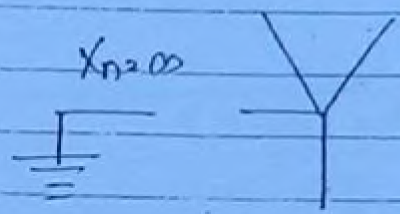


$$\% X = (\% X_A) \parallel (\% X_B)$$

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

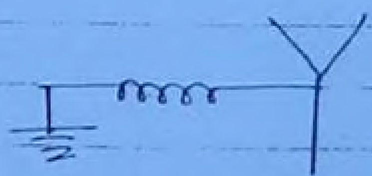
$$\boxed{X\% = 38.89\%}$$

* 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 :

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

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

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

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

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

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

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

Step 8: Short circuit current.

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

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

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

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

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

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

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

Full load current I :

I is calculated as

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

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

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

$$I_L = 1154.7 \text{ A}.$$

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

∴ 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 coz 98% of working is on T.L.

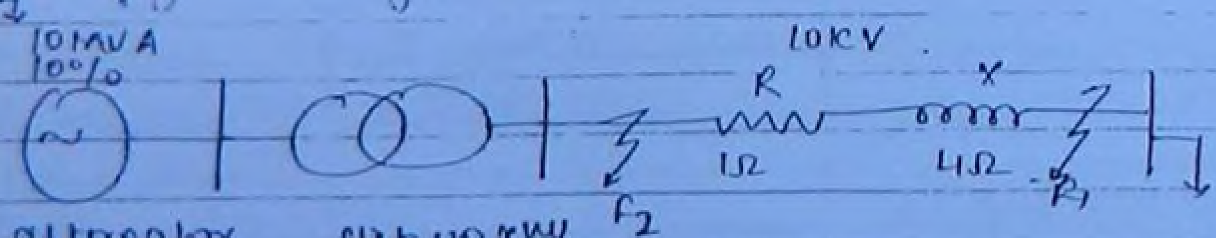
$$\boxed{X_{in\Omega} = 0.375\Omega}$$

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 bars 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 the % 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.

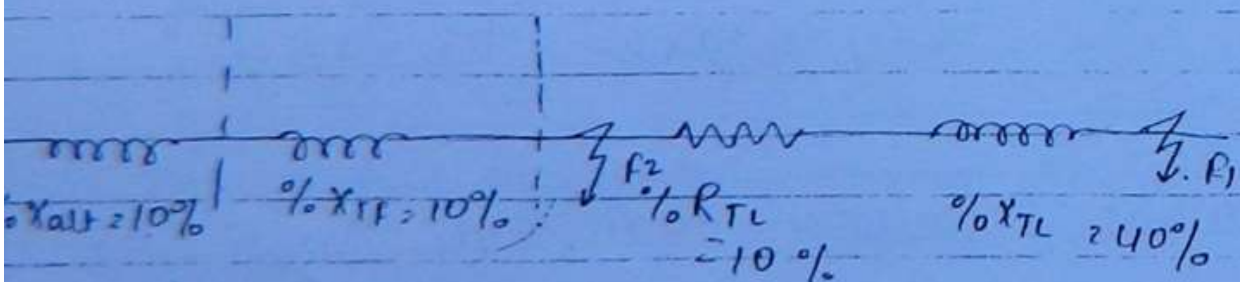
$$\%X_{TL} = \frac{\cancel{100} \times 4 \times 10}{\cancel{100}} = 40\%.$$

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

% 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.

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

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

$$\boxed{MVA_{SC_{F_1}} = 16.44 MVA}$$

Step 4: Short circuit MVA upto fault point F_2.

Total Reactance upto F_2

$$\%X_T = 20\%$$

$$\%R_T = 0$$

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

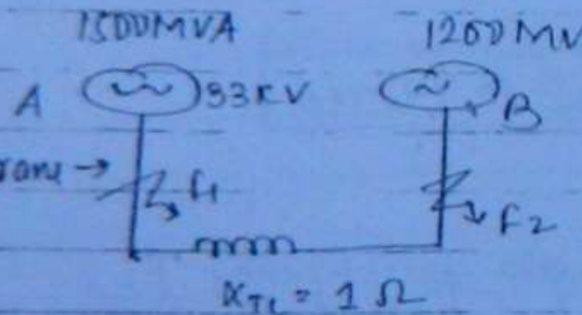
$$\boxed{MVA_{SC_{F_2}} = 50 MVA}$$

→ 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 1Ω 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$_B$

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

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

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

→ $\%X_{a\parallel B}$ @ w.r.t MVA_b :

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

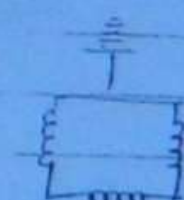
$$= \frac{100 \times 100}{1200} = 8.34\%$$

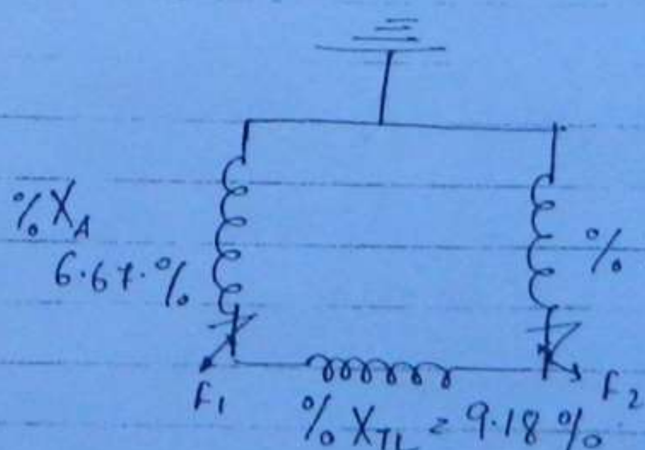
$$\boxed{\%X_{a\parallel B} = 8.34}$$

→ $\%X_{T.L}$ w.r.t MVA_b and KV_b.

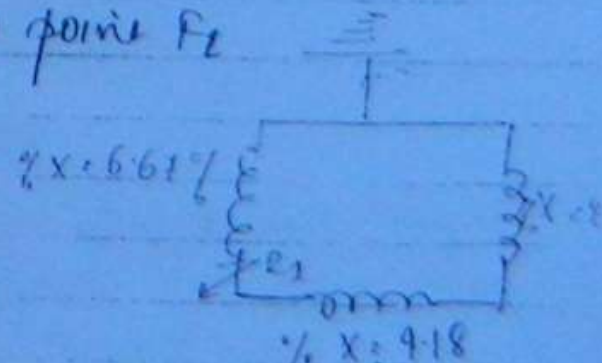
$$\Rightarrow 100 \times 1 \times \frac{100}{(33)^2} = 9.18\%$$

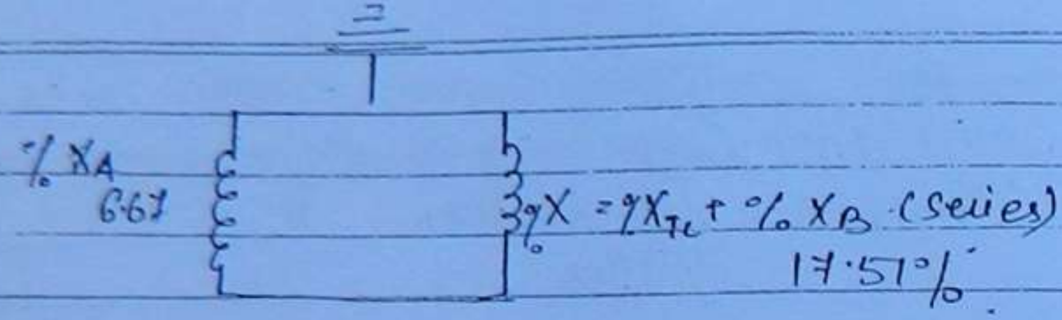
$$\boxed{\%X_{TL} = 9.18\%}$$





Step 3: Short circuit MVA upto fault point F_1





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

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

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

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

~~Step~~ → Total reactance upto fault F_2:

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

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

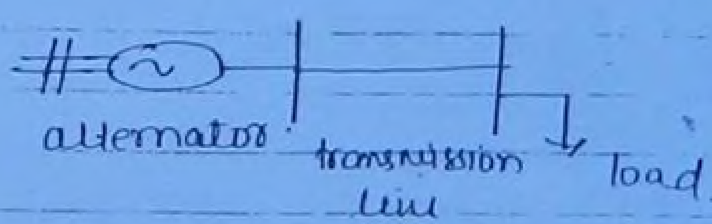
$$MVA_{sc} = \frac{100}{5.46} \times 100 = 1831.39 \text{ MVA}$$

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

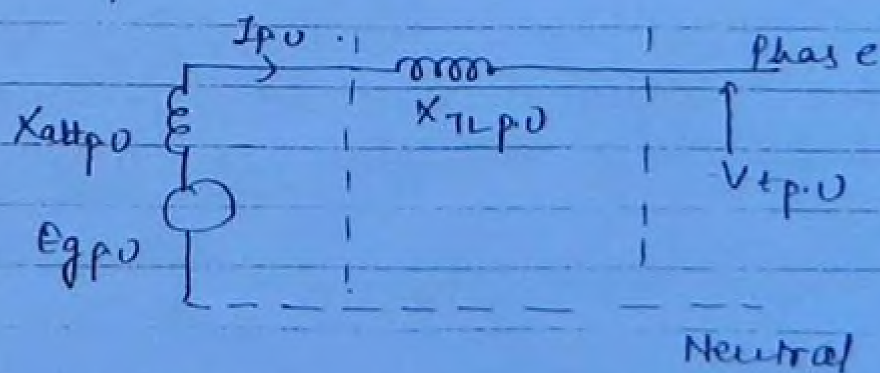
Symmetrical Components :-

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

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

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

* 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'

$$\underbrace{V_R}_{3\text{-unbalanced}} = \underbrace{V_{R0} + V_{R1} + V_{R2}}_{9\text{-balanced}}$$

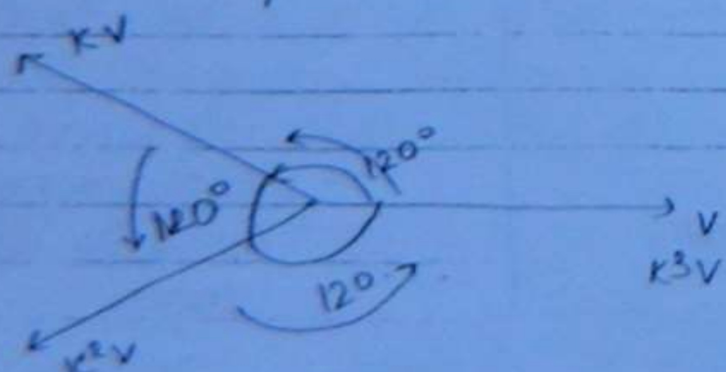
$$V_Y = V_{Y0} + V_{Y1} + V_{Y2}$$

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

→ 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.

As operator K rotates a vector in Anticlock wise direction, phase angle (+120°)

$$K = 1\angle +120$$
$$1\{\cos 120 + j\sin 120\}$$
$$1.\{-1/2 + j\tfrac{\sqrt{3}}{2}\}$$
$$\boxed{K = -0.5 + j\,0.867}$$

$$K^2 = K.K.$$
$$1\angle 120 . 1.\angle 120.$$
$$1\angle 240$$
$$1.\{\cos 240 + j\sin 240\}$$
$$= 1\{\tfrac{-1}{2} - j\tfrac{\sqrt{3}}{2}\}.$$
$$= \boxed{K^2 = -0.5 - j0.867}$$

$$K + K^2 = -0.5 + j0.867 - 0.5 - j0.867$$
$$= -1$$

$$\boxed{K + K^2 + 1 = 0.}$$
$$\downarrow$$
$$\Rightarrow \boxed{K + K^2 + K^3 = 0}$$

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).

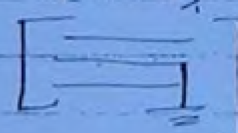
Fault Analysis

- 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 considered.

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 balanced condit^n.

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

B

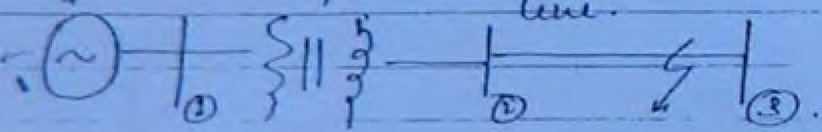
= R

* Single line diagram: the single line diagram representat^n of

* circuit Breaker rating should be high

power system indicates that original power 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 (3):-



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.

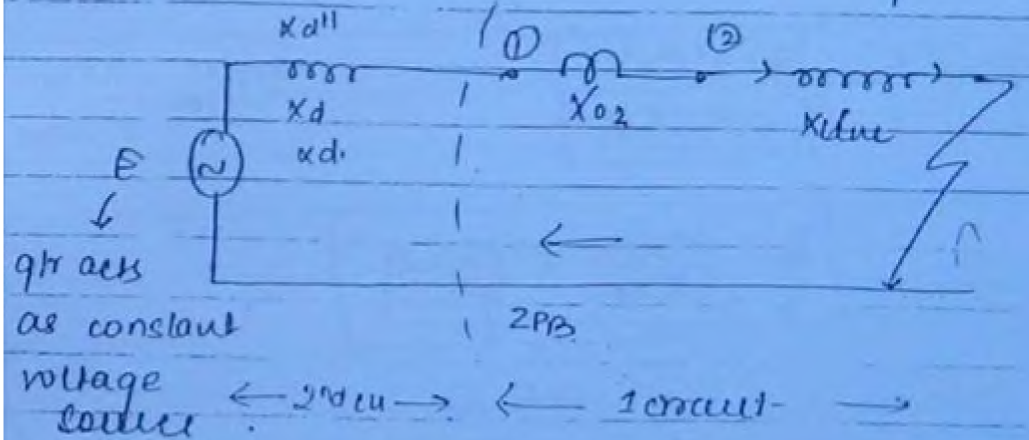
* Whenever fault occurs, the voltage of other phase decreases due to armature reaction (demagnetization - low magnetic field).

* Fault current is max^m in subtransient state as minimum reactance.

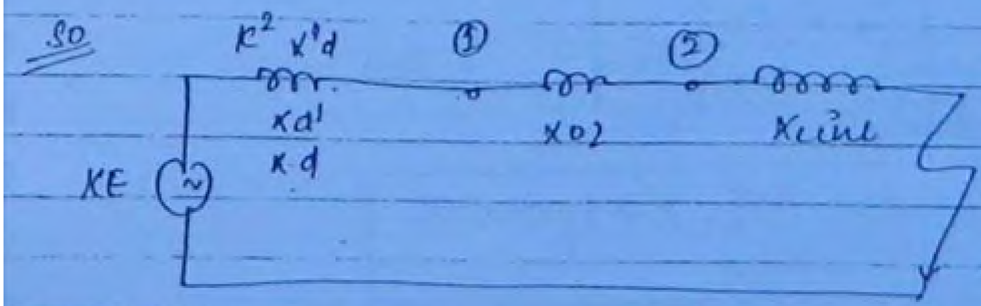
③ Effect of saliency (salient pole) is neglect ; the effect of non-uniform air of salient pole is neglected.

* During s.c the voltage is effected, frequency constant (Active powe not change where as reactive)!

* In load analysis the frequency prominently changes



→ Xmer can be represented as:
X_{01} (primary)
X_{02} (secondary)



converting gtr 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 - Xmer are represented as the series reactance and discontinuity is removed as the value of impende, 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) = $\boxed{I_b = \frac{KVA_b}{KV_b}}$.

$\frac{200}{100} = 2 \times 100$
$= 2000A$

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

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.

$$\boxed{Z_{b,1\phi} = \frac{KV_{b1\phi}^2}{MVA_{b1\phi}}}$$

$$\boxed{Z_{b,3\phi} = \frac{KV_{b,line}^2}{MVA_{b3\phi}}}$$

$$\Rightarrow \frac{(\sqrt{3} \times KV_{b1\phi})^2}{3 \times MVA_{b3\phi}} = \frac{K^2V_{b1\phi}}{MVA_{1\phi}}$$

$$\boxed{Z_{b3\phi} = Z_{b,1\phi}}$$

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

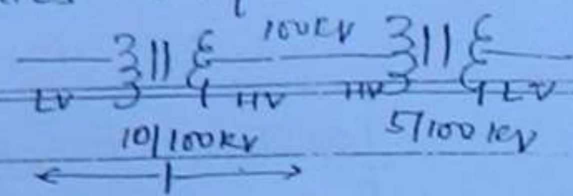
$$Z_{pu,old} = \frac{Z_{actual}}{Z_{b,old}} = \frac{Z_{actual}}{KV_b^2 old / MVA, old}$$

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

*

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

:→ If two xmer are connected in series no of base values 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 100 MVA, 10KV. Its pu impedence on 10 MVA, 100KV is ___

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

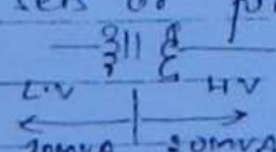
$$10 \times \frac{100}{10000} \times \frac{10}{100}$$

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

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.

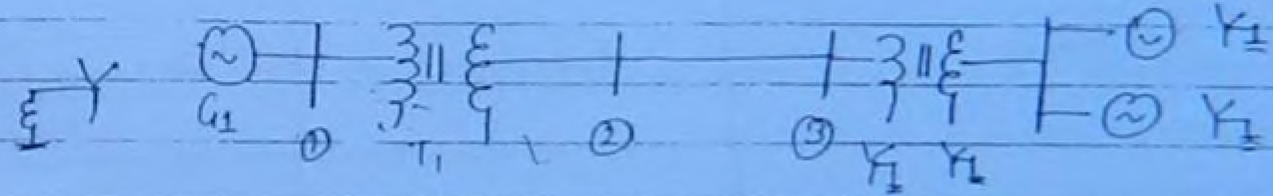
2) Common base power is selected for both sets or for entire n/w.



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 $X''_d = 0.56$

T1 = 15 MVA, 33/11 KV, $X = 15.2\ \Omega$ p.ph on HV

T2 = 15 MVA, 33/6.2 KV, $X = 16\ \Omega$/ph on HV side

T.L = 20.5 Ω/ph

Initial values (reactance)

	LV side of T1	HV side of T1 and T2	L.V side T2	
G1	1.6 pu on 30MVA, 10.5KV	—	—	
G2	—	—	1.2 pu on 15MVA, 6.6KV	
G3	$15.2 \times \frac{11}{33} = 1.69\ \Omega$	15.2 pu.	0.56 pu on 25MVA 6.6KV	
T1				
T2		16 Ω/ph	0.86 Ω/ph	0.56 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

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

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

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

Actual / Base.

G2:- 1.2 pu on 15MVA, 6.6 KV

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

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

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

G3:. 0.56 pu on 2.5 MVA 6.6 KV

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

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

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

T1:. 1.69 p.Ω w.r.t LV side
base impedence on LV side of T1 = 4.03 Ω

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

1.52 Ω/ph w.r.t HV side
base impedence. = 36.33 Ω ✓

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

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

T2

0.56 Ω/ph w.rt ~~1.28~~ LV side of T_2
base impedence on LV side of T_2 = 1.28 Ω

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

16Ω/ph w.r.t to H.V side of T2

Base value = 36.33 Ω

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

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

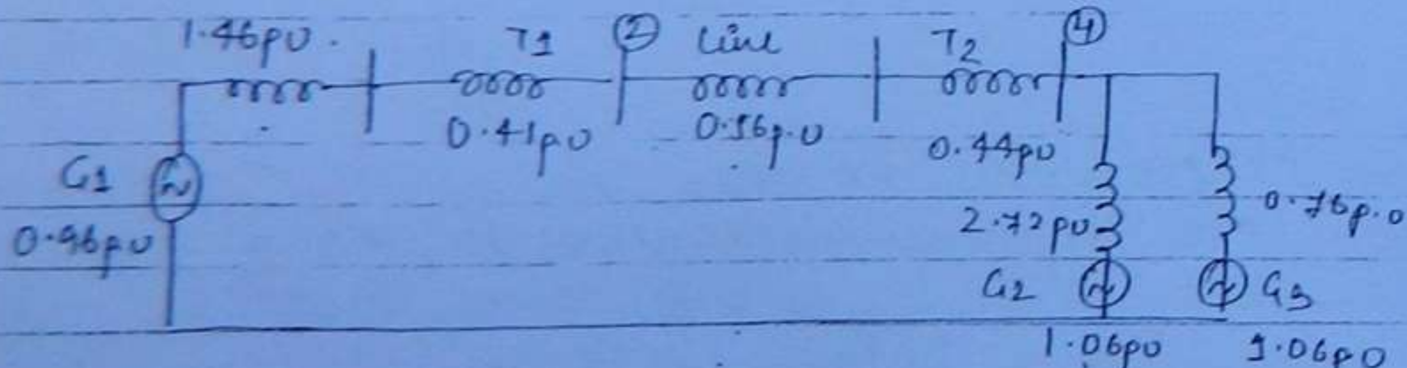
Line

$X_L = 20.5$ on HV side T2 and T1

base value = 36.33Ω

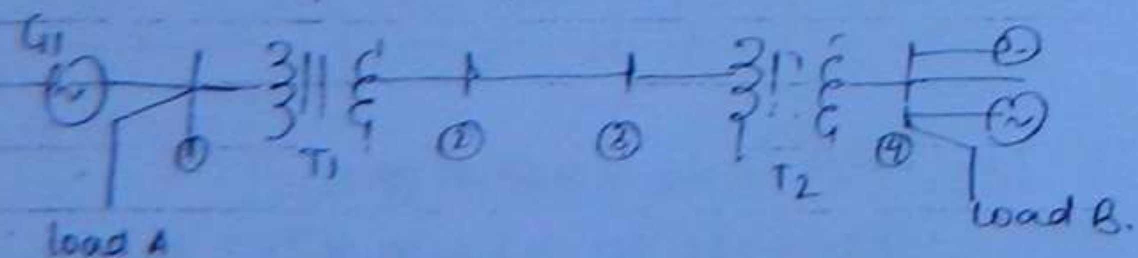
$$X_{line} = \frac{20.5}{36.33} = 0.56 \text{ p.u.}$$

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



Per unit reactance diagram.

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



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

load B 40MW 66kV, 0.5 pf lag.

represent them in reactance diagram

Solution:

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

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

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

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

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

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

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

Load B

$V = 40 \times \dfrac{11}{11} \times \dfrac{16}{62} = 1.06\ p.u.$

$\cos\phi = 0.5.$

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

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

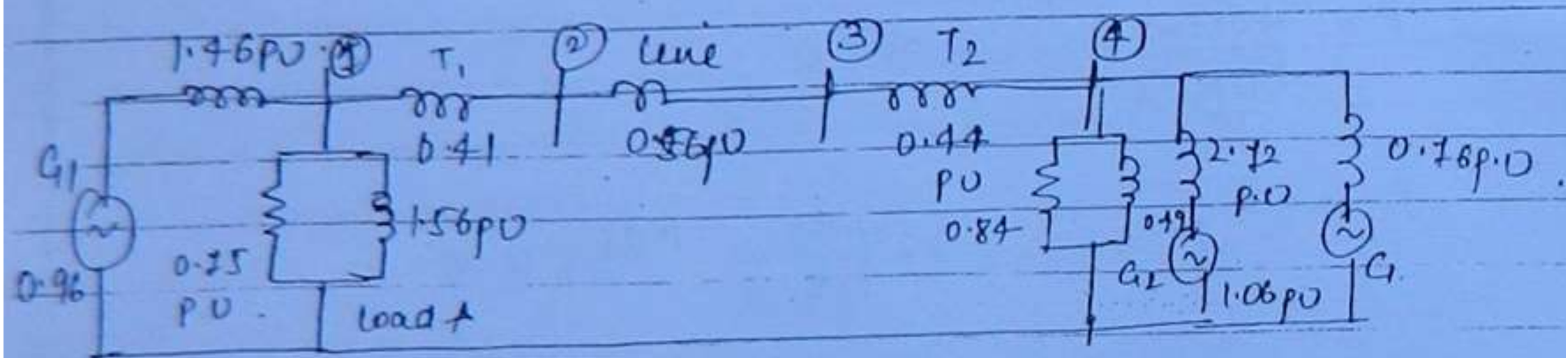
$Q = S\sin\phi = 2.28\ pu$

* load in S.C → constant impedance

load in stability → constant admittance.

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

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



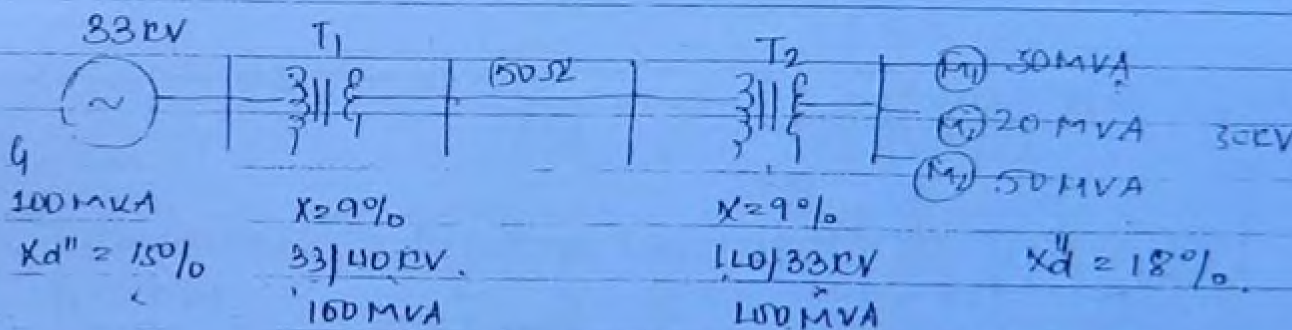
$X_{load A} = V^2/P = 1.06^2 / 1.33 = 0.84$ p.u

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

Date:
5-Sept 12

Example:-

A 100 MVA, 33kV 3-ϕ g/r has sub-transient 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/Fs 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 T1/T2 = 33kV
" " of HV side of T1 & T2 = 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

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

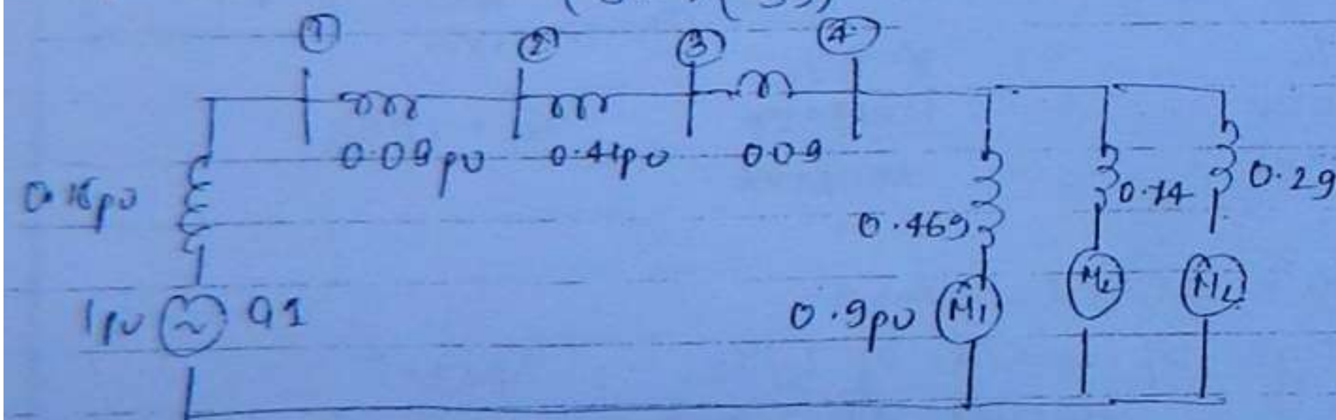
4) $X_{T_2} = 0.09\,p.u$

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

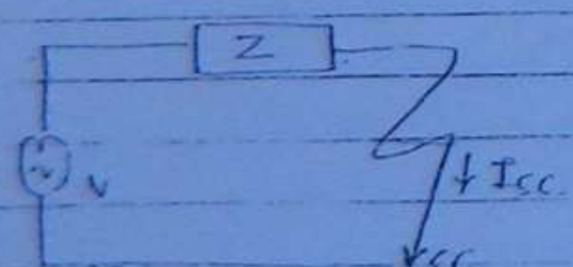
$$= 0.18\left(\frac{100}{500}\right)\left(\frac{30}{33}\right)^2 = 0.496\,p.u$$

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

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



Short circuit KVA:-



V = Rated voltage

I = Rated current

Z = internal impedance

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

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

$$Z_{base} = V/I$$

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

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

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

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

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

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

Procedure of short circuit calculation :-

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

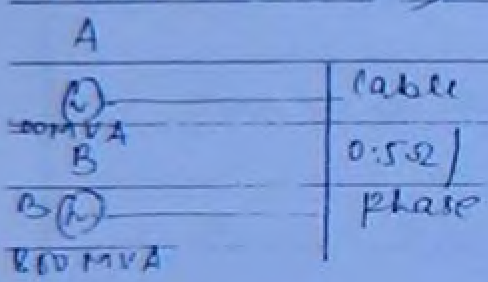
2) Identify the fault terminal. Across the fault terminals reduce the n/w into thevenins equivalent ckt

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 are 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

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

$$\%X_B = 150\%$$

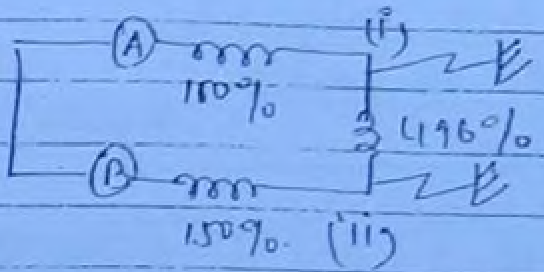
$$Z_{base} = \frac{KV_b^2}{MVA_b} = \frac{(11)^2}{1200} = 0.1008\Omega$$

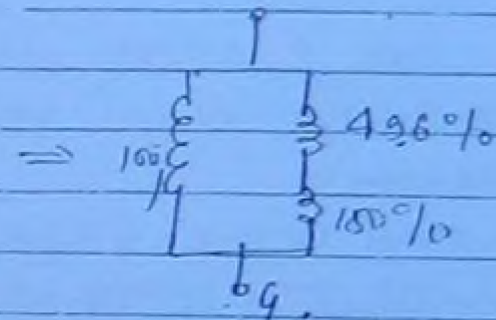
$$X_{cable} = \frac{0.5}{0.1008} = 4.96\ p.u.$$

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

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

and sectⁿ (B-ii).

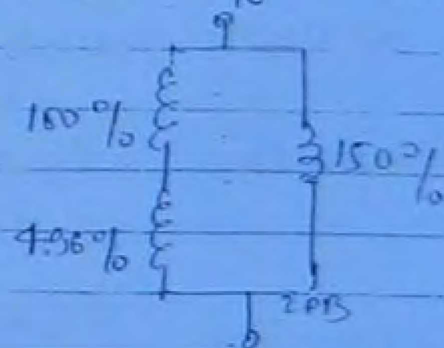




$\%Z_{th} = 86.59\%$.

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.

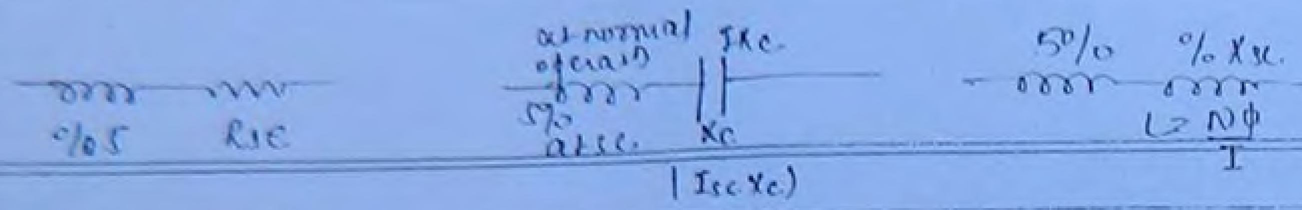
Questⁿ

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 —

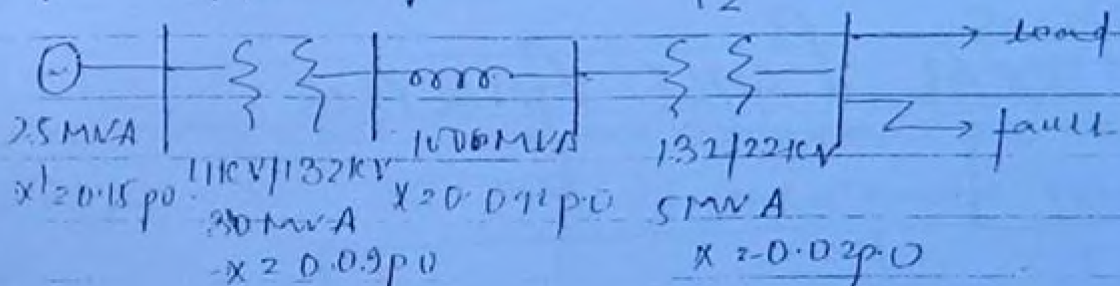
$$500 = \frac{150 \times 100}{5\% + X_{sc}\%}$$

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

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

Example:-

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



Let the common base MVA = 100 MVA

$$X_{G_1} = 0.15 \times \left(\frac{100}{25}\right)\left(\frac{11}{11}\right)^2 = 0.6 \text{ p.u}$$

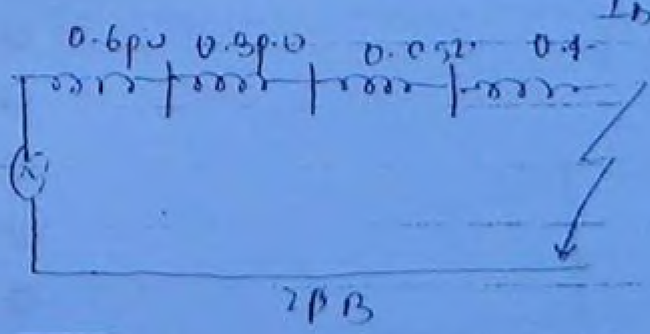
$$X_{T_1} = (0.09) \times \left(\frac{100}{30}\right) = 0.3 \text{ p.u}$$

$$X_{uni} = 0.092 \text{ p.u}$$

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

Base current on LV side of T_2 is

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



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

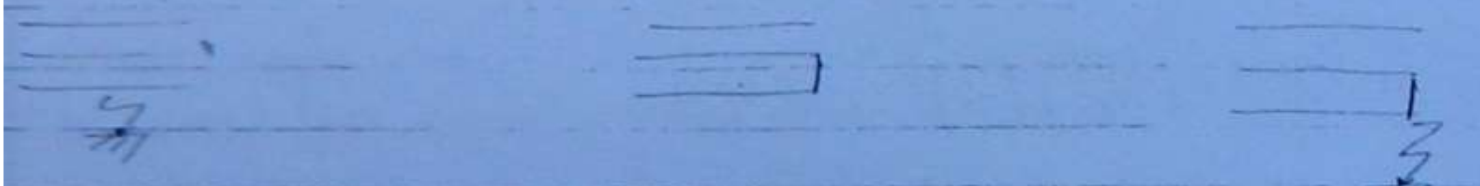
I_f (actual) = I_f(p.u) × I_f (base)

I_f (actual) = 0.718 × 26424.3 = 1884.27 Amp.

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

UNSYMMETRICAL FAULT ANALYSIS

LG Fault — LL Fault — LLG Fault

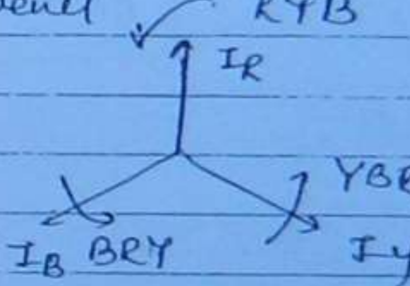


In symmetrical fault all the 3ϕ are at different condition
∴ By working on 1-ϕ base, we cann't claim that we have complete 3ϕ analysis

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

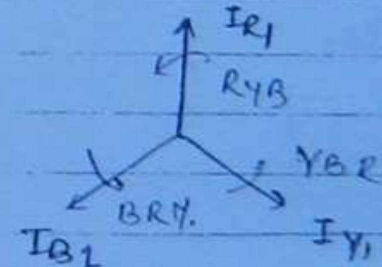
$$\begin{matrix} I_R = \\ I_Y = \\ I_B = \end{matrix} \begin{bmatrix} I_{R_1} \\ I_{Y_1} \\ I_{B_1} \end{bmatrix} + \begin{bmatrix} I_{R_2} \\ I_{Y_2} \\ I_{B_2} \end{bmatrix} + \begin{bmatrix} I_{R_0} \\ I_{Y_0} \\ I_{B_0} \end{bmatrix}$$

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

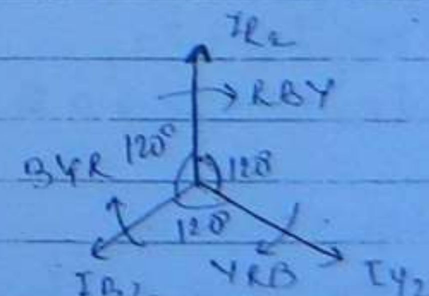


Sequence Components:

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

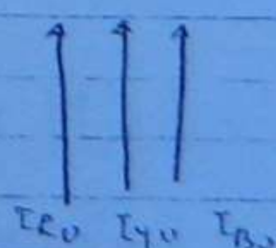


-ve sequence: these component have a sequence exactly opposite to that of original unbalance vector.



Zero Sequence —

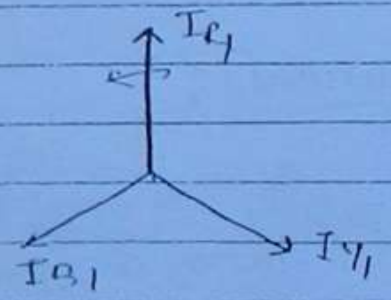
these components have no sequence. (equal magnitude)



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

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

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



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

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

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

$$\boxed{\begin{aligned} I_{R_2} &= I_{R_2}\angle 0^\circ \\ I_{Y_2} &= I_{R_2}\angle 120^\circ \\ &\quad a I_{R_2} \\ I_{B_2} &= I_{R_2}\angle 240^\circ \\ &\quad a^2 I_{R_2} \end{aligned}}$$

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

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

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

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

$$\boxed{\begin{aligned} [I]_{RYB} &= [A][I]_{012} \\ [V]_{RYB} &= [A][V]_{012} \end{aligned}}$$

Relation of operator 'a' →

('a') → also known as transformation

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

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

→ $a^3 = 1\angle 360^\circ = 1$

→ $a^4 = a^3 . a = a$

→ $a^5 = a^3 a^3 = a^2$

→ $1 + a^2 + a = 0$

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

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

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

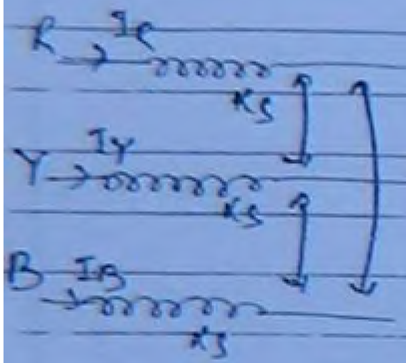
→ $[I]_{RYB} = [A][I]_{012}$

→ $[I]_{012} = [A^{-1}][I_{RYB}]$

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/Ws 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, -ve, zero sequence N/Ws are mutually disjoined.

Example:-

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

$X_0 = X_S + 2X_m$

$j0.6 + 2(j0.1)$

$= j0.8\ \Omega$

$X_1 = X_S - X_m$

$= j0.6 - j0.1$

$= j0.5\Omega$

$X_2 = X_S - X_m$

$= j0.6 - j0.1$

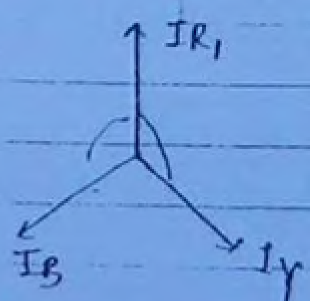
$= j0.5\Omega$

→ 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:-



$I_R = 10\angle 0°$

$I_Y = 10\angle 240° = a^2 10$

$I_B = 10\angle 120° = a 10$

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

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

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

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

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

→ 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 = $I_R = 10\angle 0°$ $I_Y = I_B = 0$

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

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

SEQUENCE IMPEDENDEES:

[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)

(salient P/r)

$$X_{a_1} \begin{cases} \rightarrow X_{a_1} = \dfrac{X_d'' + X_q''}{2}, \dfrac{X_d' + X_q'}{2}, \dfrac{X_d + X_q}{2} \\ \rightarrow X_{a_1} = X_d'', X_d', X_d. \end{cases}$$

(cylindrical r/r)

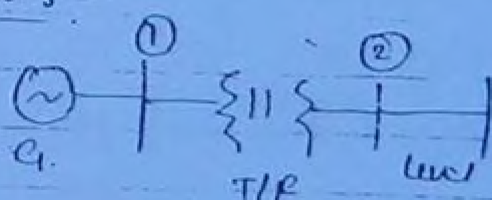
$$\boxed{X_{G_0} << X_{a_1}}$$

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

$$X_1 = X_2$$

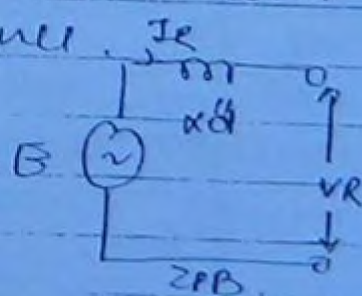
$$X_0 >> X_1$$

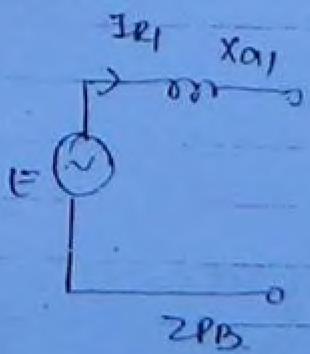
Sequence N/W :-



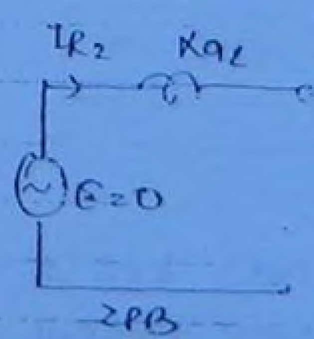
Generator Representation:

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

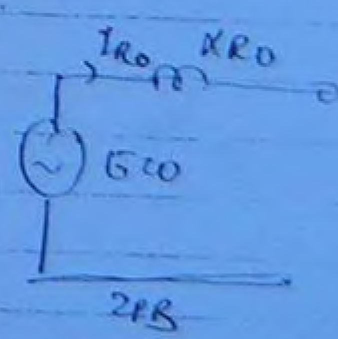




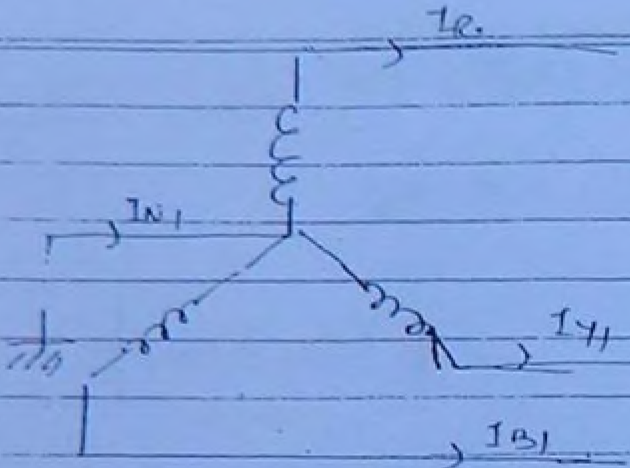
(positive)



(Negative)



(zero)



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

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

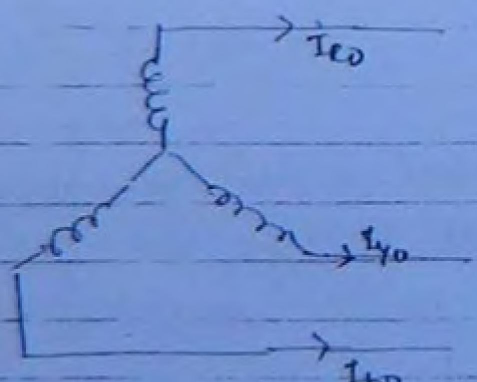
I_{n0} = sum of outgoing current = 0

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

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

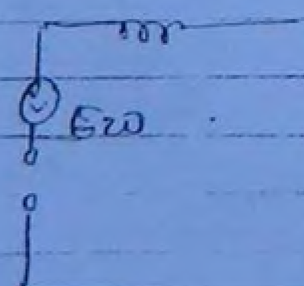
→ If neutral grounded with inductor then :-

1)

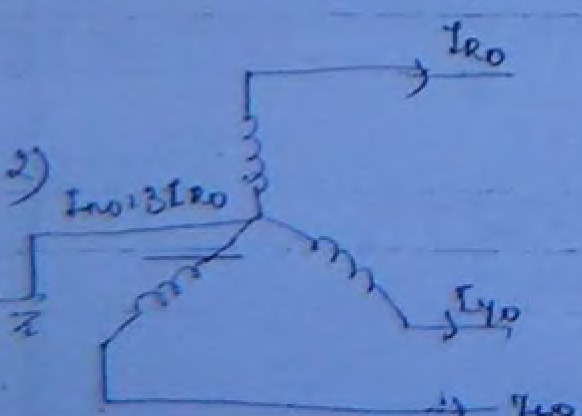


sum of incoming current to sum of out going current = $3I_{R0}$
KCL not satisfied.
So such current doesnot exist

∴ Open circuit



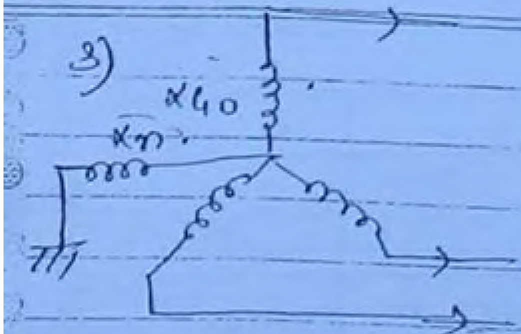
2)



Here KCL is satisfied so now current can flow

∴ 

3)



Now neutral is not ZPB

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

∴ unbalanced condⁿ.

$V_{R1} = 3 I_{R0} X_{n0} + I_{n0} X_{G0}$.

$$\boxed{X_0 = (x_{G0} + 3x_n)}$$

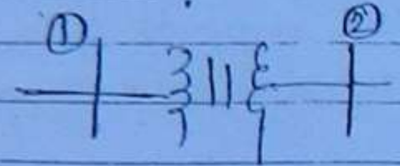
Notes

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.

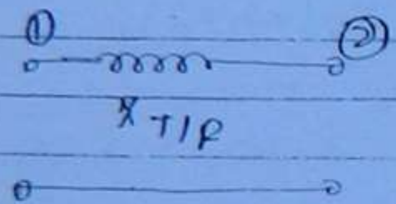
If the neutral is grounded with reactance x_n, $3x_n$ must be added to zero sequence reactance of g/r. x_{G0} to get total zero sequence reactance

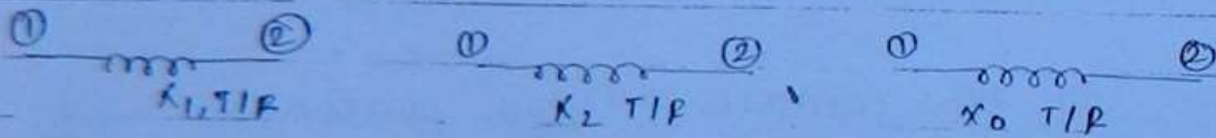
$$\boxed{X_0 = x_{G0} + 3x_n}$$

Transformer Representatⁿ :



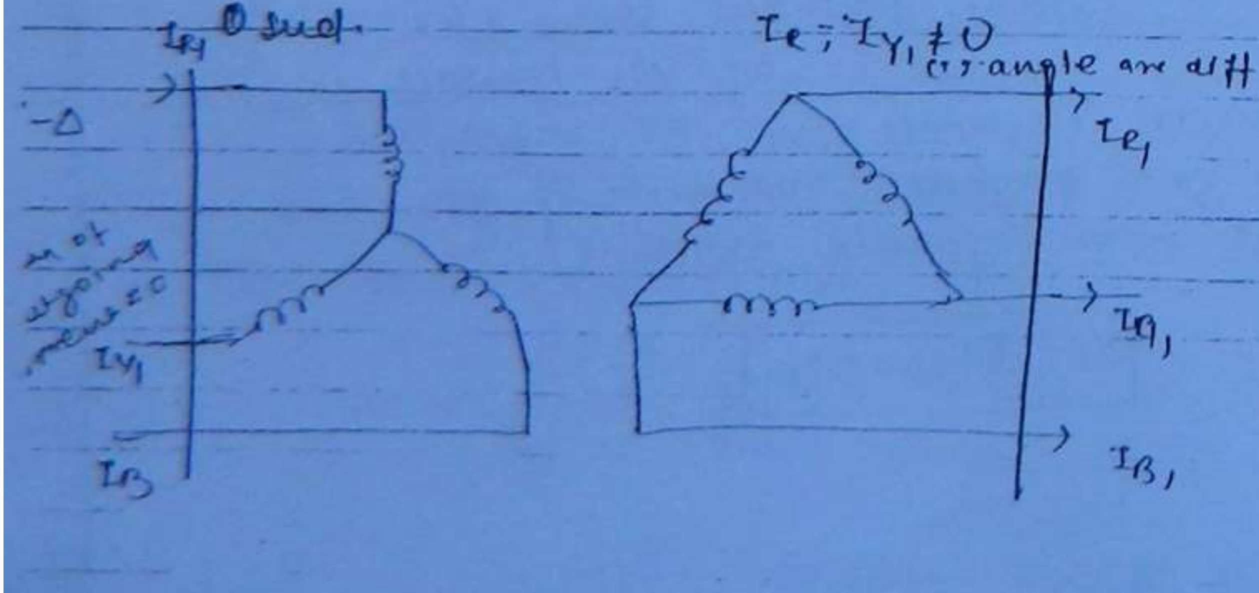
→ In original n/w T/F is shown as series reactance.





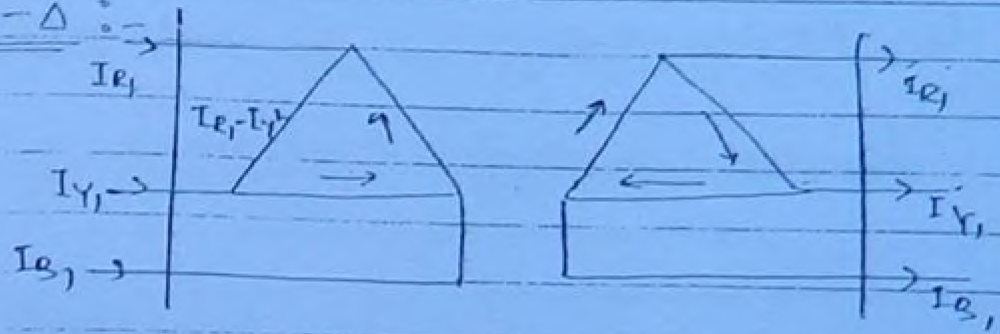
ZPB	ZPB	ZPB
positive seq	Negative seq	Zero seq.

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



∵ type of windg has no balance of T/F

Δ - Δ :-



Condition:

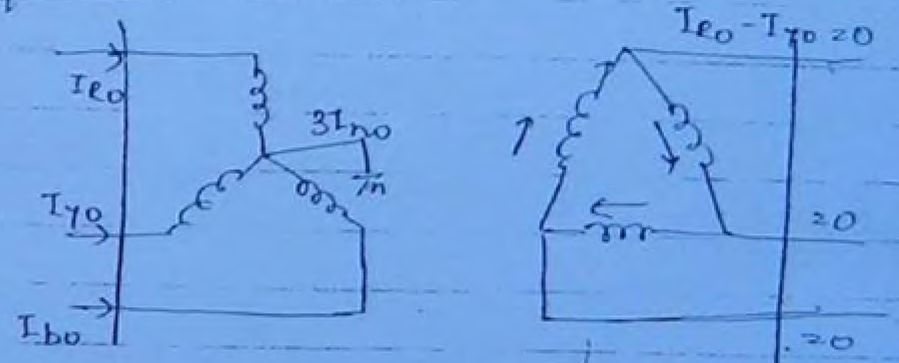
xmer has no effect of type of n/w whether Y or Δ no effect due to neutral ground

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

∴ Mag is same but phase angle = 120°

Zero sequence:

1) Y - Δ

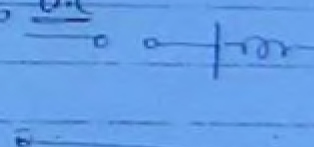


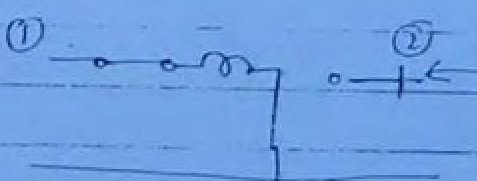
KCL is not satisfied

∴ incoming = $3I_R$

outgoing = 0

∴ O.C

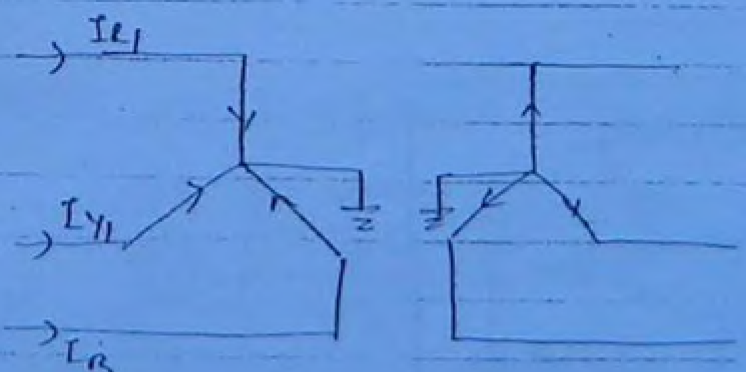




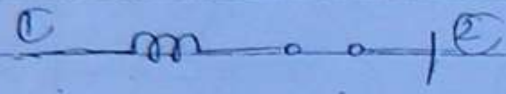
→ If star point is grounded then KCL is satisfied

SC

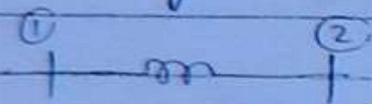
2) Y - Y



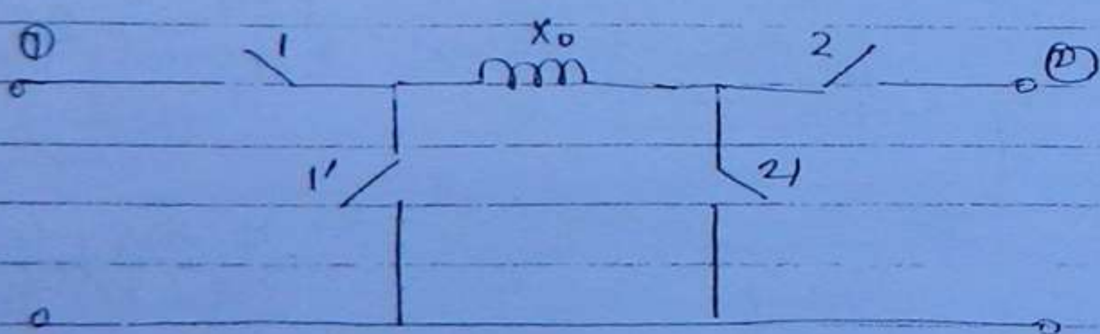
→ If secondary is ungrounded.



→ If it is grounded.



SWITCH DIAGRAM:

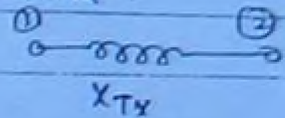


*

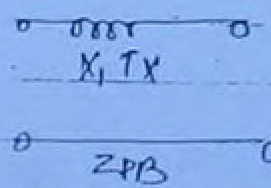
1, 1' →	Primary
2, 2' →	Secondary
1, 2 →	Series switches
1', 2' →	Shunt switches

Representatⁿ of Transmission Line :-

In symmetrical fault represented as series reactance.

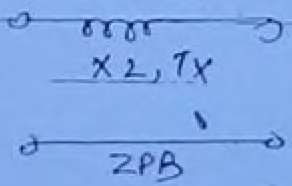


1. +ve sequence

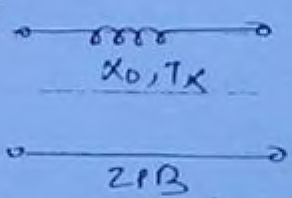


→ No conditⁿ for T.L

2. -ve sequence



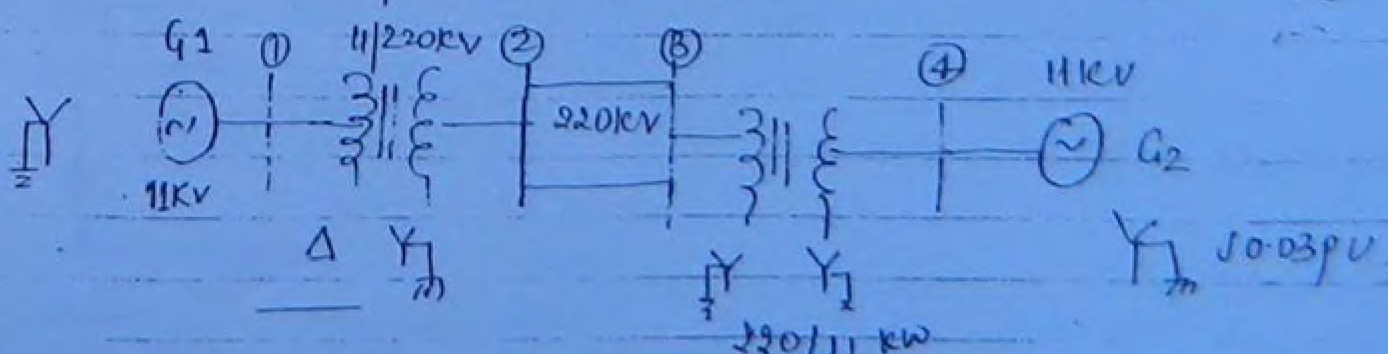
3. Zero sequence



* 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



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

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

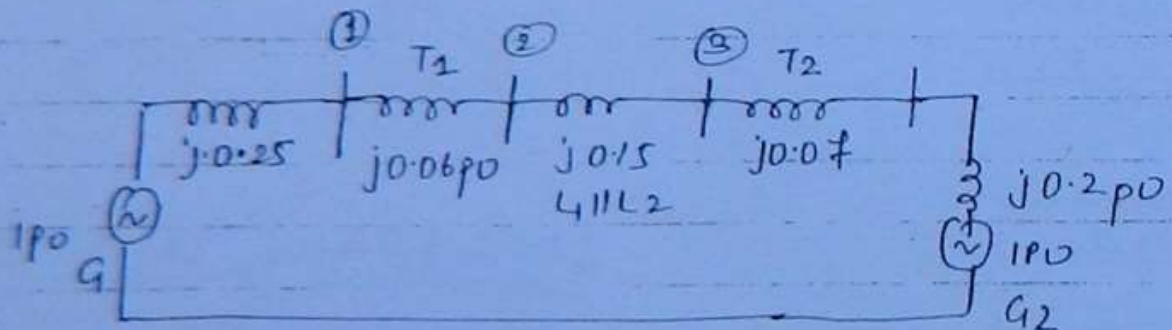
$T_1 \rightarrow X_1 = X_2 = X_0 = j0.06$ p.u.

$T_2 \rightarrow X_1 = X_2 = X_2 = j0.07$ pu

$L_1, L_2 \rightarrow X_1 = X_2 = X_0 = j0.3$.

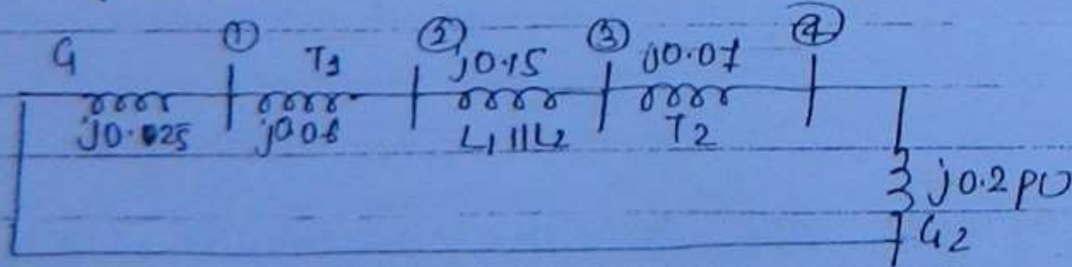
Common base MVA = 100.

Solution:

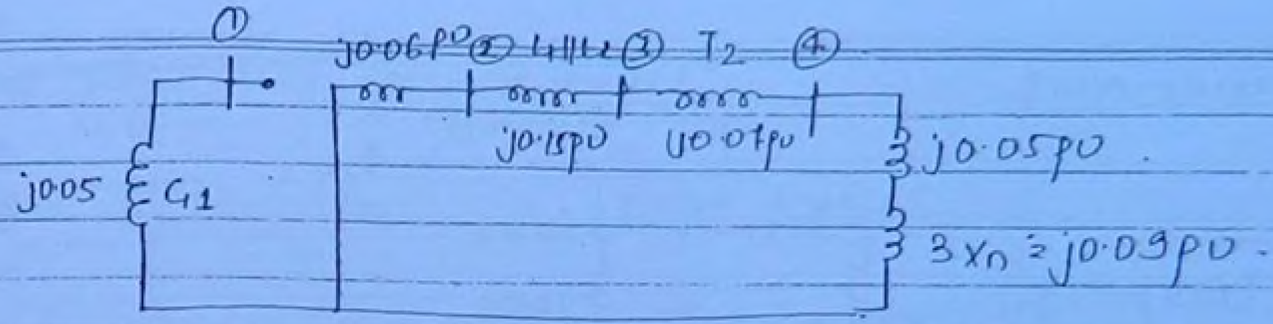


↳ Positive sequence N/W.

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



→ Zero sequence N/W:

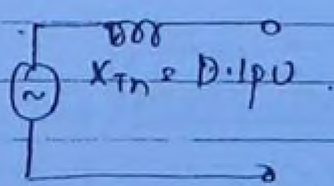


Part B

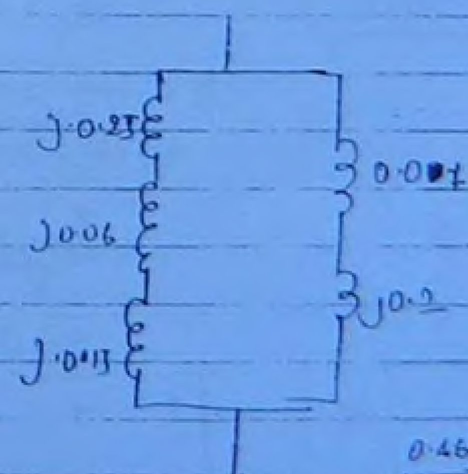
Let the fault is occured on bus 3, reduce the 3-sequence n/w into thevenin equivalent n/w.

∴ the voltage on both side is same so circulating current is zero, so drop is also zero, so the same voltage 1pu appeals across bus 2 (parallel).

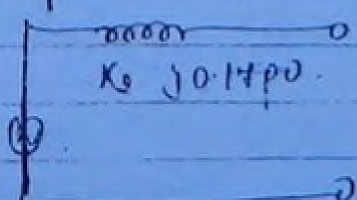
Thevenin's ~~equa~~ equivalent V_{th} = 1pu ; X_{Th} = j0.17pu.



Positive sequence.



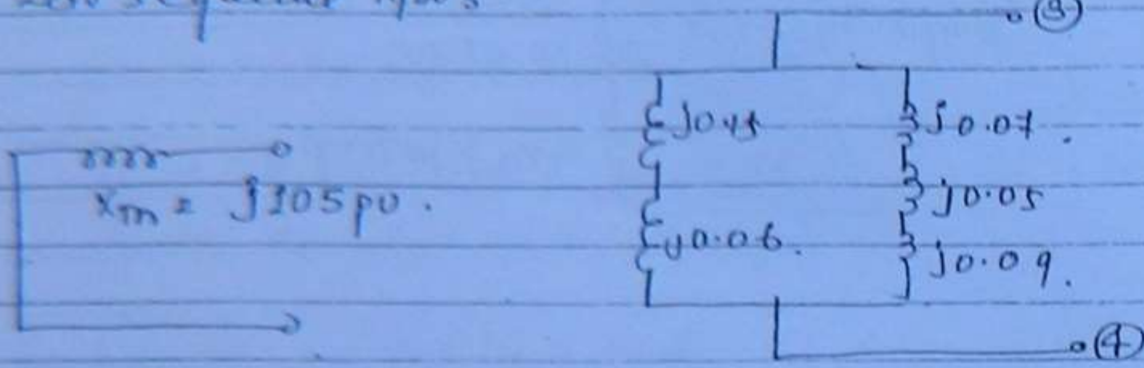
-ve sequence n/w same with no voltage



0.46j =
0.23j

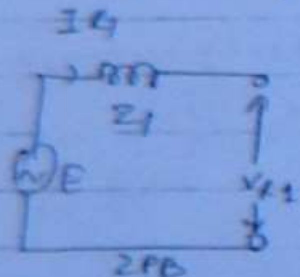
Zero sequence n/w flow 4m (G2)

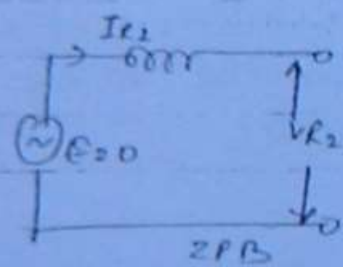
→ zero sequence n/w :-

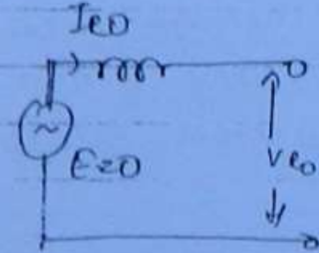


0.21P

Voltage Sequence :-







$\boxed{V_{R1} = E - I_{R1} Z_1}$

$V_{R2} = E - I_{R2} Z_2$

$\boxed{V_{R2} = -I_{R2} Z_2}$

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

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

positive S.　　Negative　　Zero

$$\begin{bmatrix} V_R \\ V_Y \\ V_B \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} V_{R0} \\ V_{R1} \\ V_{R2} \end{bmatrix}$$

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

Single line Ground fault:

R $\xrightarrow{I_R = I_f}$ Z_f

Y

B

Befor fault:-

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

During fault

$$\boxed{I_R = I_F}$$

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

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

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

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

→ 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.

$$\Rightarrow E - I_{a_1} Z_1 - I_{R_1} Z_2 - I_{R_1} Z_0 = 3 I_{R_1} Z_f$$

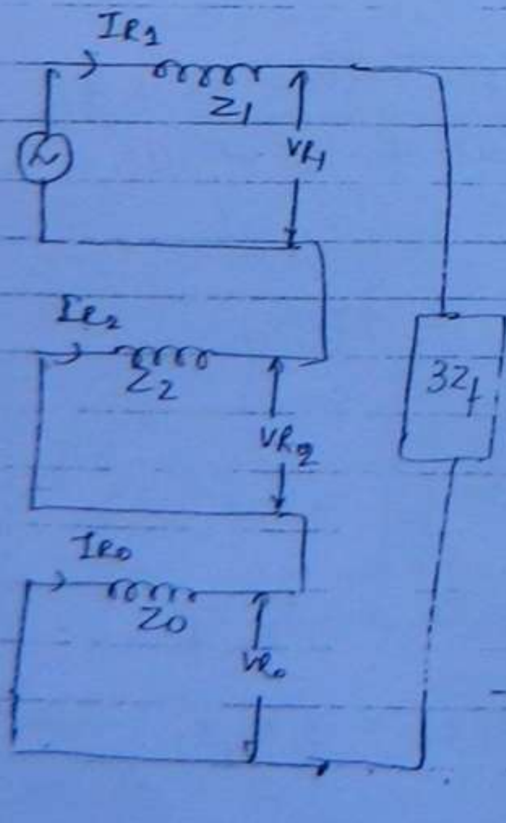
$$\boxed{I_R = \frac{E}{Z_1 + Z_2 + Z_0 + 3Z_f} = I_{R2} = I_{R0}} \rightarrow (2)$$

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

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

Objective:-

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



→ for LG fault.

→ Zero sequence is possible with Grounding only

§ Comments

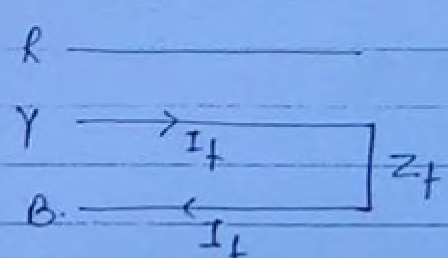
For LG fault :-

→ All sequence n/w are connected in series

→ All sequence currents are equal.

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

Line to line fault :-

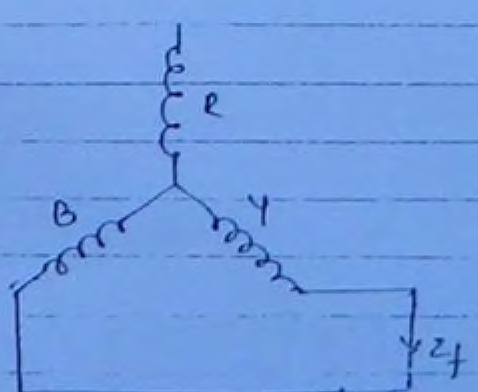


Before fault

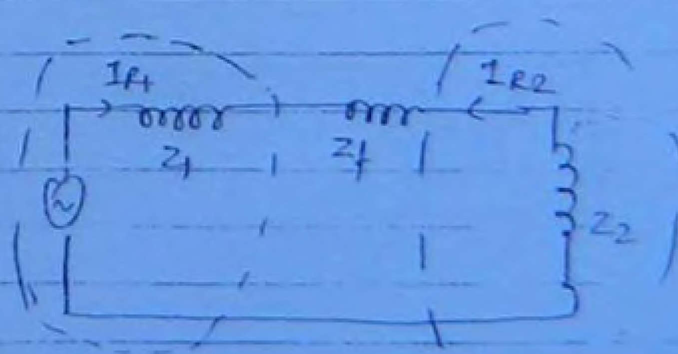
$I_R = I_Y = I_B = 0$

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.
$a^2 - a$

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

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

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

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

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

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

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

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

Comments:

For line to line fault :-

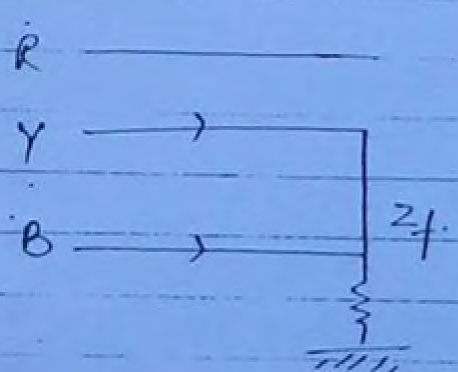
→ Positive and negative sequence n/w are connected in series opposition.

→ $\boxed{I_{R_1} = -I_{R_2}}$ and $\boxed{I_R = 0}$

→ Magnitude of fault current is

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

Double line Ground fault:



Before fault

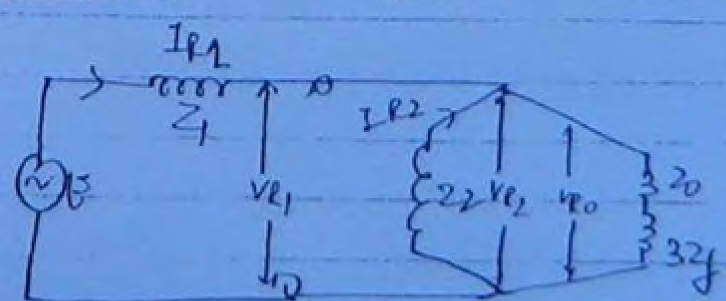
$I_R = I_B = I_Y = 0$

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

$$\rightarrow \boxed{V_{R_1} = V_{R_2} = V_{R_0}}$$

$$\boxed{I_{R_1} = -(I_{R_2} + I_{R_0}).} \rightarrow \text{objective}$$

Magnitude:

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

$$\boxed{I_{R_2} = -I_{R_1} \times \frac{Z_0 + 3Z_f}{Z_2 + Z_0 + 3Z_f}}$$

$$\boxed{I_{R_0} = -I_{R_1} \times \frac{Z_2}{Z_2 + Z_0 + 3Z_f}}$$

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.

$$I_R = 0$$

$$I_{R_1} + I_{R_2} + I_{R_0} = 0$$

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

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

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

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

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

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

Problems:-

In a balanced 3-ϕ s/m.

Comment:→

→ All sequence n/w are connected in parallel.

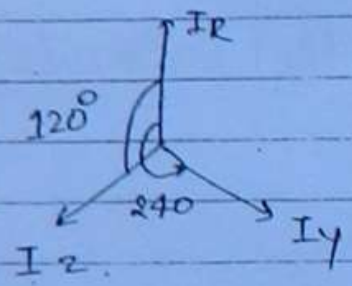
→ $V_{R1} = V_{R2} = V_{R0}$.

→ $I_{R1} = -(I_{R2} + I_{R0})$

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:



$I_R = 10\angle 0° = 10.$

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

$I_B = 10\angle 120° = a10$

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

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

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

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

Problem 2:

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

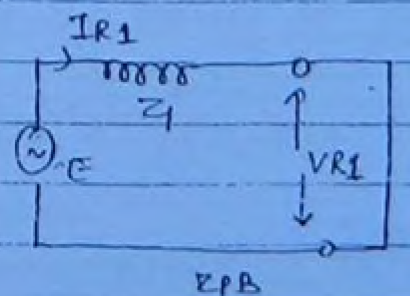
$I_Y = I_b = 0$; $I_R = 10$

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

$$I_{R0} = I_{R1} = I_{R2} = 10/3$$

* Under balanced condition we only have +ve sequence curr

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



$$\begin{bmatrix} I_R \\ I_Y \\ I_B \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix}\begin{bmatrix} 0 \\ I_{R1} \\ 0 \end{bmatrix}$$

$$\boxed{I_{f,3\phi} = I_{R1} = E/Z_1}$$

$I_R = I_{R1}$

$I_Y = a^2 I_{R1}$

$I_B = a I_{R1}$

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

not limited by impedance 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 +ve sequence voltage is zero.

Comparison:-

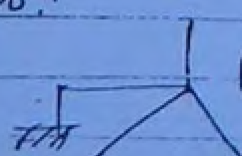
3-ϕ fault

Line to ground fault.

$I_{f\text{-}3\phi} = \frac{E}{Z_1}$; $Z_f = 0$

→ $I_{fLG} = \frac{3E}{Z_1+Z_2+Z_0}$

Case: 1 Solidly grounded alternator:



$\boxed{Z_n = 0}$

$Z_0 = Z_{a0} + 3Z_n$

$= Z_{a0}$.

∵ 4 alternal sequence current

$Z_2 \simeq Z_1$

$Z_0 >> Z_1$

$I_{f3\phi} = \frac{E}{Z_1}$ — ①

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

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

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

- For solidly grounded alternator LG fault is more severe.

Case 2: Alternator neutral grounded with the impedance Z

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

Z_0 depends on Z_n.

$$I_{f3\phi} = \frac{E}{Z_1} \qquad I_{fLG} = \frac{3E}{Z_1 + Z_2 + Z_{g0} + 3Z_n}$$

- Here severity of fault is decided by Z_n

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

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

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

*

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

If Z_n

$\rightarrow \; < \frac{1}{3}(Z_1 - Z_{g0})$; $I_f\,LG > I_f\,3\phi$

~~$I_f\,LG > I_f\,3\phi$~~

$\rightarrow \; = \frac{1}{3}(Z_1 - Z_0) \Rightarrow I_f\,LG = I_f\,3\phi$

$\rightarrow \; > \frac{1}{3}(Z_1 - Z_{g0}) \Rightarrow I_f\,3\phi > I_f\,LG$.

Objectives.

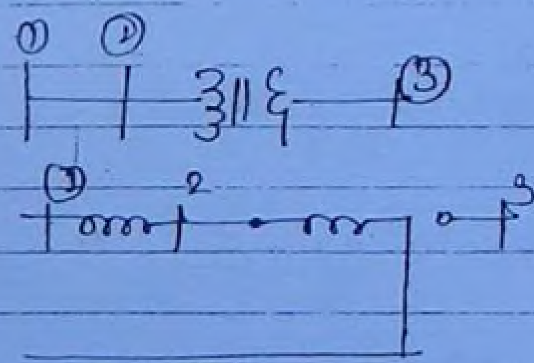
(1) zero sequence current can flow from a line into a xmer bank if the winding of xmer are.

a) Y – Δ

b) Δ – Y

c) Y – Y⏚

d) Δ – Δ.



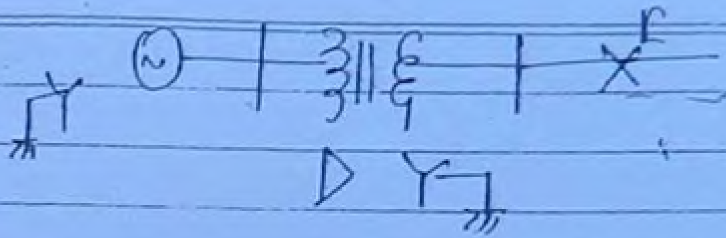
(2) for s/m shown in figure what is the L-G fault on ~~right~~ side of xmer equivalent to

a) L-G fault on G/r side of xmer

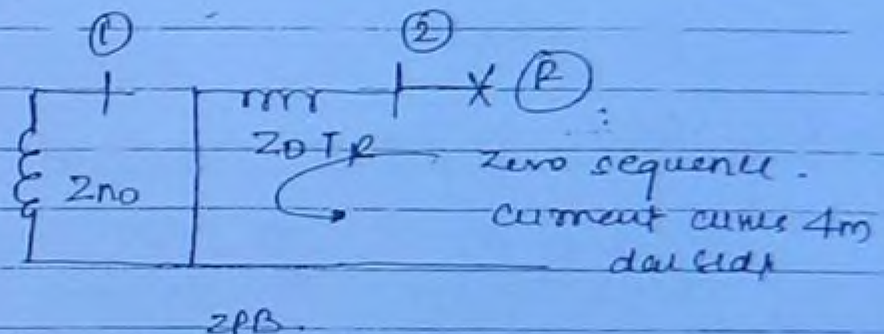
b) L-L fault on G/r of xmer

c) LLG fault on G/r side of xmer

d) 3φ fault on G/r xmer.



zero sequence diagram.



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, $Z_1 = Z_2 = Z_{1\&2}\ j0.1$ and $Z_0 = j0.05$ p.u for the alternator, then the required inductive reactance 4 nodal grounding is _

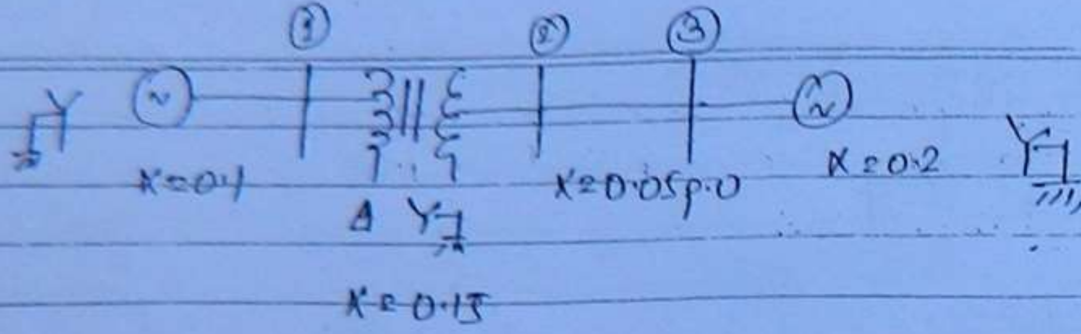
$$Z_n = \frac{1}{3}(Z_1 - Z_{G0})$$

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

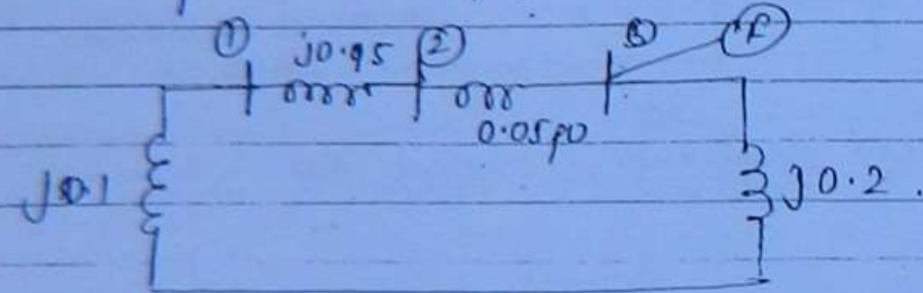
$$\Rightarrow 0.0166j$$

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



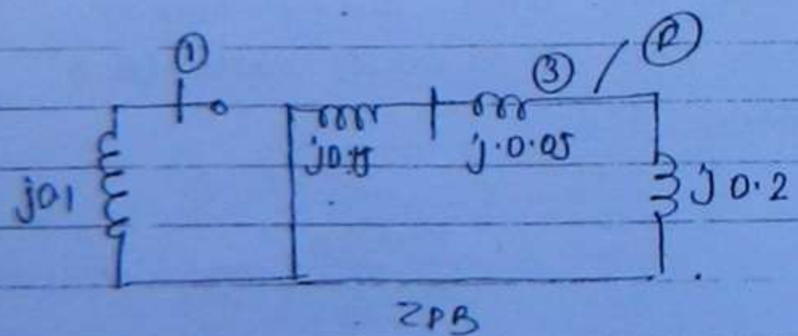
→ Reducing two sequence reactance :-



(+ve and -ve)

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

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



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

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

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

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 $3 - j\sqrt{3}$ $-3 + j\sqrt{3}$

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

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

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

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

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

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

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

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

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

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

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

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

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

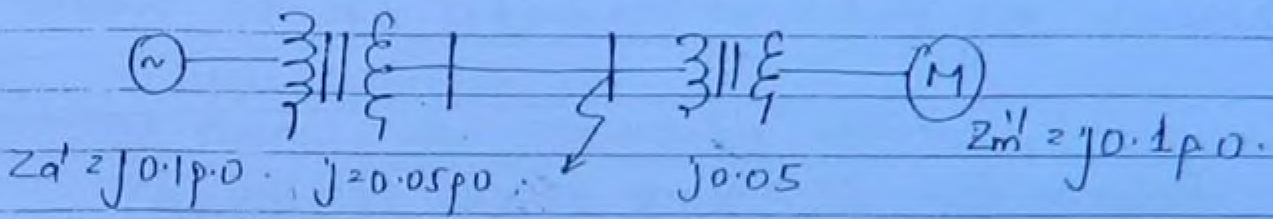
$\therefore$ $I_{fLG} = 6\,p.u$

Since MVA = 6pu.

Base MVA = 25MVA

Since MVA = $6 \times 25 = 150$ MVA.

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 ___



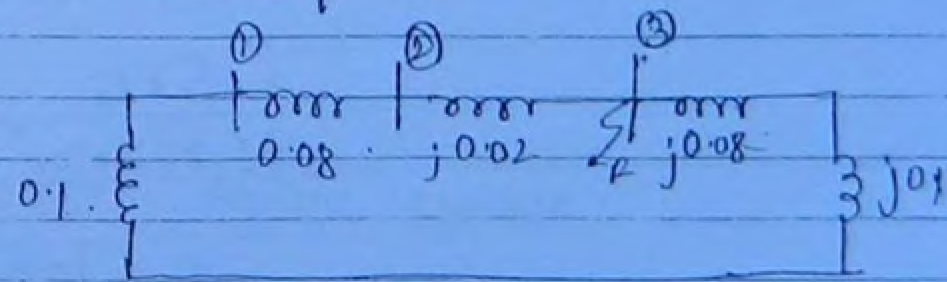
Hint:* $\frac{I}{I_{sc}} = Z_{p.u}$; I, I_{sc} – in p.u

$I = 1$ p.u.

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

Equivalent reactance diagram:

0.7°



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

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

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

$$= 16.137\Omega$$

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

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

$$Z_0 = 10.863\ \Omega$$

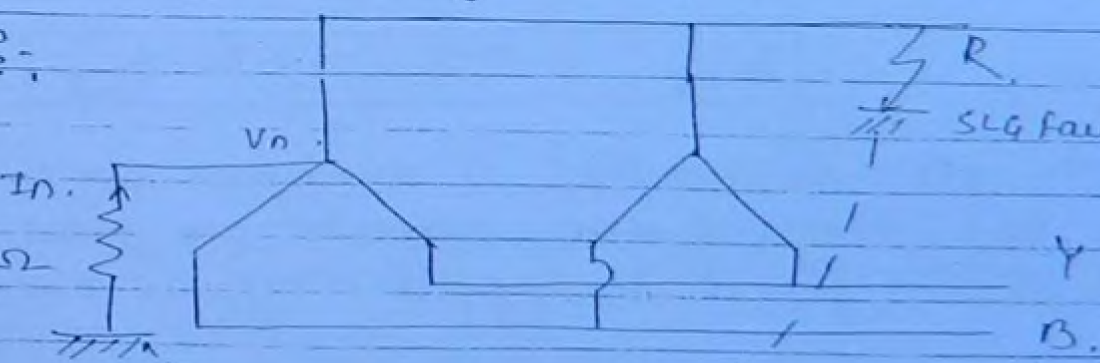
[redacted]

Example:-

Two 11 KV 20MVA, 3φ ; Y connected g/r operated in parallel. The positive, negative and zero sequence reaction 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 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 voltag

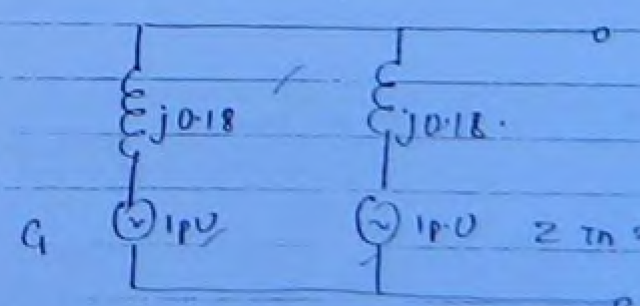
Solution:-



To find

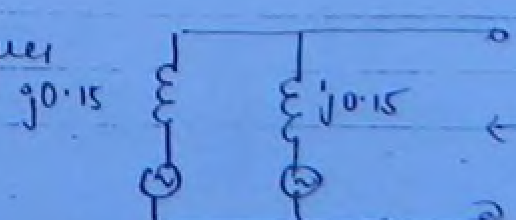
a) I_{FSLG}.
b) I_n
c) V_n

Sequence N/W :- Positive Sequence.

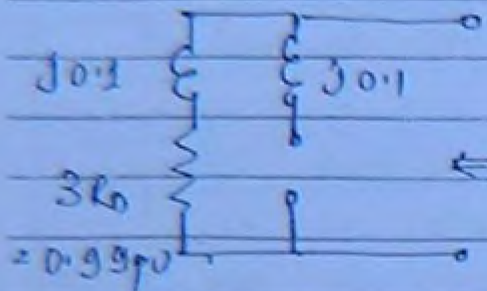


$Z_{Th} = 0.09 pu$

-ve the Sequence



$\leftarrow \; 0.75 = Z_{Th}$



$\leftarrow Z_{0,Th} = (0.99 + j0.11) pu$ Gt

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

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

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

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

Note:

a) Since g1r 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

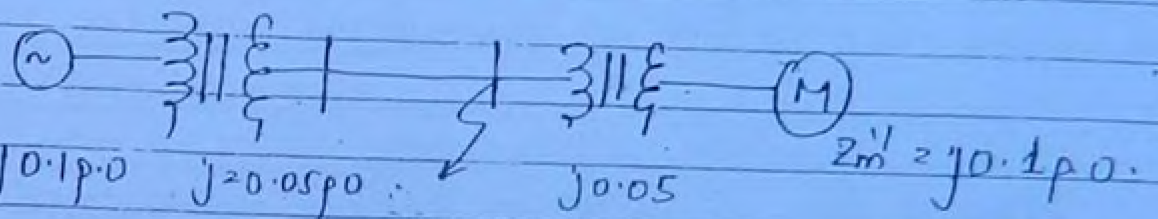
b) Current in grounding resistor is equal to fault current since ~~fault~~ R_L act as return path for fault current

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

$$V_L = 2.92 \times 0.33$$
$$= 0.9636 \ p.u$$

$$\text{Per phase voltage} = 0.9636 \times \frac{11 k}{\sqrt{3}} = 6.12 KV$$

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 HV side, the fault current will be ___

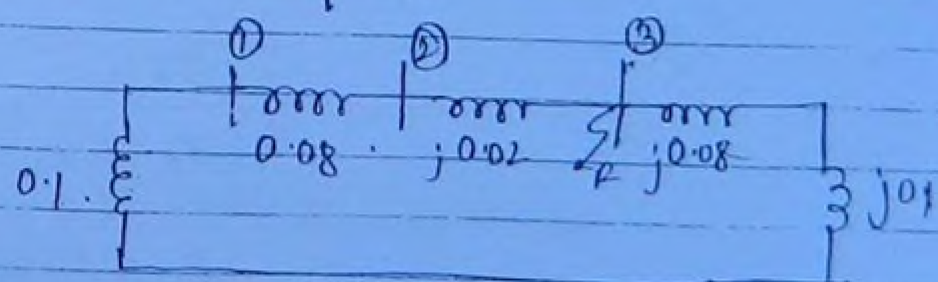


Hint:- $\frac{I}{I_{sc}} = Z_{p.u}$; I, I_{sc} – in pu

$$I = 1 \text{ pu}.$$

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

Equivalent reactance diagram:



0.7

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

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

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

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

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

$$= 16.137\,\Omega$$

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

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

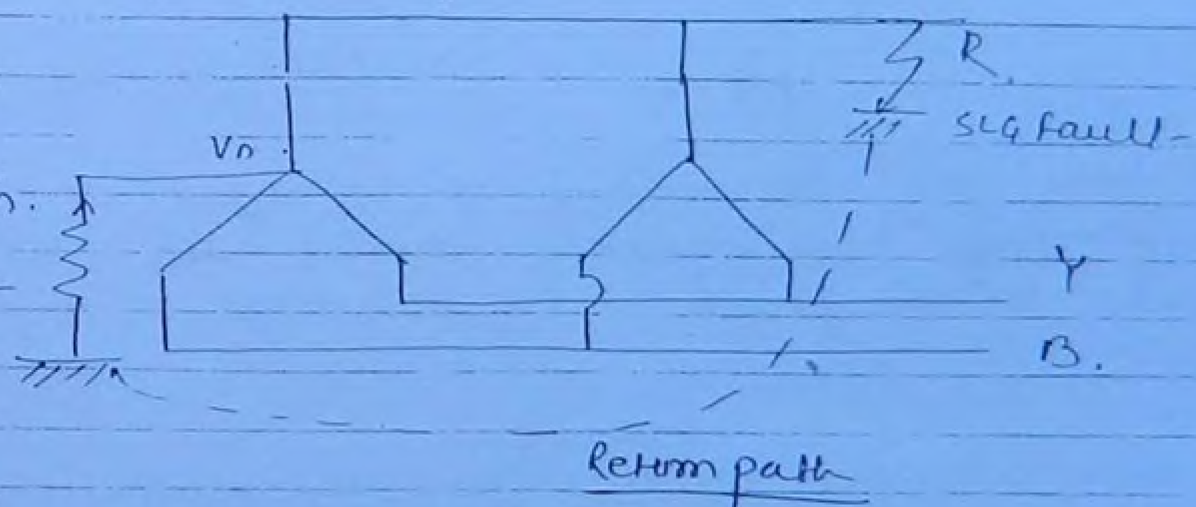
$$Z_0 = 10.863\,p.u$$

Example:- [redacted]

Two 11 kV 20 MVA, 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 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 accross grounding resistor (phase voltag

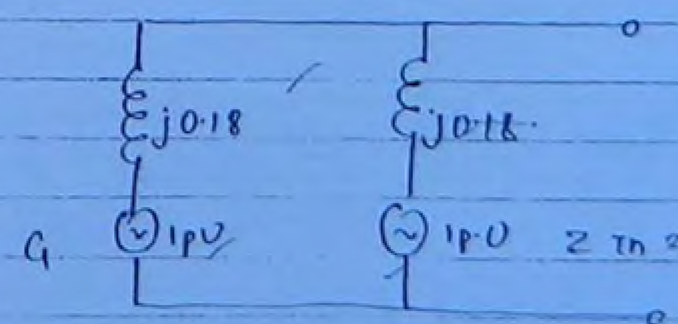
Solution:-



To find

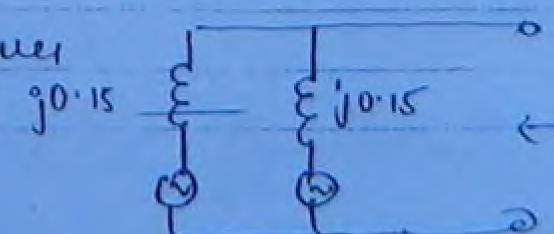
a) I_{FSLG}.
b) I_n
c) V_n

Sequence N/W :- Positive Sequence.

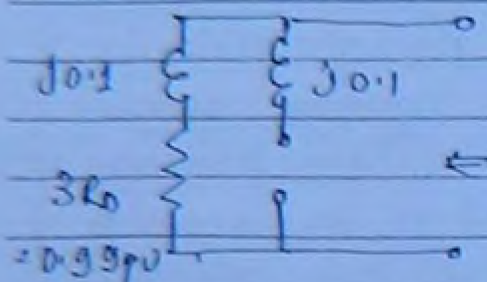


$Z_{th} = 0.09$ p.u

-ve Sequence



$\leftarrow = 0.075 = Z_{th}$



$\leftarrow Z_{0,in} = (0.33+j0.1)\,pu$

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

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

$I_{f\,SLG} = \frac{3E}{Z_1+Z_1+Z_0+3Z_f} = \frac{3\times 1}{j0.05+j0.05+(0.99+j0.1)}$

$$\boxed{I_{f\,LG} = 2.92\angle -14.98\ Amp.}$$

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 G1 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

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

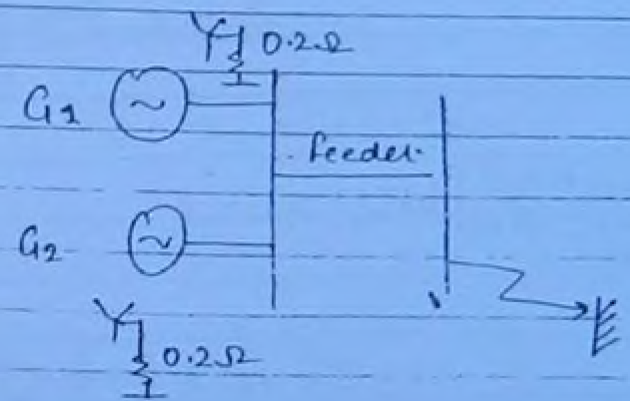
$V_L = 2.92 \times 0.33$
$= 0.3636\ p.u$

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

Problem:-

Two identical 11kV, 50MVA, 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 neutral 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 n/w~~: $Z_{base} = \frac{11kV^2}{50} = 2.42\Omega$

$G_1 \& G_2$

$x_1 = j0.68/2.42 = j0.28$ p.u $\qquad j0.68/2.42 = 0.28$

$x_2 = j0.4/2.42 = \cancel{j0.4}\ j0.16$ p.u

$x_0 = j0.2/2.42 = j0.08$ pu.

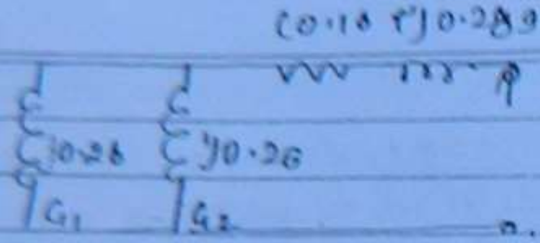
$R_n = j0.2/2.42 = j0.08$ p.u

Feeder

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

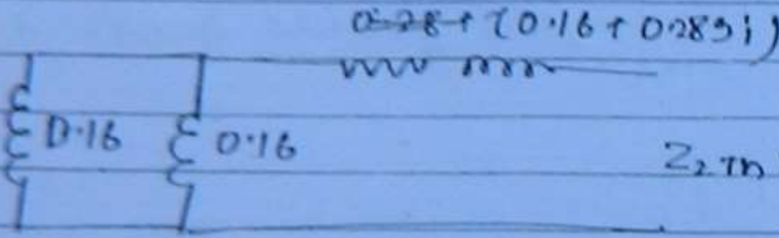
$Z_0 = (0.7 + j3\Omega)/2.42 = (0.28 + j1.239)$ p.u

+ve sequence



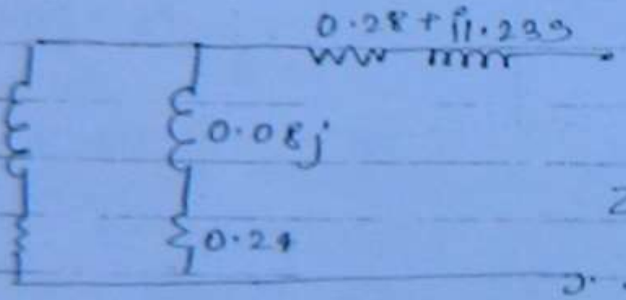
$Z = 0.16 + j\,0.419$ p.u.

-ve sequence



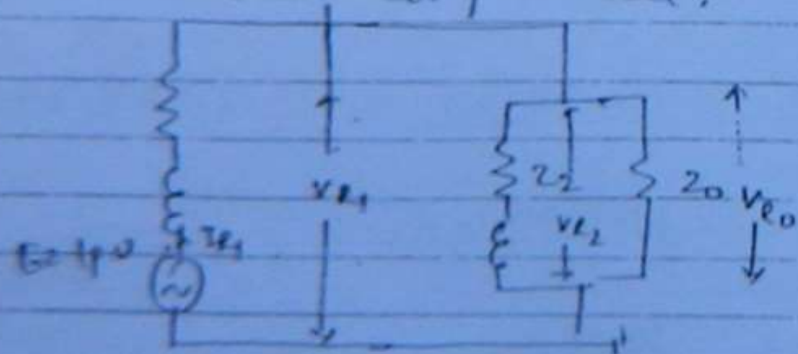
$Z_{2\,th} = 0.16 + j\,0.369$ p.u.

Zero sequence



$Z_{0\,th} = 0.4 + j\,1.279$.

For 3φ are connected in parallel!



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

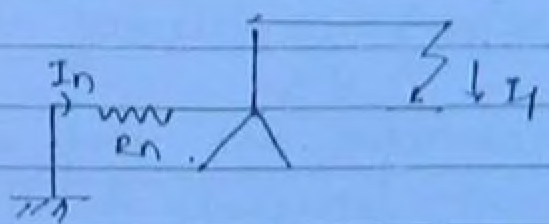
$$V_{R_1} = E - I_{R_1} Z_1$$

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

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

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)

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

$$= 8 ~~(0.496 - j1.223) \times (0.4 + j~~$$

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

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

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

$$(0.0823 - 0.293i)$$

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

$V_n = 3 I_{R0} R_n$

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

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

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

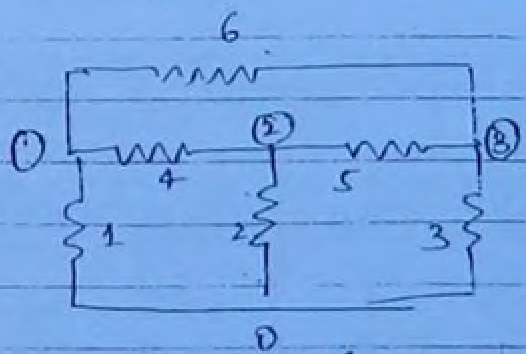
→ N/w analysis can be carried by using either loop analysis or nodal analysis.

→ 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

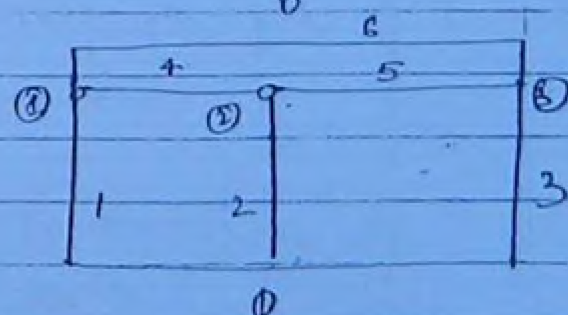
→ We pass the information regarding structure of n/w to computer through incidence matrices (+1,-

Network :→



node = 4
element e = 6.

Graph :→



→ structure remains

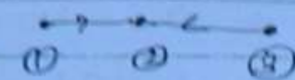
→ when direction is given → oriented graph.

→ No overlapping → Planar Graph.

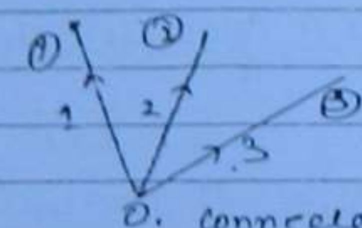
* Graph theory cannot be applied on Non-Planar graph

→ main graph.

* Sub-graph :- graph from original. ·2,



* connected sub-grap :- One can go 4m One to another node



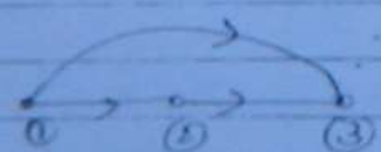
connected graph.

* 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.



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

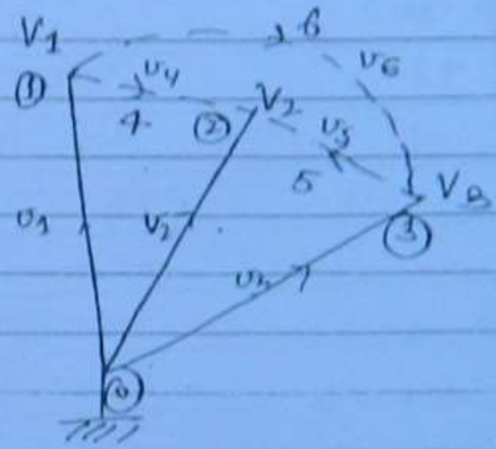
links = e − (twigs)
= e − (n−1)

$\boxed{\text{links = e − n + 1}}$

no of node increase by 1.

* Whenever twig element is added we get → node (n
Whenever link element is added we get → Loop. (n

Example :-



$V_0 = 0$.

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

$A =$ [element ↓, n-1 node →, a_{ij}] $e \times (n-1)$

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

	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

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

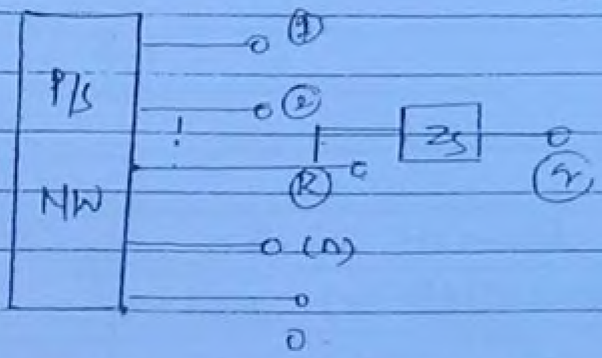
$$[v] = [A][V].$$

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

→ **Type 2 Modification:**

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

*(new element is added to Kth bus)



$Z_{bus}^{(new)} \neq Z_{bus}^{(old)}$ qth co

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

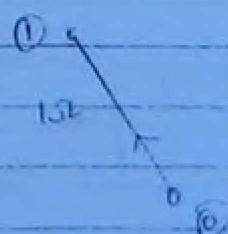
$(n+1) \times (n+$

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

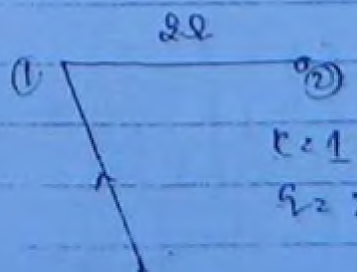
- Z_{kj} (row) is copy for row Z_{q1}
- Z_{1k} (coloumn) is copy for Z_{1q}.

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

Example:



$Z_{bus}(old) = ① \,[\, 1\Omega \,]$



$k = 1$

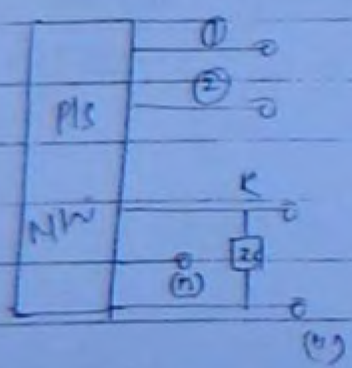
$q = 2$

$$Z_{bus}(new) = \begin{array}{c|c|c} & ① & ② \\ \hline ① & 1 & K_{1K} \\ ② & Z_{K1} & Z_{\cdot} \end{array}$$

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

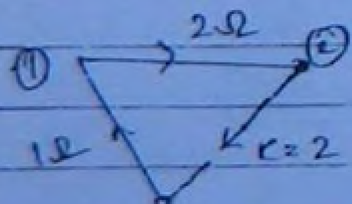
⇒ **Type 3 Modification :-**

An element with self impedence is added b/w old bus (k) and reference bus (0).



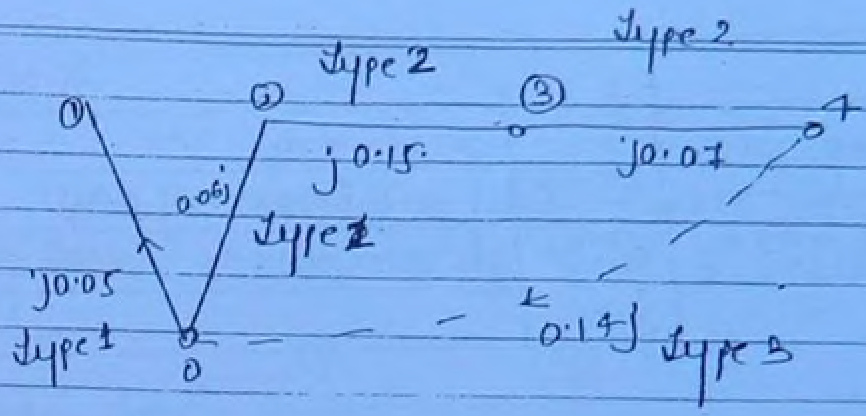
$$\boxed{Z_{bus}(new) = Z_{bus}(old) - \frac{1}{Z_{kk} + Z_s} \underset{A\,(n\times 1)}{\begin{bmatrix} Z_{1k} \\ Z_{2k} \\ \vdots \\ Z_{nk} \end{bmatrix}} \underset{(1\times n)}{\begin{bmatrix} Z_{k1} & \cdots & Z_{kn} \end{bmatrix}}}$$

Example:



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

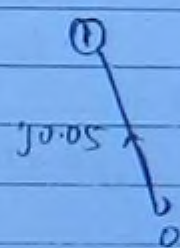
$$= \begin{bmatrix} 1 & 1 \\ 1 & 3 \end{bmatrix} - \frac{1}{3+3} \begin{bmatrix} 1 \\ 3 \end{bmatrix} \begin{bmatrix} 1 & 3 \end{bmatrix}$$



Step 1:

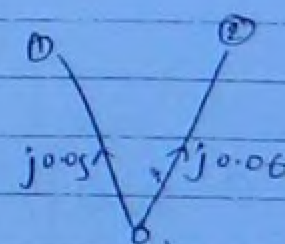
Z_{bus}

	1
1	j0.05



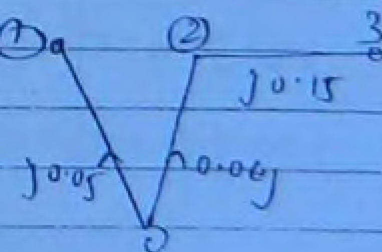
Z_{bus} =

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



Z_{bus}

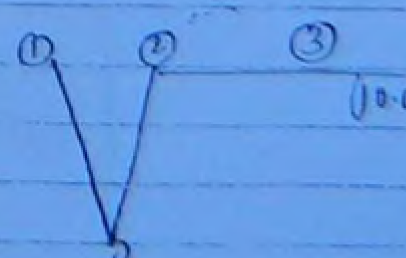
	1	2	3
1	j0.05	0	0
2	0	j0.06	j0.06
3	0	j.06	j0.21



0.06
0.15
———
.21

Z_{bus} =

	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
.07

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

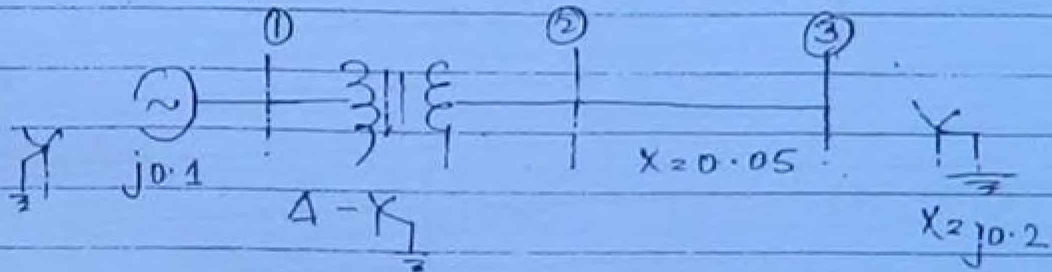
$$= Z_{bus\,(old)} - \frac{1}{j0.42} \begin{bmatrix} 0 & -3.6\times10^{-3} & -0.0126 & 0.0168 \\ 0 & -3.6\times10^{-3} & -0.0126 & 0.0168 \\ 0 & -0.0126 & -0.0441 & 0.0588 \\ 0 & -0.0168 & -0.0588 & 0.078 \end{bmatrix}$$

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

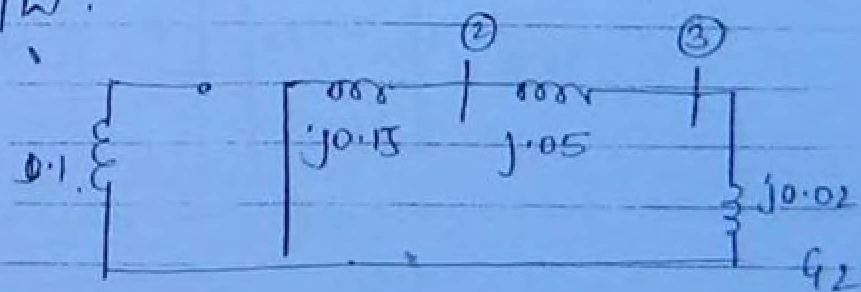
$$Z_{bus(new)} \begin{bmatrix} j.05 & 0 & 0 & 0 \\ 0 & j0.257 & j0.03 & j0.02 \\ 0 & j0.03 & j0.105 & j0.07 \\ 0 & j0.02 & j0.07 & j01.58 \end{bmatrix}$$

IES - 1999

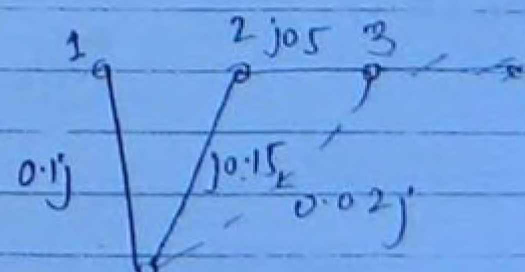
The per unit zero sequence reactances of the n/w are shown in figure. The zero sequence driving point reactance of ~~bus~~ node 3 will be.



Zero sequence n/w.



Graph



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

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

Z_{bus} =

	1	2	3
1	j0.1	0	0
2	0	j0.15	j0.15
3	0	j1.15	j0.2

0.15
+05

Z_{us} =

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

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

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

$$0.2j - 0.1j$$

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

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 ~~voltage~~ voltages are zero

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

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 $i = 1, 2 \ldots n$

$i \neq k$

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

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)

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

Z_{bus} Building Algorithm:

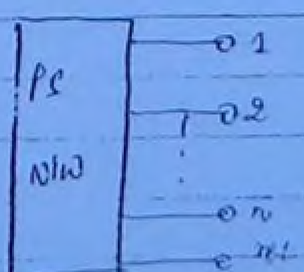
The bus admittance matrix (Y_{bus}) can be obtained easily by taking inverse of Y_{bus} bus impedance matrix Z_{bus} can be obtained. But this method has following disadvantages :-

→ Y_{bus} 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 Y_{bus} and then we have to find Z_{bus}. this is quite difficult process.

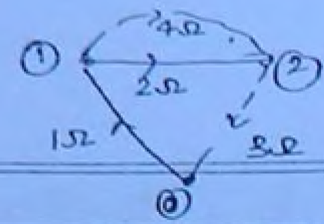
→ To avoid above difficulties Z_{bus} Building algorithm is used. For a given power s/m bus impedance matrix $Z_{bus}(old)$ already exist. For the N/w changes now this matrix will be updated

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



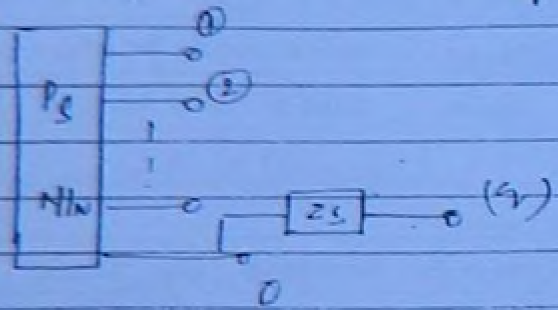
$$Z_{bus}\,old = \begin{bmatrix} Z_{11} & Z_{12} & \cdots & Z_{1n} \\ \vdots & \vdots & & \vdots \\ Z_{n1} & Z_{n2} & \cdots & Z_{nn} \end{bmatrix}_{n \times n}$$

[redacted]



TYPE MODIFACATION :-

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



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

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

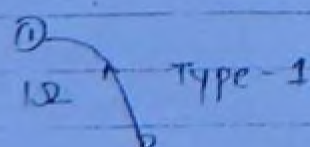
* All element are zero except diago

$$Z_{1q} = Z_{q1} = 0$$
$$Z_{2q} = Z_{2q} = 0$$
$$Z_{iq} = Z_{qi} = 0$$

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

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

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.

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

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

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

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

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

$$\text{for } i = 1, 2, \dots n \quad i \neq K.$$

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)

i) Fault at bus (2)

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

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

$$|I_f| = 6.36 \times 262.43 = 1669.9 \text{ Amp}$$

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

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

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

Voltages:

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

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

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

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

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

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

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

*

$P=$

dcat SC → no current flow through other.

$P = \frac{V I \cos\phi}{V I} \rightarrow$ P.U / $\frac{2}{\cos\theta}$ = MVA (rated)

$I_{f\,LG} = 7.26 \angle 269.43$ A.

$I_{f\,LG} = 1905.4 \angle -90^\circ$

Consideration of Prefault load current:

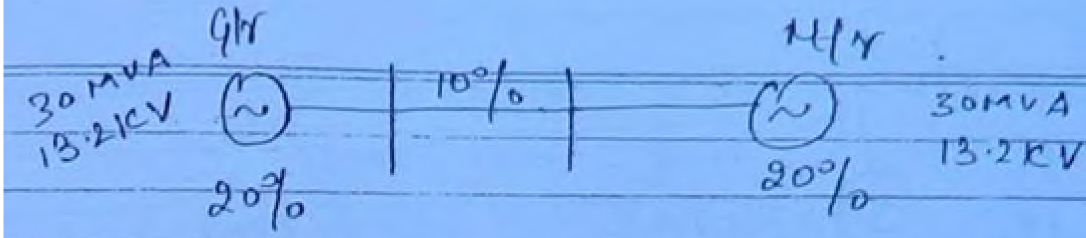
Using the load condition the first step being the calculatn of internal emf's of g/r and m/r. when the fault occurs the two sources at the two ends will drive the current into fault. The following numerical is show below:-

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

$\cos\phi = 0.8$.

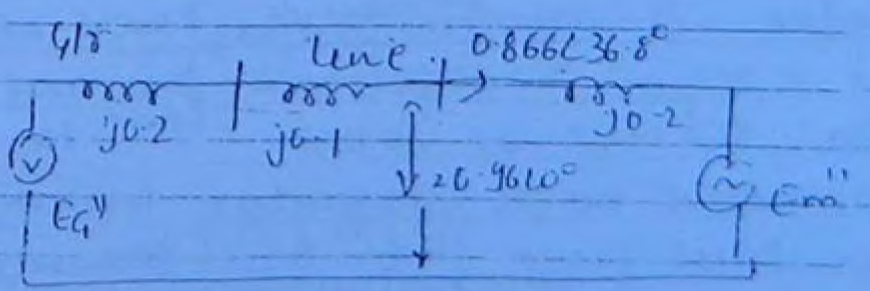
$$\boxed{V_{pu}\ I_{pu}\cos\phi = P_{pu}}$$

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

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

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

Let $V = 0.96 \angle 0°\ p.u.$

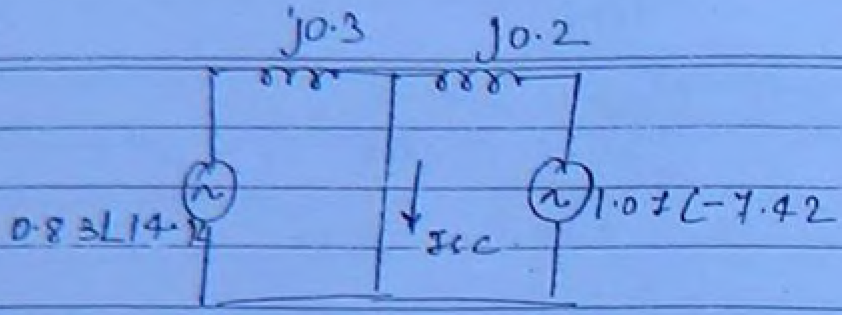


$E_G'' = 0.96\angle 0° - .866\angle 36.8 \times 0.3\angle 90°$

$= 0.83 \angle 14.50$

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

$= 1.07\angle -7.42$



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

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

$$= 7.99\angle -89.3$$

$$|I_{sc}| = 7.99 \times \frac{30\times10^6}{\sqrt{3}\times13.2\times10^3}$$

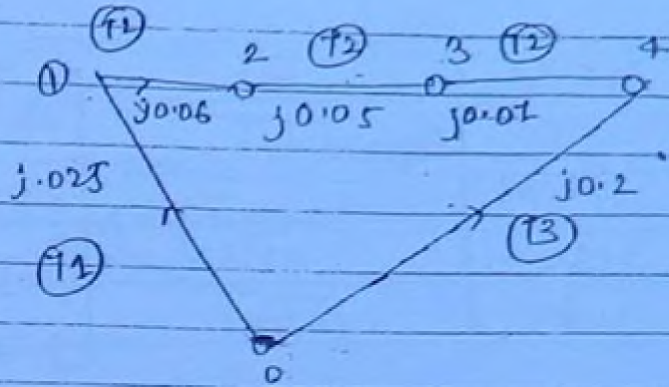
$$= 7.99 \times 10.48$$

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

Numerical :

A 50Hz alternator is rated 500MVA, 20KV with $X_d = 1p.u$, $X_d'' = 0.2p.u$. 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

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

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

Z_{bus}

	1	2
1	j0.25	j0.25
2	j0.25	j0.31

(0.25+0.06)

$Z_{kk} + Z_s$

$Z_{bus}.2$

	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

$Z_{bus}2$

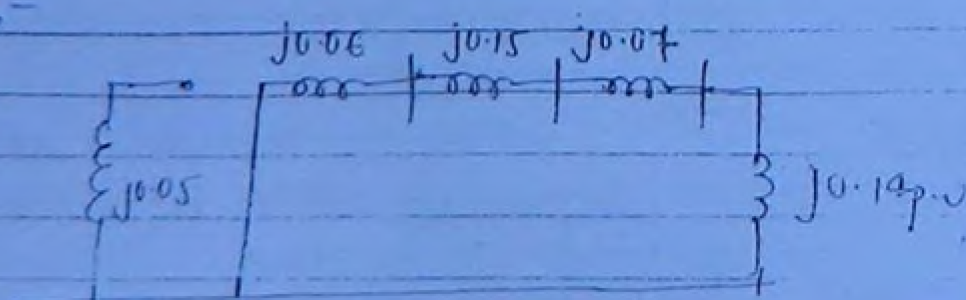
	1	2	3	4
1	j0.25	j0.25	j0.25	j0.25
2	j.025	j0.31	j.31	j.31
3	j.25	j0.31	j.36	j0.36
4	j.025	j.31	j.36	j0.36+j0.2

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

$$
Z_{bus}(old) = \frac{1}{j0.63} \begin{bmatrix} -j0.0625 & -0.0775 & -0.09 & -0.1075 \\ -0.0775 & -0.0961 & -0.1116 & -.1333 \\ -0.09 & -.1116 & -.1236 & -0.1548 \\ -0.1075 & -0.1333 & -0.1548 & -0.1849 \end{bmatrix}
$$

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

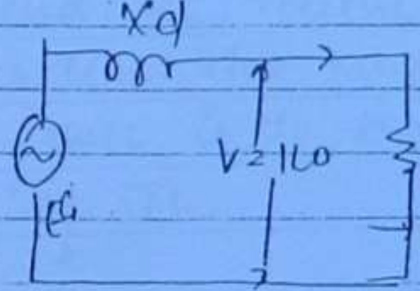
Zero sequence :-



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

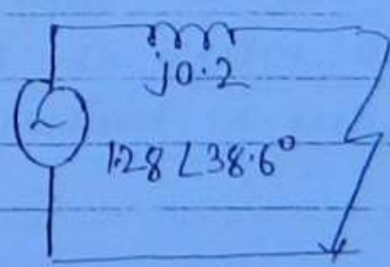
$I_{pu} = \dfrac{11547}{14433} = 0.8$ p.u

Before fault:



Prefault generate Emf = $1\angle 0 + 0.8\angle 0 \times 1\angle 90$
$1.28 \angle 38.65^\circ$ p.u.

During short ckt



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

$I_{sc}'' = 6.4 \times 14433.75$
92.32 kA.

[redacted]

* Question:-

A 33 KV 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 7.5 MVA 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 do not 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. therefore the given data refers to nominal π method.

$V_R = 32 KV_{L-L}$

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

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

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

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

$I_{RL} = 135.32\, A$

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

$V_S = A V_R + B I_R$

$= (1\angle 0°)\left(\frac{32000}{\sqrt{3}}\right) + (11.18\angle 63.43°)(135.2\angle -31.79°)$

$= 19771.7 \angle 2.34°$.

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

[redacted]

$AD - BC = 1$

$1 \times 1 - 11.8 \angle 62.43 = 1$

$\Rightarrow \boxed{C = 0}$

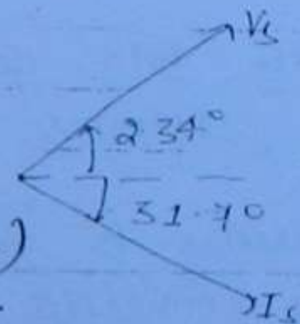
$\therefore \quad CV_R + DI_R = I_S$

$\Rightarrow \cancel{I_S = CV_R}$

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

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

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



$\phi_S = 2.34 + 31.7^\circ$

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

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

$P_S = \cancel{6.2}\ 6.64\ MW$

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

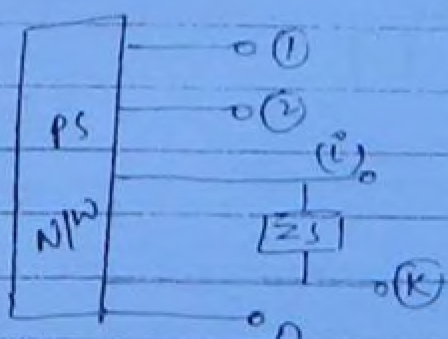
$= \begin{bmatrix}1 & 1\\ 1 & 3\end{bmatrix} - \cancel{\frac{1}{6}[1\ 1]}$ $\begin{bmatrix}1 & 1\\ 31 & 3\end{bmatrix} - \frac{1}{6}\begin{bmatrix}1 & 3\\ 3 & 9\end{bmatrix}$

$= \cancel{\begin{bmatrix}1 & 1\\ 1 & 3\end{bmatrix} - \frac{7}{6}}$

$= \begin{bmatrix}1 & 1\\ 1 & 3\end{bmatrix} - \begin{bmatrix}1/6 & 1/2\\ 1/2 & 3/2\end{bmatrix} = \begin{bmatrix}0.83 & 0.5\\ 0.5 & \cancel{0.33}\ 1.5\end{bmatrix}$

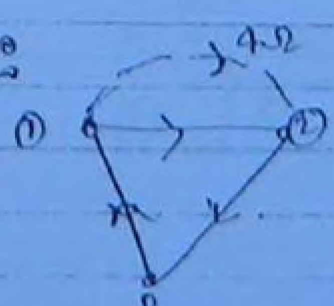
⇒ Type 4 modification :-

An element with self impedance Z_s is added b/w old bus (i) and (k) (other than reference bus) :



$$Z_{bus(new)} = [Z_{bus(old)}] - \frac{1}{Z_s + Z_{ii} + Z_{kk} - 2Z_{ik}} \begin{bmatrix} Z_{1i} \\ \vdots \\ Z_{ni} \end{bmatrix} \times [Z_{i1} - Z_{k1}, \cdots Z_{in} - Z_{kn}]$$

Example:



$i = 1$

$k = 2$

$$Z_{bus(new)} = \begin{bmatrix} 0.83 & 0.5 \\ 0.5 & 1.5 \end{bmatrix} - \frac{1}{4 + Z_{11} + Z_{22} - 2Z_{12}}$$

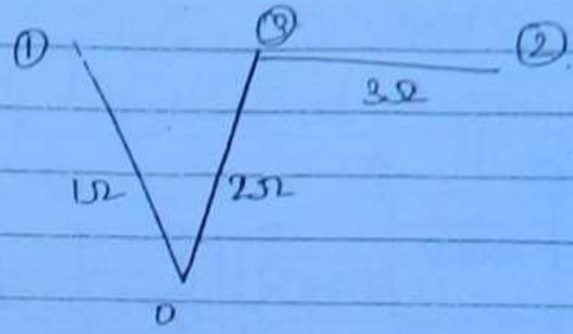
$$\begin{bmatrix} Z_{11} - Z_{12} \\ Z_{21} - Z_{22} \end{bmatrix} \begin{bmatrix} Z_{11} - Z_{21} & Z_{12} - Z_{22} \end{bmatrix}$$

$$\Rightarrow \begin{bmatrix} 0.83 & 0.5 \\ 0.5 & 1.5 \end{bmatrix} - \frac{1}{4 + 0.83 + 1.5 - 2 \times 0.5} \begin{bmatrix} 0.85 - 0.5 \\ 0.5 - 1.5 \end{bmatrix} \begin{bmatrix} 0.8 \\ 0. \end{bmatrix}$$

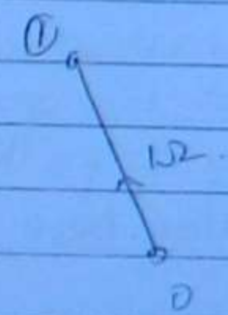
$$= \begin{bmatrix} 0.83 & 0.5 \\ 0.5 & 1.5 \end{bmatrix} - \frac{1}{5.3} \begin{bmatrix} 0.33 \\ 1 \end{bmatrix} \begin{bmatrix} 0.33 & 1 \end{bmatrix}$$

$$Z_{bus(new)} = \begin{bmatrix} 0.812 & 0.559 \\ 0.559 & 1.39 \end{bmatrix}$$

IES - Numerical:



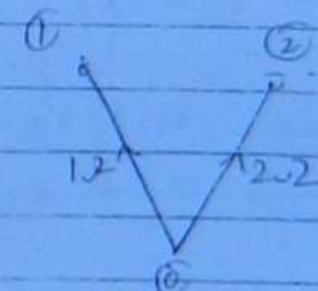
Step 1:



Type 0

$$Z_{bus} = \begin{array}{c|c|} & (1) \\ \hline (1) & 1\Omega \\ \hline \end{array}$$

Step 2:



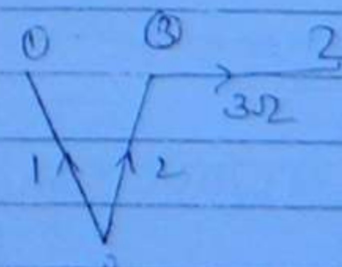
Type 1

$$Z_{bus} = \begin{array}{c|c|c|} & (1) & (3) \\ (1) & 1\Omega & 0 \\ (3) & 0 & 3\Omega \end{array}$$

Step 3:

$K = 3$

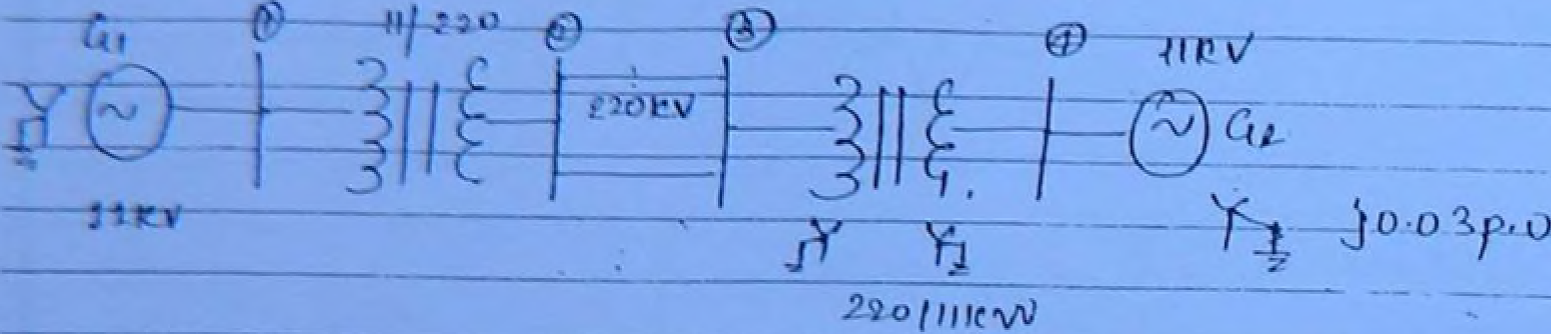
$q = 2$.



Type 2

$$Z_{bus} = \begin{array}{c|c|c|c|} & (1) & (3) & (2) \\ (1) & 1 & 0 & 0 \\ (3) & 0 & 2 & 2 \\ (2) & 0 & 2 & 5 \end{array}$$

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

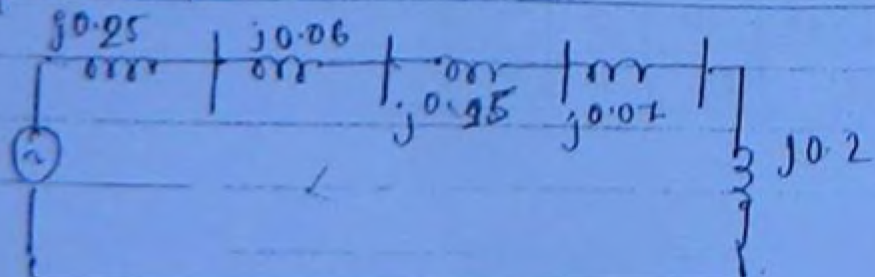
$T_2 \rightarrow X_1 = X_2 = X_0 = j0.07$ p.u

$L_1, L_2 \rightarrow X_1 = X_2 = X_0 = j0.3$.

Solution:

$\Rightarrow$ Positive sequence n/w

$\frac{0.03}{2}$

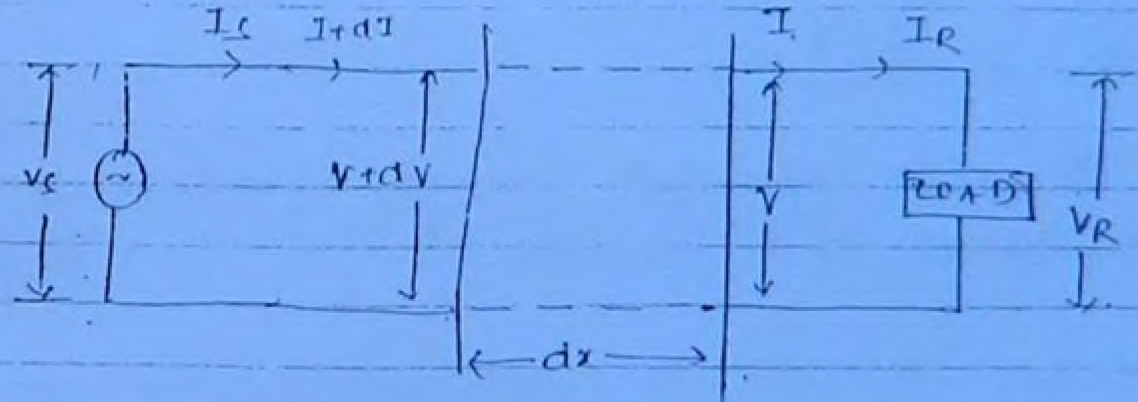


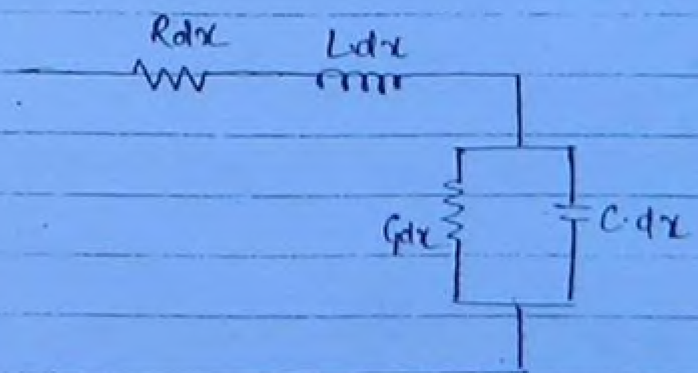
2PB

The four methods of Medium transmission line improve the p.f of line at different locatn?-

→ Long Transmission lines: (800km)

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) w.r.t 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 equatn. the solution of equatn (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

$R = 0.1\ \Omega/Km$; $X = 2mH/Km$ $C = 0.01\ \mu F/Km$.

G=0, calculate the characteristic impedance and propagation constant of T.L

2π

$$Z_C = \sqrt{\frac{R+j\omega L}{G+j\omega C}} = \sqrt{\cancel{0.1+jx}}$$

in per phase.

$$R = 0.1 \times 500 = 50\,\Omega$$

$$L = 2 \times 10^{-3} \times 500 = 1H.$$

$$C = 0.01 \times 10^{-6} \times 500 = 5 \times 10^{-6} F$$

$$2\pi \cancel{\omega} f = 2 \times 3.14 \times 50 \,.$$

$\Rightarrow$

$$Z_C = \sqrt{\frac{50 + j \times 2 \times \pi \times 50 \times 1}{0 + j\, 2 \times \pi \times 50 \times 5 \times 10^{-6}}} = \sqrt{\frac{Z\angle\phi}{Y\angle\phi}}$$

$$= \sqrt{\frac{317.96 \angle 80.95^\circ}{1570 \angle 90^\circ}} \quad 450.1 \angle{-4.5^\circ}$$

$$\gamma = \sqrt{ZY} = \sqrt{} \qquad \gamma \quad 0.707 \angle 85.47$$

Questⁿ:

2) A 66kV, 3-ϕ, 50Hz, 150 km long T.L is open circuited at the receiving end, each conductor has resistance of 0.25 Ω/km and inductive reactance of 0.5 Ω/km and capacitive admittance to the neutral is $B_c = 4 \times 10^{-6}$ 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 $Z/\phi = R/\phi + jX/\phi$

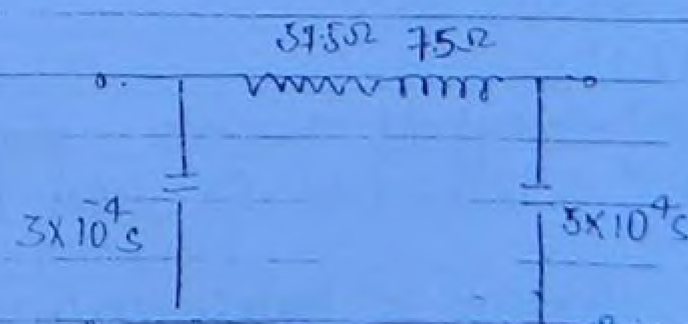
$$= \left(\frac{0.25\,\Omega}{km} \times 150 + j \frac{0.5\,\Omega}{km} \times 150\,k \right.$$

$$Z/\phi = (37.5 + j75)\,\Omega$$

$$Y/\phi = G/\phi + jB/\phi$$

$$0 + j \frac{4 \times 10^{-6}\,S}{km} \times 150$$

$$Y/\phi = j6 \times 10^{-4}\,S.$$



2) $I_R = 0$

$\Rightarrow \quad V_S = AV_R + BI_R$

$V_S = A \cdot V_{R0}$

$V_{R0} = \frac{V_S}{A} = \frac{V_S}{1 + \frac{YZ}{2}}$

$V_{R0} \Rightarrow \frac{66 \times 10^3}{1 + \frac{(37.5 + j75)(j6 \times 10^{-4})}{2}}$

$$\boxed{V_{R0} = 67.5 \angle -0.66^\circ kV}$$

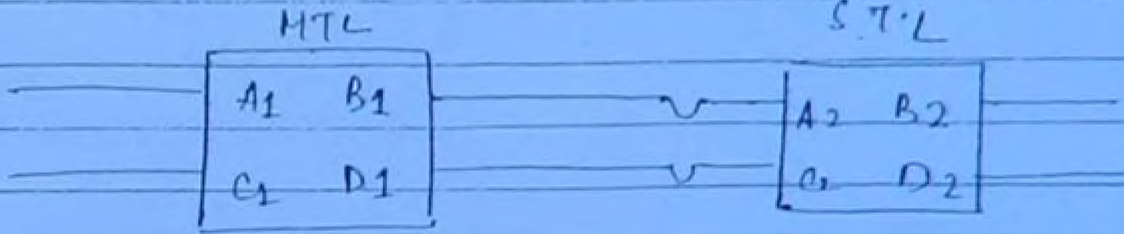
Quest^n

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.



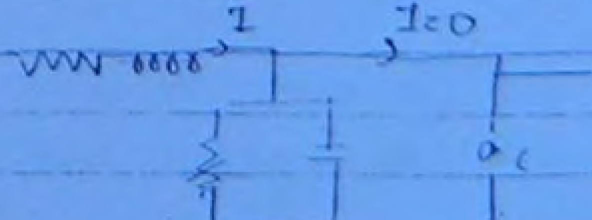
$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1+\frac{YZ}{2} & Z\left(1+\frac{YZ}{4}\right) \\ Y & 1+\frac{YZ}{2} \end{bmatrix} \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} \left(1+\frac{YZ}{2}\right), & Z\left(1+\frac{YZ}{2}\right)+Z\left(1+\frac{YZ}{4}\right) \\ Y & YZ+1+\frac{YZ}{2} \end{bmatrix}$$

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.



$I_S = CV_R + DI_R$

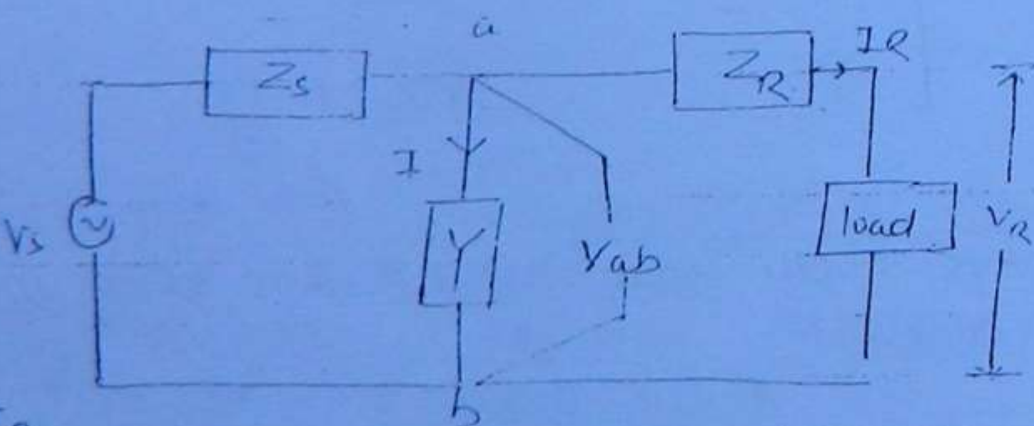
$I_R = 0 \Rightarrow I_S = CV_R$

$5 \times 10^{-5} \times \left(\frac{220 \times 10^3}{\sqrt{3}} \right) = \frac{11}{\sqrt{3}} A$

NOMINAL T AND π NETWORK FOR

LONG T.L:

condition 1: T network.



$V_{ab} = V_R + Z_R I_R$

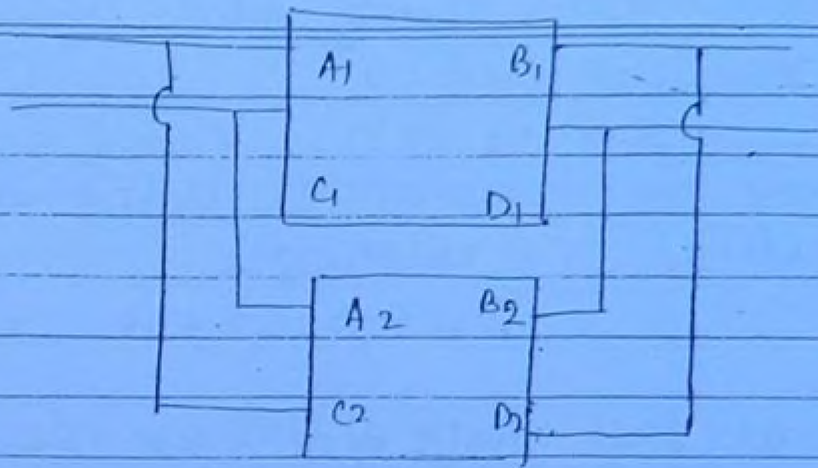
$I = Y V_{ab} = Y(V_R + Z_R I_R) = YV_R + YZ_R \cdot I_R$

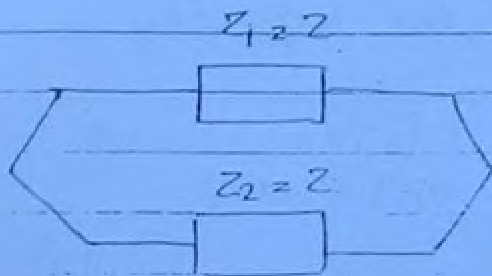
$I_S = I + I_R = (YV_R + YZ_R I_R) + I_R$

$I_S = YV_R + I_R(1 + YZ_R)$ — (1)

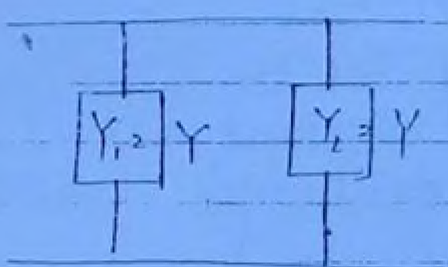
$A_0 = A_1 = A_2$

$D_0 = D_1 = D_2$





$B_0 = Z/2 = \frac{B}{2} = \frac{100\angle 75}{2} = 50\angle 75$



$C_0 = Y_1 + Y_2 = 2Y = 2C = 2(5\times10^{-4}\angle 90^\circ)$

$10\times10^{-4}\angle 90^\circ\ S$

Objectives :-

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

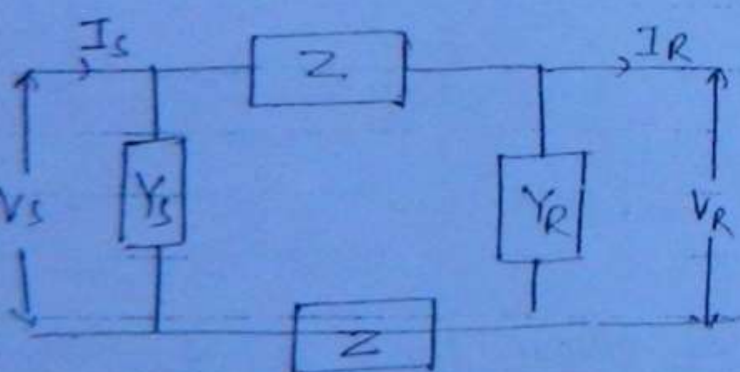
it is more than the actual value when calculated by nominal π method.

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

) to increase the power transferred, the surge impedance must be decreases from (1)

$$\boxed{C = Y, \quad D = 1 + Y \cdot Z_R}$$

$$V_S = V_R + I_S Z_S + I_R Z_R$$

$$V_S = V_R + \{ Y V_R + I_R (1 + Y Z_R) \} Z_S + I_R Z_R$$

$$V_S = (1 + Y Z_S) + I_R (Z_S + Y Z_S Z_R + Z_R) \quad \text{—— (2)}$$

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

$$Z_S \to \frac{1}{2} Z_T, \quad Z_R = \frac{1}{2} Z_T; \quad Y = Y_T$$

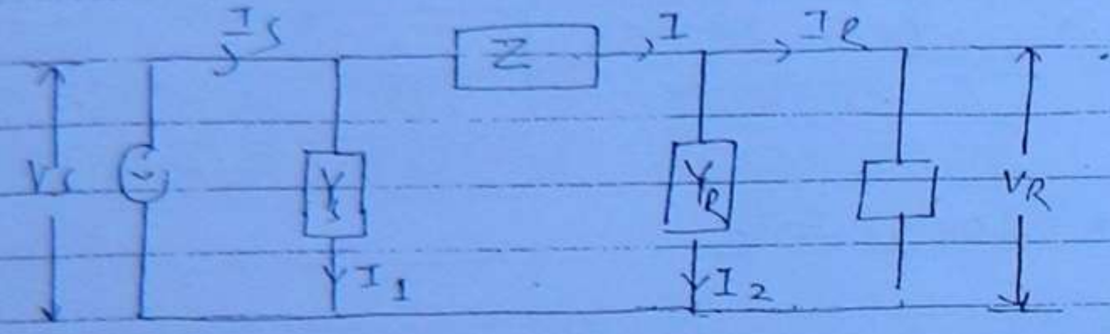
$$A = 1 + Y Z_S = 1 + \frac{Y_T Z_T}{2}$$

$$D = 1 + Y Z_R = 1 + \frac{Y_T Z_T}{2}$$

$$B = Z_S + Z_R + Y Z_S Z_R = \frac{1}{2} Z_T + \frac{1}{2} Z_T + Y_T \frac{Z_T}{2} \frac{Z_T}{2}$$

$$C = Y = Y_T$$

Condition 4: Nominal π network:-



$$I_1 = Y_S V_S \quad \text{------} \quad (1)$$

$$I_2 = Y_R \cdot V_R \quad \text{------} \quad (2)$$

$$I = I_R + I_2 \quad \text{------} \quad (3)$$

$$I_R + Y_R \cdot V_R \quad \text{------} \quad (3)$$

$$I_S = I_1 + I$$

$$Y_S V_S + (I_R + V_R Y_R) \quad \text{---} \quad (4)$$

now

$$V_S = V_R + IZ$$

$$V_R + (I_R + Y_R V_R) Z$$

$$V_R + I_R Z + V_R Y_R Z$$

$$V_S = V_R (1 + Z Y_R) + Z I_R \quad \text{---} \quad (5)$$

from eqⁿ 5

$$\boxed{\begin{aligned} A &= 1 + ZY_R \\ B &= Z \end{aligned}}$$

substituting ⑤ → ④

$$I_S = Y_S\{V_R(1+ZY_R) + ZI_R\} + I_R + Y_R V_R$$

$$= V_R(Y_S + ZY_S Y_R + Y_R) + I_R(1 + ZY_S)$$

$$\therefore \boxed{\begin{aligned} C &= Y_S + Y_S + ZY_S Y_R \\ D &= 1 + ZY_S \end{aligned}}$$

<u>symmetrical π - n/w</u>:-

$$Z = Z_\pi, \; Y_S = \frac{Y_\pi}{2}, \; Y_R = \frac{Y_\pi}{2}$$

$$\boxed{\begin{aligned} A &= 1 + Z, Y_R = 1 + Z_\pi \cdot \frac{Y_\pi}{2} \\ B &= Z = Z_\pi \end{aligned}}$$

$$C = Y_S + Y_R + ZY_S Y_R$$

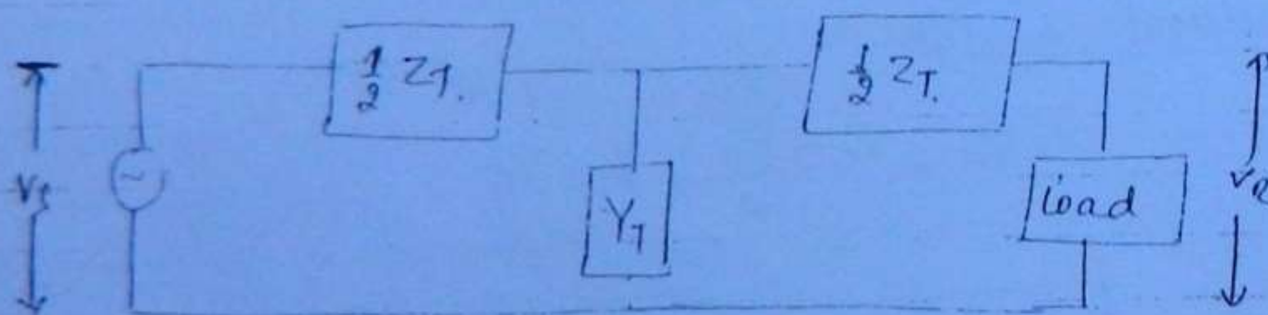
$$\frac{Y_\pi}{2} + \frac{Y_\pi}{2} + Z_\pi \frac{Y_\pi}{2} \frac{Y_\pi}{2}$$

$$\boxed{C = Y_\pi + \frac{Z_\pi Y_\pi^2}{4}}$$

$$D = 1 + ZY_S = 1 + Z_\pi \frac{Y_\pi}{2}$$

	T	π
A	$1+YZ_S$	$1+Y_RZ$
B	$Z_S+Z_R+Z_SZ_RY$	Z
C	Y	$Y_S+Y_R+Y_SY_RZ$
D	$1+YZ_R$	$1+Y_SZ$

EQUIVALENT T-NETWORK OF LTL :



$$A = D = 1 + \frac{Y_T \cdot Z_T}{2}$$

$$C = Y_T$$

$$B = Z_T\left(1 + \frac{Y_T Z_T}{4}\right)$$

$$\frac{1}{2} Z_T = ?$$

$$1 + \frac{Z_T Y_T}{2} = A$$

$$\Rightarrow \frac{Z_T Y_T}{2} = A - 1$$

$$\Rightarrow \frac{Z_T Y_T}{2} = \cosh \gamma x - 1$$

$$\frac{Z_T}{2} = \frac{\cosh \gamma x - 1}{Y_T}$$

$$\frac{Z_T}{2} = \frac{\cosh \gamma x - 1}{C} = \frac{\cosh \gamma x - 1}{\frac{1}{Z_c} \sinh \gamma x} = Z_c \frac{(\cosh \gamma x - 1)}{\sinh \gamma x \; x}$$

$$\Rightarrow Z_c \frac{\cancel{2} \sinh^{\cancel{2}} \gamma x/2}{\cancel{2 \sinh \gamma x/2} \cosh \gamma x/2}$$

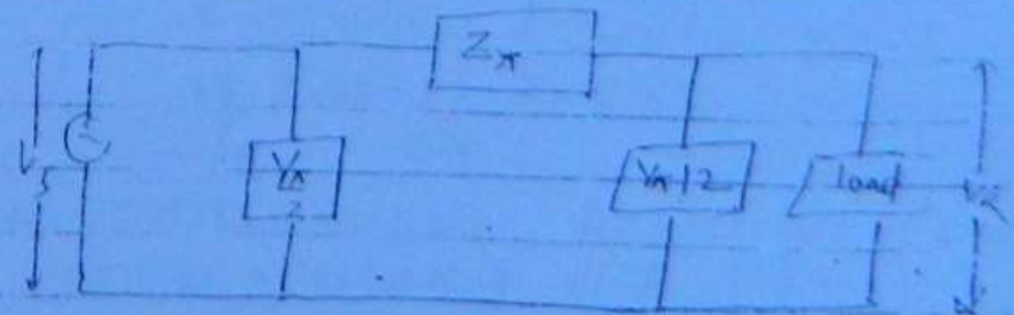
$$\frac{Z_T}{2} = Z_c \tanh \frac{\alpha x}{2}$$

we know that $Z_c = \sqrt{\frac{Z}{Y}} \Rightarrow \sqrt{\frac{Z \cdot Z}{Z Y}} = \frac{Z}{\gamma}$.

$$= \frac{Z \cdot x}{\gamma \cdot x} = \frac{\text{total series impedence } (Z)}{\gamma x}.$$

$$\boxed{\frac{Z_T}{2} = \frac{Z}{2} \left(\frac{\tanh \gamma x/2}{\frac{\gamma x}{2}} \right)} \quad (1)$$

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 :- $Z_\pi = ?$

$$\frac{Y_\pi}{2} = ?$$

$$1 + \frac{1}{2} Y_\pi Z_\pi = A$$

$$\frac{1}{2} Y_\pi Z_\pi = A - 1$$

$$\frac{Y_\pi}{2} = \frac{A-1}{B}$$

$$\frac{Y_\pi}{2} = \frac{\cosh \gamma x - 1}{Z_c \sinh \gamma x}$$

$$\frac{Y_\pi}{2} = \frac{1}{Z_c} \frac{2 \sinh^2 \gamma x/2}{2 \sinh \frac{\gamma x}{2} \cosh \gamma x/2}$$

$$\frac{Y_\pi}{2} = \frac{1}{Z_c} \tanh \frac{\gamma x}{2}$$

$$Z_c = \sqrt{\frac{Z}{Y}} = \sqrt{\frac{Z\cdot Y}{Y\cdot Y}} = \frac{\gamma}{Y}$$

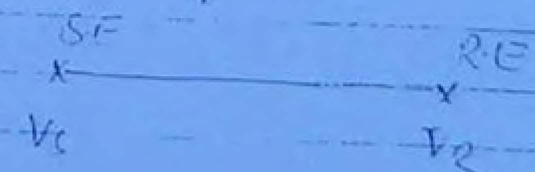
$$\cancel{Z\cdot x} \quad \frac{\gamma\cdot x}{Y\cdot x} = \frac{\gamma\cdot x}{Y} = \frac{\gamma x/2}{Y/2}$$

$$\frac{Y_\pi}{2} = \frac{1}{\gamma x/2 \,/\, Y/2} \tanh\frac{\gamma x}{2}$$

$$\boxed{\frac{Y_\pi}{2} = \frac{Y}{2}\left(\frac{\tanh\frac{\gamma x}{2}}{\gamma x/2}\right)}$$

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 → 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'')

$$\boxed{I'' = \frac{V''}{Z_L}}$$

- 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).

$$\frac{V''}{R} = \frac{+V}{Z_c} + \frac{(-V')}{Z_c}$$

$$\frac{V+V'}{R} = \frac{+V}{Z_c} + \frac{(-V')}{Z_c}$$

$$V\left[\frac{1}{R} - \frac{1}{Z_c}\right] = -V\left[\frac{1}{R} + \frac{1}{Z_c}\right]$$

$$\underline{Z_c+R} \quad V\left[\frac{Z_c-R}{R\,Z_c}\right] = -V'\left[\frac{R+Z_c}{R\cdot Z_c}\right] \quad \cdots (2)$$

- 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).

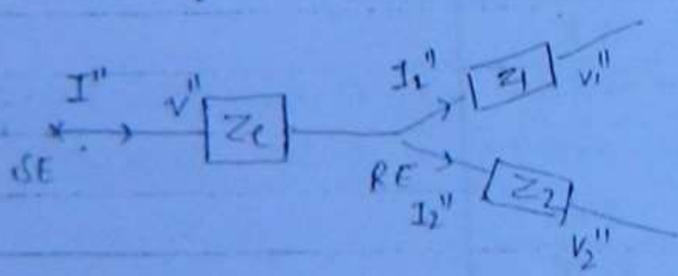
- $\tau_v = \dfrac{2Z_1}{Z_c + Z_1}$ → replace R by Z_1.

- $\tau_I = \dfrac{2Z_c}{Z_c + Z_1}$

- $\rho_v = \dfrac{Z_1 - Z_c}{Z_c + Z_1}$

- $\rho_I = \dfrac{Z_c - Z_1}{Z_c + Z_1}$.

Condition 3: Receiving end of T.L line forming a T junc^n.



* Z_1, Z_2 connected in parallel.

$$V_1'' = V_2'' = V''$$

$$I'' = I_1'' + I_2''$$

$$\Rightarrow \quad I'' = I + I'.$$

$$\Rightarrow \quad I_1'' + I_2'' = I + I'$$

Expressing transmitted voltage (V'') in terms of incident voltage (V), and transmitted current (I'') in-terms of incident current (I):-

$$I_1'' + I_2'' = I + I'$$

$$\Rightarrow \frac{V_1''}{Z_1} + \frac{V_2''}{Z_2} = \frac{V}{Z_c} + \left(\frac{-V'}{Z_c}\right)$$

$$\Rightarrow \frac{V''}{Z_1} + \frac{V''}{Z_c} = \frac{V}{Z_c} - \frac{V'}{Z_c}.$$

$$\Rightarrow V''\left(\frac{1}{Z_1} + \frac{1}{Z_c}\right) = \frac{V}{Z_c} - \frac{V'}{Z_c}.$$

$$\Rightarrow V''\left[\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_c}\right] = \frac{2V}{Z_c}$$

$$V'' = \frac{V(2/Z_c)}{\left[\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_c}\right]} \quad \text{------} \ (1).$$

- ~~reflection~~ Transmitted 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 equatn (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 $\boxed{\tau_I = \dfrac{I_1''}{I} = \dfrac{2/Z_1}{\frac{1}{Z_1}+\frac{1}{Z_2}+\frac{1}{Z_c}}}$

$$\therefore \quad \boxed{\tau_{I_2''} = \frac{I_2''}{I} = \frac{2/Z_2}{\frac{1}{Z_1}+\frac{1}{Z_2}+\frac{1}{Z_c}}}$$

• Expressing reflected voltage in terms of incident voltage and reflected current in terms of incident current

$$I_1'' + I_2'' = I + I'$$

$$\Rightarrow \frac{V_1''}{Z_1} + \frac{V_2''}{Z_2} = \frac{V}{Z_c} + \left(\frac{-V'}{Z_c}\right)$$

$$\frac{V''}{Z_1} + \frac{V''}{Z_2} = \frac{V}{Z_c} - \frac{V'}{Z_c}$$

$$\Rightarrow V''\left(\frac{1}{Z_1}+\frac{1}{Z_2}\right) = \frac{V}{Z_c} - \frac{V'}{Z_c}$$

$$\Rightarrow (V+V')\left(\frac{1}{Z_1}+\frac{1}{Z_2}\right) = \frac{V}{Z_c} - \frac{V'}{Z_c}$$

$$\Rightarrow V'\left(\frac{1}{Z_1}+\frac{1}{Z_2}+\frac{1}{Z_c}\right) = \frac{V}{Z_c} - \frac{V}{Z_1} - \frac{V}{Z_2}$$

$$\Rightarrow V' = V \frac{\left(\frac{1}{Z_c} - \frac{1}{Z_1} - \frac{1}{Z_2}\right)}{\left(\frac{1}{Z_c} + \frac{1}{Z_1} + \frac{1}{Z_c}\right)} \quad \text{-----} \; (a)$$

- 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 $\boxed{\rho_i = \frac{I'}{I} = \left[\frac{1/Z_1 + 1/Z_2 - 1/Z_c}{\frac{1}{Z_c} + \frac{1}{Z_1} + \frac{1}{Z_2}}\right]}$

$\tau_v = \left(2/Z_c\right) / \left(1/Z_c + \frac{1}{Z_1} + 1/Z_2\right)$

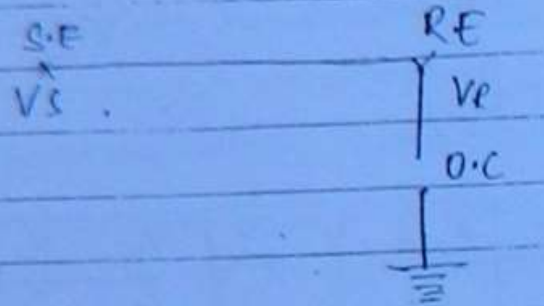
$\tau_i = \left(2/Z_1 \text{ or } 2/Z_2\right) / \left(1/Z_c + 1/Z_1 + \frac{1}{Z_2}\right)$

$\rho_v = \left(\frac{1}{Z_c} - \frac{1}{Z_1} - \frac{1}{Z_2}\right) / \left(1/Z_c + 1/Z_1 + 1/Z_2\right)$

$= \left(\frac{1}{Z_1} + \frac{1}{Z_2} - \frac{1}{Z_c}\right) / \left(1/Z_c + 1/Z_1 + \frac{1}{Z_2}\right)$

Imp

* Condition 4: Receiving end of T.L is open circuited.



$\frac{1}{2}LI^2$ $\frac{1}{2}CV^2$

$I = 0$

$\frac{1}{2}LI^2 = 0$

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' volts.

so $\frac{1}{2}LI^2 = \frac{1}{2}Ce^2$

$I^2 = e^2 / L/C$

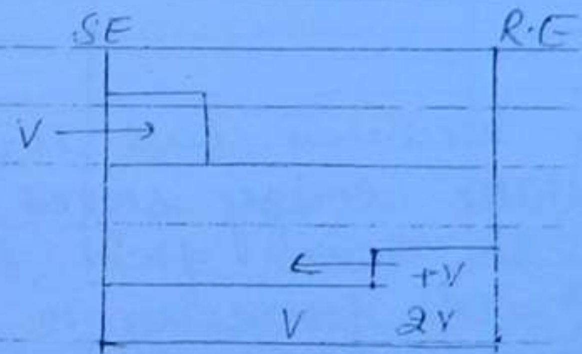
$I^2 = e^2 / Z_c^2$

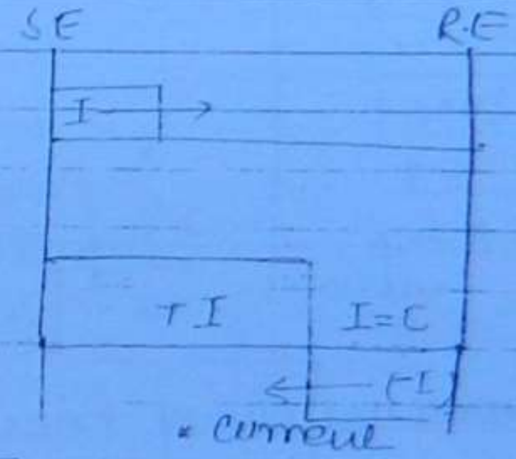
$$\underbrace{}_{}\text{incident current}$$

$$= \quad e^2 = I^2 Z_c^2$$

$$\boxed{e = I \cdot Z_c = V.}$$

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

$$\boxed{\text{reflection coefficient } \rho_I = \frac{-I}{+I} = -1}$$

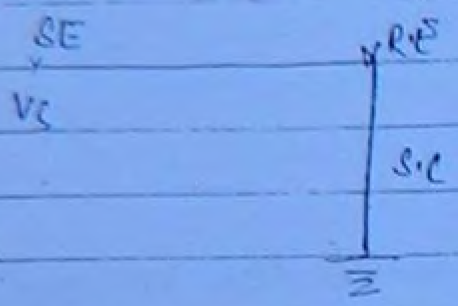
$$\tau_V = \frac{V''}{V} = \frac{V'+V}{V} = \frac{V+V}{V} = 2$$

$$\boxed{\tau_V = 2}$$

$$\tau_I = 0/I = 0$$

$$\boxed{\tau_I = 0}$$

Condition 5: Receiving end to T.L short-circuited.



$V=0$

$\frac{1}{2}LI^2 , \frac{1}{2}\underset{\downarrow 0}{C V^2} \rightarrow 0$.

$\frac{1}{2}LI^2$.

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.

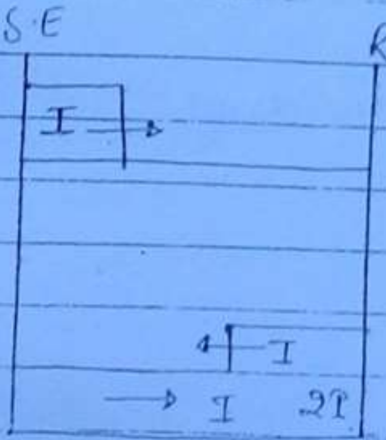
Let the current be increased by (i Amp)

$$\frac{1}{2}Li^2 = \frac{1}{2}CV^2$$

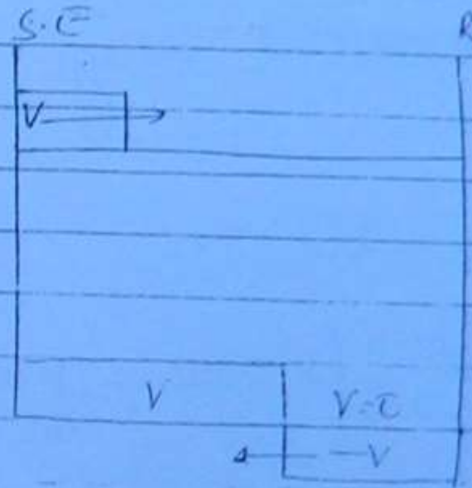
$$\Rightarrow i^2 = \frac{V^2}{L/C} = \frac{V^2}{Z_c^2}$$

$$\boxed{i = \frac{V}{Z_c} = I}$$

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.



Current



voltage

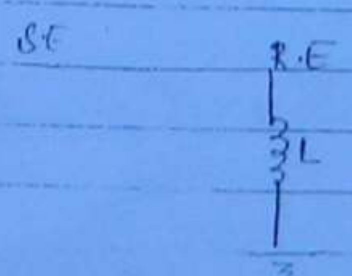
$$\rho_I = \frac{I}{I} = 1$$

$$\tau_I = \frac{2I}{I} = 2$$

$$\rho_V = -V/V = -1$$

$$\tau_V = 0/V = 0$$

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.

$$\frac{1}{L}\left\{\frac{V''(s)}{s}\right\} + \frac{V''(s)}{Z_c} = \frac{2V}{sZ_c}.$$

$$V''(s)\left[\frac{1}{sL} + \frac{1}{Z_c}\right] = \frac{2V}{sZ_c}.$$

$$\Rightarrow V''(s)\cdot\left\{\frac{sL+Z_c}{\cancel{s}L\cancel{Z_c}}\right\} = \frac{2V}{\cancel{s}\cancel{Z_c}}.$$

$$V''(s) = \frac{2VL}{sL+Z_c}.$$

dividing by L.

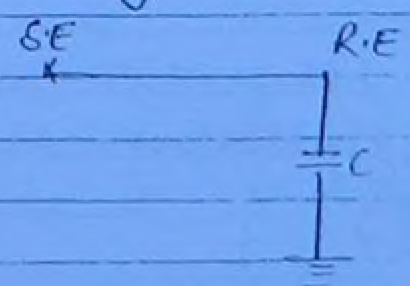
$$V''(s) = \frac{2V}{s+\frac{Z_c}{L}}.$$

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



$$V'' = V+V'$$
$$I'' = I+I'$$

$$I = V/Z_c\ ;\ I' = -V'/Z_c.$$

$$I'' = \frac{C\,dV''(t)}{dt}$$

$$I+I' = \frac{C\,dV''(t)}{dt}$$

$$\frac{V}{Z_c} - \frac{V'}{Z_c} = C\frac{dV'(t)}{dt} \Rightarrow \frac{C\,dV''(t)}{dt} + \frac{V''(t)}{Z_c} = \frac{2V}{Z_c}.$$

applying Laplace Transform

$$\frac{V(s)}{Z_c} - \frac{V'(s)}{Z_c} = \frac{C}{s}$$

$$\Rightarrow C\{sV''(s)\} + \frac{V''(s)}{Z_c} = \frac{2V}{sZ_c}$$

$$\Rightarrow V''(s)\left\{Cs + \frac{1}{Z_c}\right\} = \frac{2V}{sZ_c}.$$

$$\Rightarrow V''(s)\left\{\frac{sCZ_c+1}{Z_c}\right\} = \frac{2V}{sZ_c}$$

$$\Rightarrow V''(s) = \frac{2V}{s(sCZ_c+1)}$$

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 800 mH connect two sectn of T.L each having surge impedence of 350 Ω & 500

A 500 kV, infinite rectangular surge travels along the line towards the inductance. The maxm value of transmitted wave is. $V'' = 2V e^{-Z_C/L \, t}$

$$V'' = 2 \times 500 \times e^{-\left(\frac{350}{800 \times 10^{-6}}\right)\left(2 \times 10^{-6}\right)}$$

$$V'' = 416.86 \text{ kV}$$

4) A 500kV, 2μsec rectangular wave surge on T.L having surge impedance of 350Ω approaches, a generating statⁿ at which the concentrated earth capacitance is 3000pF the maxᵐ value of the transmitted wave is

V

$$V'' = 2V\left(1 - e^{-\tau/Z_C}\right).$$

$$V'' = 2\times 5000\left[1 - e^{-(2\times10^{-6}/350\times3000\times10^{-12})}\right]$$

$$V'' = 850\,kV.$$

5) A voltage surge of 60kV travelling in a line of natural impedence 500Ω, arrives at a junctⁿ with two T.L of impedence, 650Ω, 250Ω. The surge voltages and current transmitted into each branch of line are as:

$Z_c = 500\Omega$

$Z_1 = 650, \quad Z_2 = 250.$

$$V'' = V\left(\frac{2/Z_c}{\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_1}}\right)$$

$$V'' = 31.24\,kV.$$

$$I_1'' = \frac{V_1''}{Z_1} = \frac{31.84\times10^3}{650} = 48.97 \text{ Amp.}$$

$$I_2'' = V_2''/Z_2 = \frac{31.84\times10^3}{250} = 127.4 \text{ Amp}$$

4) A voltage surge of 15KV travels along a cable towards at juncⁿ with an over-head T.L. the inductance and capacitance of ~~overhead T.L~~ cable are 0.3mH, 0.4μF. the inductance and capacitance of over head T.L are 1.5mH, and 0.12 μF. the increase in voltage at the juncⁿ due to surge is?

$$Z_{c\,cable} = \sqrt{\frac{L}{C}} = \sqrt{\frac{0.3\times10^{-3}}{0.4\times10^{-6}}} = 27.38\,\Omega$$

$$Z_{c\,T.L} = \sqrt{\frac{1.5\times10^{-3}}{0.12\times10^{-6}}} = 353\,\Omega$$

$$V'' = \frac{2R}{Z_c+R} \Rightarrow \frac{2Z_{c\,cable}}{Z_c + Z_{c\,cab}}$$ as surge travel through cable

$$\frac{2\times27.38}{353+27.38}\cdot15\times10^3 = \cancel{2.948\text{kV}}$$

~~2159.4V~~

27.84 KV

A - 3ϕ overhead conductors in equilateral configuration the core characteristic impedance is 500Ω. What should be load impedance such that reflections do not occur in T.L.

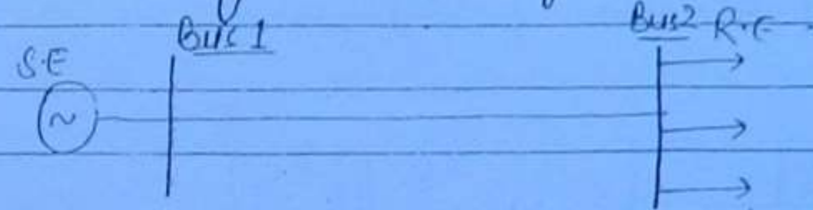
• TELEGRAPHER | WAVE EQUATION :

$$\frac{\partial^2 e}{\partial x^2} = RGe + (RC + LG)\frac{\partial e}{\partial t} + LC\frac{\partial^2 e}{\partial t^2}$$

$$\frac{\partial^2 i}{\partial x^2} = RGi + (RC + LG)\frac{\partial i}{\partial t} + LC\frac{\partial^2 i}{\partial t^2}$$

POWER CIRCLE DIAGRAMS:

Consider the single line diagram of 3ϕ T.L



V_s, I_s $\qquad\qquad$ V_R, I_R

$S_s = P_s + jQ_s$ $\qquad\qquad$ $S_R = P_R + jQ_R$

Bus1 $\longrightarrow$ 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.

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix}$$

$$\Rightarrow V_s = AV_r + BI_r \quad ----- (1)$$

$$I_s = CV_r + DI_r \quad ----- (2)$$

$$\begin{bmatrix} V_r \\ I_r \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}^{-1} \begin{bmatrix} V_s \\ I_s \end{bmatrix}$$

$$= \begin{bmatrix} V_r \\ I_r \end{bmatrix} = \frac{1}{AD-BC} \begin{bmatrix} D & -B \\ -C & A \end{bmatrix} \begin{bmatrix} V_s \\ I_s \end{bmatrix}$$

$$\begin{bmatrix} V_r \\ I_r \end{bmatrix} = \begin{bmatrix} D & -B \\ -C & A \end{bmatrix} \begin{bmatrix} V_s \\ I_s \end{bmatrix}$$

$$V_r = DV_s - BI_s \quad --- (3)$$

$$\cancel{V} \cdot I_r = -CV_s + AI_s \quad --- (4)$$

The equat^n (3) and (4) gives relation b/w. recieving end values and dececending end value.

~~sub~~ $2 \to 4$

$$I_r = -CV_s + A\{CV_r + DI_r\}$$

$$I_r[1-AD] = -CV_s + ACV_r$$

$$I_r \overline{B\cancel{C}} = -\cancel{C}V_s + A\cancel{C}V_r$$

$$\left\{P_s - \frac{|D||V_s|^2}{|B|}\cos(\beta-\Delta)\right\}^2 + \left\{Q_s - \frac{|D||V_s|^2}{|B|}\sin(\beta-\Delta)\right\}^2 = \left\{\frac{|V_s||V_R|}{|B|}\right\}^2 \quad \text{--- (15)}$$

represent the equatn of circle.

$$x \rightarrow \frac{|D||V_s|^2}{|B|}\cos(\beta-\Delta)$$

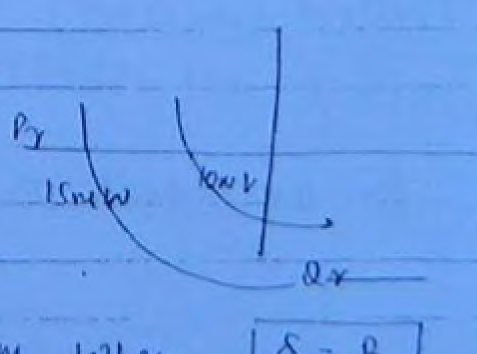
$$y \rightarrow \frac{|D||V_s|^2}{|B|}\sin(\beta-\Delta)$$

$$\text{radius} \rightarrow \frac{|V_s||V_r|}{|B|}$$

Question:-

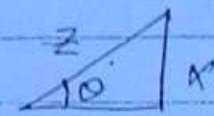
When the sending end voltage and receiving end voltage of T.L are constant the real power at the receiving end. of the T.L is max^m for the condition

$$P_r + \frac{|A||V_r|^2}{|B|}\cos(\beta-\alpha) = \frac{|V_s||V_r|}{|B|}\cos(\beta-\delta)$$



P_r is max^m when $\boxed{\delta = \beta}$

2) The power circle equation of short T.L are.



For S.T.L

$A = 1\angle 0^\circ \quad |A|\angle\alpha \quad \alpha = 0^\circ \quad |A| = 1$

$B = Z \quad |B|\angle\beta \quad \beta = \theta \quad |B| = Z$

$C = 0$

$D = 1\angle 0^\circ \quad |D|\angle\Delta \quad \Delta = 0^\circ \quad |D| = 1$

(A.)

now equatn

$$10 \rightarrow P_r + \frac{1.|V_r|^2}{Z}\cos(\theta) = \frac{|V_r||V_s|}{Z}\cos(\theta - \delta)$$

$$11 \rightarrow Q_r + \frac{|V_r|^2}{Z}\sin\theta = \frac{|V_r||V_s|}{Z}\sin(\theta - \delta),$$

$$13 \rightarrow P_s - \frac{1.|V_s|^2\cos(\theta)}{Z} = -\frac{|V_r||V_s|}{Z}\cos(\theta + \delta)$$

$$14 \rightarrow Q_s - \frac{1.|V_s|^2\sin\theta}{Z} = -\frac{|V_r||V_s|}{Z}\sin(\theta + \delta).$$

) The power circle equatn for an ideal short T.L is

$$S_r = \frac{|V_r||V_s|}{|B|} \angle \beta-\delta - \frac{|A||V_r|^2}{|B|} \angle \beta-\alpha. \quad ---- (9).$$

As $S_r = P_r + jQ_r$

$$P_r = \frac{|V_r||V_s|}{|B|} \cos(\beta-\delta) - \frac{|A||V_r|^2}{|B|} \cos(\beta-\alpha).$$

$$\Rightarrow \quad P_r + \frac{|A||V_r|^2}{|B|} \cos(\beta-\alpha) = \frac{|V_s||V_r|}{|B|} \cos(\beta-\delta) \quad --- (10)$$

Similarly:

$$Q_r = \frac{|V_r||V_s|}{|B|} \sin(\beta-\delta) - \frac{|A||V_r|^2}{|B|} \sin(\beta-\alpha)$$

$$Q_r + \frac{|A||V_r|^2}{|B|} \sin(\beta-\alpha) = \frac{|V_r||V_s|}{|B|} \sin(\beta-\delta). \quad -- (11)$$

(10) $(10)^2 + (11)^2$.

$$\left\{P_r + \frac{|A||V_r|^2}{|B|} \cos(\beta-\alpha)\right\}^2 + \left\{Q_r + \frac{|A||V_r|^2}{|B|} \sin(\beta-\alpha)\right\} = \left\{\frac{|V_s||V_r|}{|B|}\right\}^2$$

--- (12)

uation (12) represents the equation of circle with
x coordinate

$$x\text{-coordinate} = -\frac{|A||V_r|^2}{B} \cos(\beta-\alpha)$$

$$Y\text{-coordinate} = \frac{-|A||V_r|^2}{|B|} \sin(\beta-\alpha)$$

$$\text{radius} = \frac{|V_s||V_r|}{|\beta|}$$

The complex power per phase at the sending end of T.L:-

$$S_s = V_s I_s^*$$

$$\Rightarrow S_s = V_s \angle \delta \left\{ \frac{|D||V_s|}{|B|} \angle \beta - \Delta - \delta - \frac{|V_r|}{|B|} \angle \beta \right\}$$

$$P_s + jQ_s = \frac{|D||V_s|^2}{|B|} \angle \beta - \Delta - \frac{|V_r||V_s|}{|B|} \angle \beta + \Delta$$

$$P_s = \frac{|D||V_s|^2}{|B|} \cos(\beta - \Delta) - \frac{|V_r||V_s|}{|B|} \cos(\beta + \Delta)$$

$$\cancel{P_s} \cancel{=} \frac{|V_r||V_s|}{|B|} \cos(\beta + \Delta) = P_s - \frac{|D||V_s|^2}{|B|} \cos(\beta - \Delta) \quad \text{---} (13)$$

Similarly

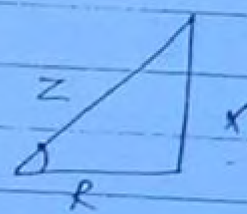
$$\cancel{Q_s} =$$

$$\cancel{Q_s} \cancel{=} \frac{|V_s||V_s|}{\beta} \sin(\beta + \Delta) = Q_s - \frac{|D||V_s|^2}{|B|} \sin(\beta - \Delta) \quad \text{---} (14)$$

$(13)^2 + (14)^2$

As ideal so no losses, resistance is neglected
$\theta \to 90^\circ$.

$\tan^{-1}\left(\frac{X}{R}\right) = 90^\circ$.



$10 \to P_r + 0 = \frac{|V_s||V_r|\sin\delta}{Z}$

$11 \to Q_r + \frac{|V_r|^2}{Z} = \frac{|V_r||V_s|\cos\delta}{Z}$.

$13 \to P_s - 0 = \frac{|V_r||V_s|}{Z}\sin\delta$.

$14 \to Q_s - \frac{|V_s|^2}{Z} = -\frac{|V_r||V_s|}{Z}\cos\delta$.

4) For a system to operate under stable conditions load angle δ must be.

$P_r = \frac{V_s \cdot V_r \sin\delta}{X}$ δ must lie b/w $0 - 90^\circ$.

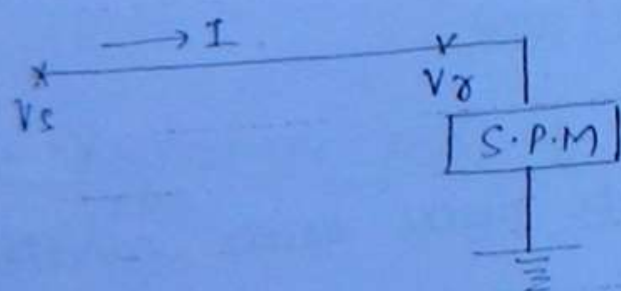
5) When sending end voltage and receiving end voltage are increased by 10% the maxm active power transferred is?

$$P_{r_{max}} = \frac{|1.1 V_s||1.1 V_r|}{X} \sin\delta$$

$$\boxed{P_{r_{max}} = 1.21 \frac{V_s V_r}{X} \sin\delta}$$

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 with the 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 requires 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

$$A = D = 0.938 \angle 1.2^\circ$$
$$B = 131.2 \angle 72.3^\circ \Omega$$
$$C = 0.001 \angle 90^\circ \text{ S.}$$

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 $I_R = 0$, $V_r \rightarrow V_{RO}$

$V_s = V_{R0}/A = \frac{230/\sqrt{3}}{0.938 \angle 1.2^\circ}$

$141.57 \angle -1.2^\circ$ KV

re $V_{S\,L-L} =$ ~~2r~~ $245.20 \angle -1.2$ KV

) charging current, current through capacitor when receiving end is O.C.

2. $I_S = CV_R + DI_R$

$I_R = 0$

$I_{charging} = I_S = CV_R$

$(0.001 \angle 90^\circ)(141.57 \angle -1.2^\circ)$

$I_{charging}\ 141.57 \angle 88.8^\circ$

(c) $P_r = \frac{|V_s||V_r| \cos \angle \beta - \delta}{|B|} - \frac{|A||V_r|^2 \cos(\beta - \alpha)}{|B|}$

P_r is max $\beta = \delta$.

$P_{r\,max} = \frac{|V_s||V_r|}{B} - \frac{|A||V_r|^2 \cos(\beta - \alpha)}{|B|}$

$$P_{rmax} = \frac{|132.79||141.57|}{131.2} - \frac{|141.57|^2|0.938|}{131.2}\cos(72.3-1.2^\circ)$$

$P_{rmax} = 91.2MW.$

→ 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 20Ω/phase. Determine the load, which the line will be supplying at 132 kV at 0.8 p.f lagging. The sending voltage is 140KV. If a SPM is connected in parallel with load to improve the powerfactor upto 0.95 lagging. determine the leading MVAR supplied by synchronous phase modifier. the receiving end voltage and load are constant. Assume ABCD 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.

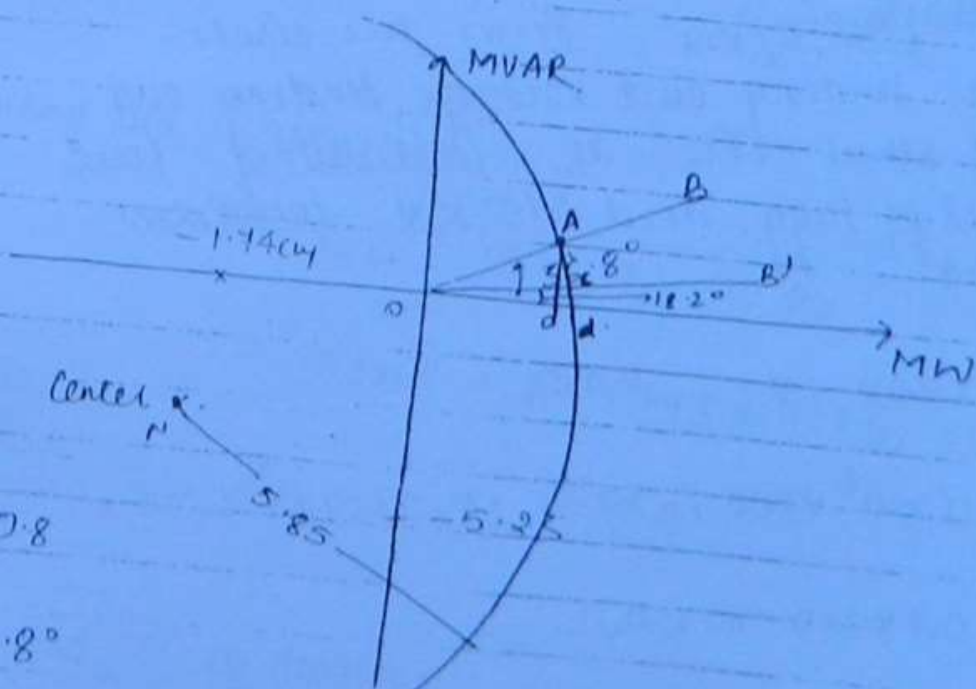
1cm = 200 MW = 200 MVA = 200 MVAR.

radius $= \frac{1168.8}{200}$ 5.85 cm.

Horizonal co-ordinate $= \frac{-347.8}{200} = -1.74$ cm.

vertical co-ordinate $= -\frac{1045.6}{200} = -5.25$ cm.

Step 3: construction 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 cm

= 0.1×200

= 20 MVAR.

when T.L is supplying at 132 KV and 0.8 p.f. The power supplied is

OD = 0.3 cm.

= 200×0.3

60 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 ∠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 = ?

$MW = \sqrt{3} V_{RL} I_{RL} \cos\phi_R$

$192 \times 10^6 = \sqrt{3} \times 275 \times 10^3 \times I_{RL} \times 0.8$

$I_{RL} = I_R = 504 A$

Receiving end circle diagram

Horizontal = $\frac{|A||V_R|^2}{|B|} \cos(\beta - \alpha)$

$= \frac{0.9075 \times 275 \cos(78.69 \ldots}{}$

vertical co-ordinate

$$-\frac{|A||V_R|^2 \sin(\beta-\alpha)}{|B|}$$

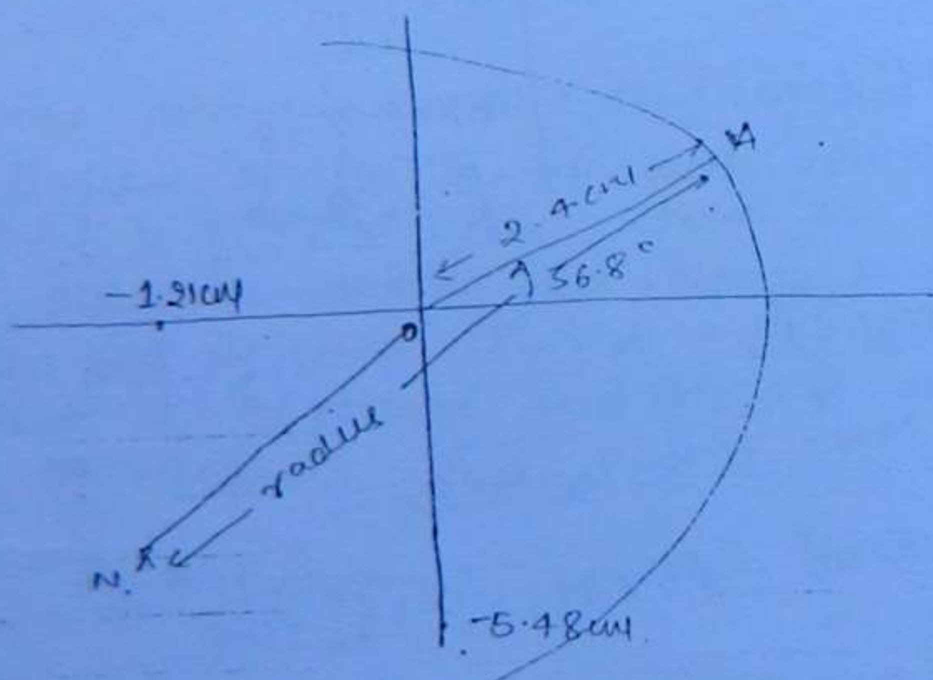
$= -548$ MVAR

Power Scale:

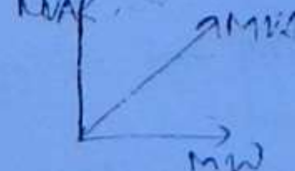
1cm = 100MW = 100MVAR

$= -1.21$ cm

$= -5.48$ cm.



Volt Ampere at the receiving end at the T.L



$V_A = \sqrt{3} \cdot V_{RL} \cdot I_{RL}$

240MVA

let 1cm = 100MVA $\Rightarrow$ VA = 2.4 cm radius of the circle is equal to $NP \Rightarrow 7.6$ cm.

$= 7.6 \times 100 = 760$ MVA.

The Resultant VA $760 = \frac{V_s V_r}{B}$.

$$760 = \frac{V_s \cdot 275}{122.38}$$

$$V_s = 338 \text{ KV}.$$

2) Sending end circle diagram:-

$$\text{Horizontal} = \frac{|D|}{|B|} |V_s|^2 \cos(\beta - \Delta)$$

$$= 183 \text{ MW}$$

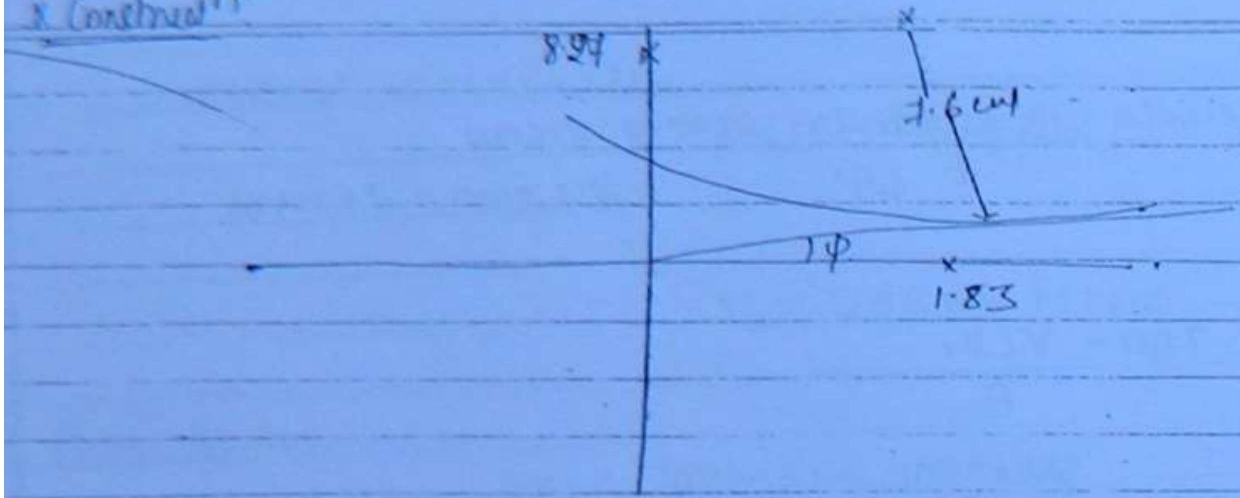
$$\text{vertical coordinate} = \frac{|D|}{|B|} |V_s|^2 \sin(\beta - \Delta)$$

$$827 \text{ MVAR}$$

$$\text{radius} \; \frac{|V_s||V_r|}{|B|} = 760 \text{ MVA}$$

1cm = 100MW = 100MVAR = 100MVA

x Construc^n:



ϕ_s(graph) = 15°

$\cos(\phi_s) = \cos 15° = 0.966$.

→ sending end current

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

$$240 \times 10^6 = \sqrt{3} \times 33 \times 10^3 \times I_{SL} \times 0.966$$

$$\boxed{I_{SL} = 410A}$$

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 max^{m} 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

Quest^{n}

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 3 hr/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

$$(10 \times 60) + (2 \times 1000)$$

$$= 2600 \text{ W}$$

2) demand factor = $\dfrac{\text{Max demand}}{\text{Connected load}}$

$$= \frac{1000}{2600} = 0.38$$

3) Energy consumed per day = $(8 \times 5 \times 60) + (2 \times 1000 \times 3)$

$$= 8400 \text{ W}$$

$$= 8.4 \text{ kWh}$$

4). Average load = $\frac{\text{Total E.G}}{\text{No of hour}} = \frac{8400}{24} = 350W$.

5) Load factor = $\frac{A.L}{\text{Max demand}} = \frac{350}{1000} = 0.35$.

7) DIVERSITY FACTOR

sum of the individual max^m demand by max^m demand existing on s/m.

$$D.f = \frac{\Sigma(I.M.D)}{M.D\ of\ s/m} > 1.$$

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 − Max^m 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 max^m demand on G/r station is 80 MW. the plant capacity factor and Plant utilizat^n 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 stat^n operates at max^m demand of 100 MW. load factor 0.65, plant capacity factor is ~~equa~~ 0.5 Plant use factor 0.75. Calculate

1) Average load
2) No of units Generated
3) Plant capacity
4) Reserve Capacity
5) Max^m energy that can be generated by power stat^n
6) No of hours the generating stat^n operates.

CORONA

→ Electrical power transmission takes place through power conductor

→ the power conductor is in the atmosphere.

→ the ionisation of air surrounding the power conductor is known as corona

→ If the electric field intensity around the power conductor is grstr than the dielectric strength of air then corona occurs otherwise corona donot occurs.

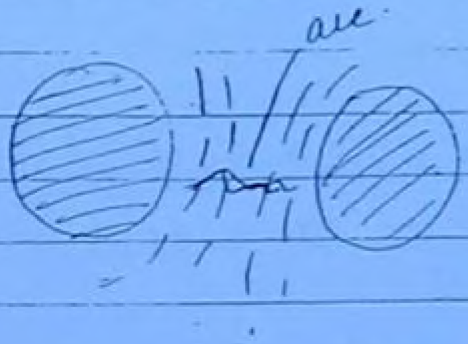
→ corona can be eliminated by

1) decreasing electric field intesity
2) Increasing dielectric strength of air
3)

→ Due to radio activity no of free electrons around the power conductor results in high electric field intensity

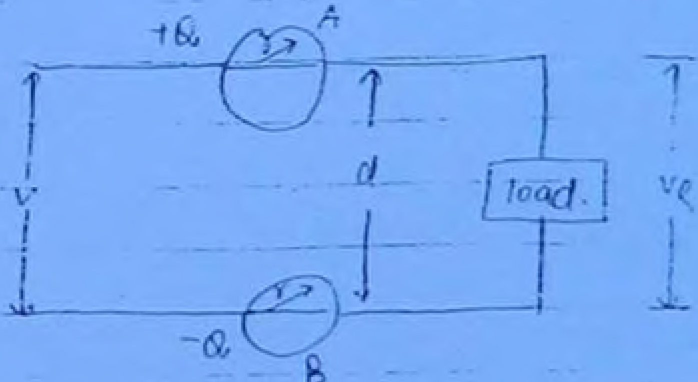
→ for EHV T.L where the operating voltage is greater 275 KV the free electrons travel at a higher velocity such that Dielectric strength of air is neglected

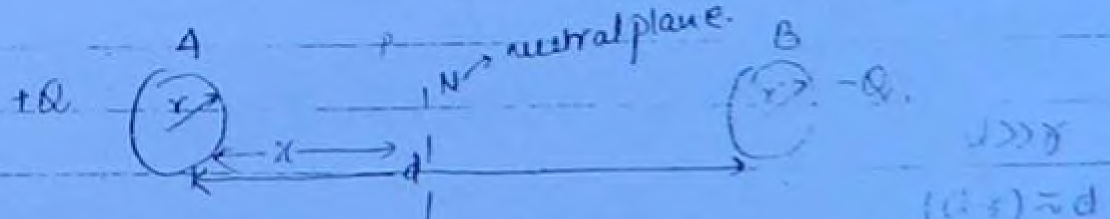
→ When corona occurs due to two power conductors arc is formed in the air resulting in line to line fault.



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'

$$E_{x_A} = \frac{Q}{2\pi\varepsilon_0\varepsilon_r x} = \frac{Q}{2\pi\varepsilon_0 x} \quad \text{---} (1) \quad \because \varepsilon_r = 1 \text{ (air)}$$

$$E_{x_B} = \frac{Q}{2\pi\varepsilon_0\varepsilon_r (d-x)} = \frac{Q}{2\pi\varepsilon_0 (d-x)} \quad \text{---} (2)$$

• Electric field intensity at the point P due to conductor 'B' is eqn (2)

• Total electric field intensity b/w the two conductors

$$E_x = E_{x_A} + E_{x_B}$$

$$\boxed{E_x = \frac{Q}{2\pi\epsilon_0}\left[\frac{1}{x} + \frac{1}{d-x}\right]}$$ --- 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

$$\boxed{V = \frac{Q}{\pi\epsilon_0}\ln\frac{d}{r}}$$ $\because (d-r) = d$

In 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

$$E_x = \frac{Q}{2\pi\epsilon_0}\left[\frac{1}{x} + \frac{1}{d-x}\right]$$

$$= \frac{Q}{2\pi\epsilon_0}\left\{\frac{d-x+x}{x(d-x)}\right\}$$

$$\boxed{E_x = \frac{Q}{2\pi\epsilon_0}\left[\frac{d}{x(d-x)}\right]} \quad \text{------} \quad 5.4.$$

substituting (3) in (4) Value $Q = \dfrac{\pi\epsilon_0 V}{\ln(d/r)}$

$$E_x = \frac{\pi\epsilon_0 V}{\ln(d/r)} \cdot \frac{1}{2\pi\epsilon_0}\left\{\frac{d}{x(d-x)}\right\}$$

$$\boxed{E_x = \frac{V}{2\ln(d/x)}\left\{\frac{d}{x(d-x)}\right\}}$$

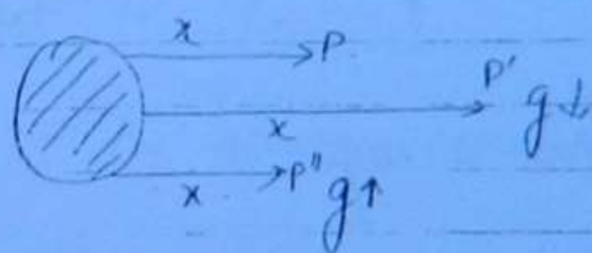
- In above equat^n ($V/2$), these voltage represents the potential of conductor A w.r.t neutral plane.

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.

Definition :-

The voltage at which complete disruption 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

$$\boxed{V' = V_d = \gamma_0 \cdot r \cdot \ln\left(\frac{d}{r}\right)}$$

$g_{max} \rightarrow \gamma_0 \rightarrow g_0$.

γ_0 is dielectric strength in KV/cm/peak value.

$$\boxed{\gamma_0 \rightarrow 30 KV/cm/peak \text{ at NTP}}$$

where $P \rightarrow$ 76cm of Hg $\approx$ 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) $\rightarrow$ for ~~at other~~ than NTP.

- For any value of temperature and pressure $(\gamma_0' < \gamma_0)$.
- At any other temp and pressure.

$$\boxed{V_d = (\gamma_0 \cdot \delta) \cdot r \cdot \ln(d/r)}$$

$$\boxed{V_d = (21.1\,\delta)\, r \ln(d/r)} \text{ kV/rms.}$$

- 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

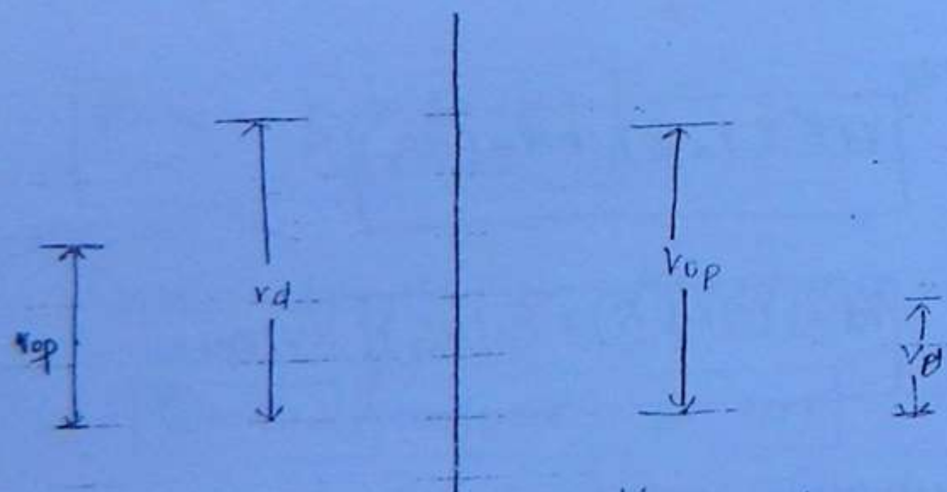
4). $m = 0.9$ → cable > 7 strands.

o,

$$\boxed{V_d = (8\,(\gamma_{0.8})(m)(r)\ln(d/r).}$$

$$\boxed{V_d = (21.18)\cdot m\, r \ln(d/r).}$$

Example:



Vop < Vd
corona do not occur.

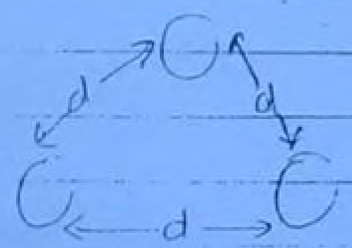
Vop > Vd
Corona occurs.

electric field intensity must be more so operating voltage must be more > Vd

- In terms of GMD.

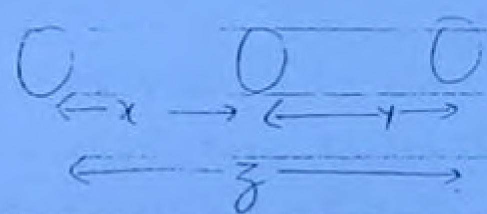
$$V_d = 21.18\, m \cdot r \ln\left(\frac{GMD}{r}\right)$$

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 $\boxed{\gamma_v = (21.1\,\delta)\left(1 + \frac{0.5}{\sqrt{\delta r}}\right)}$

- $\boxed{V_v > V_d}$

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)

$\frac{P_{60Hz}}{1.2} = \frac{85}{75}$

$$\boxed{P_{60Hz} = 1.36 \text{ KW/Km/ph}}$$

2). for 400KV ac line P_{loss} 3 KW/Km/ phase

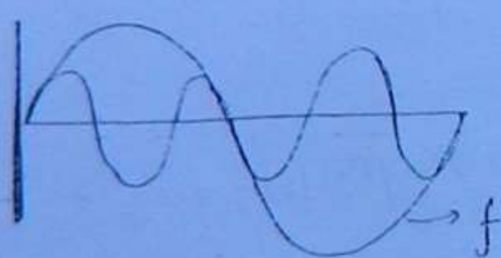
for 400KV DC line

$P_{DC} = ?$

Soln

$\Rightarrow$ 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 = 50Hz

1: $P_{AC} \propto (50+25) = 75$

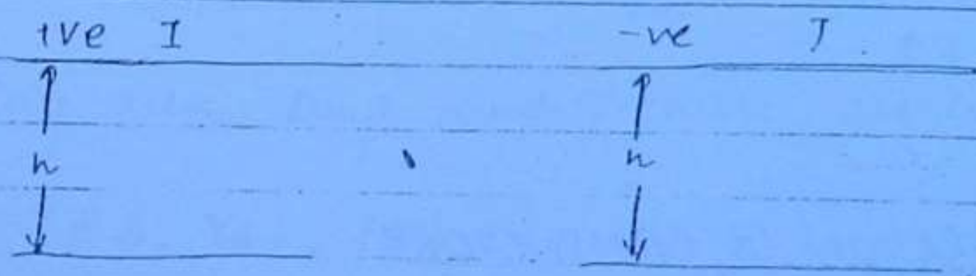
2: $P_{AC} \propto (50+150+125) = 225$ ... 3rd

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.



$P_{loss} \uparrow$ $\qquad\qquad$ $P_{loss} \downarrow$

- In positive polarity conductor mobility of conductor is high corona loss increases.

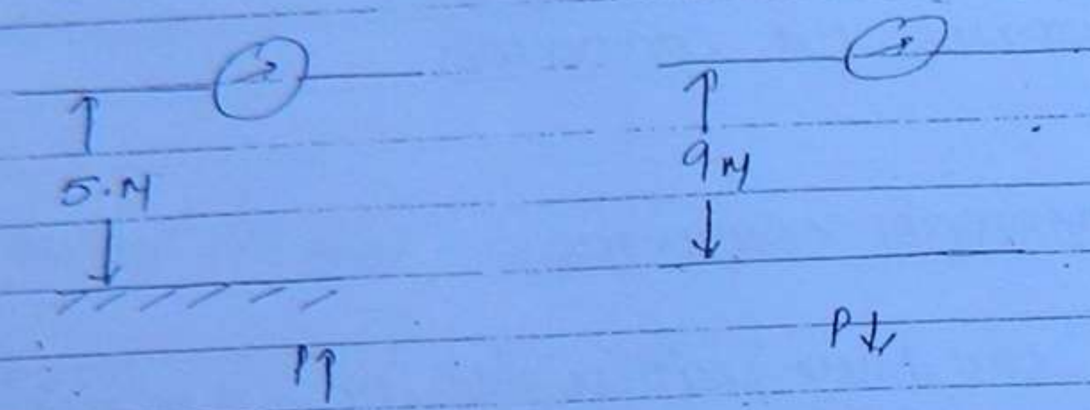
4) DISTANCE B/W CONDUCTORS

$$\boxed{P \propto 1/\sqrt{d}}$$

$d \uparrow , P \downarrow$

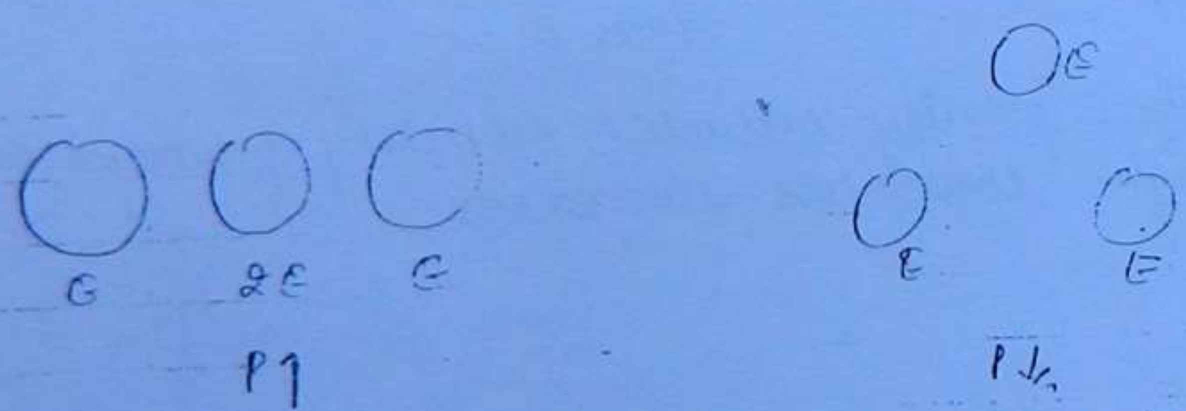
$d \downarrow , P \uparrow$

- At higher distance corona loss decreases



(EFI ↓, so
is ionisation ↓.
as a result P↑.

5) CONFIGURATION OF CONDUCTORS



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:

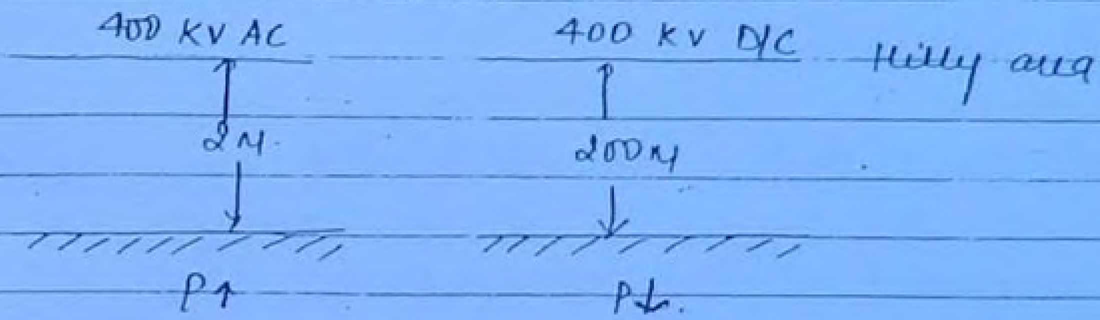
1) temperature and pressure

- As $\delta\uparrow$ $V_d\uparrow$, $P\downarrow$

→ Temperature and pressure ⇒ P ↓
→ deposition of ice → P ↑

Questn :-

for the given 400KV ac line.



- 1 hilly area temp and pressure are less. ($\delta \downarrow$)

($\delta \downarrow$, $V_d \downarrow$, $P \uparrow$)

2) Diposition of ice / snow on surface of conductor.

$M \downarrow$, $V_d \downarrow$ and $P \uparrow$

C) FACTORS RELATED TO SIZE OF CONDUCTORS:-

- Corona can be decrease by selecting a conductor of small radius.

- If $r \downarrow$, $V_d \downarrow$, corona ↑, so while selecting radius of conductor disruptive voltage V_d 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~~ $V_d \uparrow$, $P \downarrow$

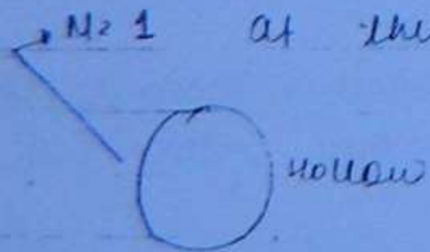
DISADVANTAGE OF CORONA

- 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.

$\mu = 1$ as 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. 5m apart. the air temp is 52°C and altitude is 3000m corresponding to pressure of 415 mm of Hg. the frequency of spl is 50Hz. Irregularity factor is 0.88 for the critical disruptive voltage and 0.75 for visual critical voltage.

Soln

$d = 5m$

• $\pi r^2 = 100$

$r = \sqrt{\frac{100}{3.14}} = 5.64 mm = 5.64 \times 10^{-3} m$

• $\ln(d/r) = \ln\left(\frac{3000}{5.64}\right) = 6.28 = ~~1298~~ 15.18$

$\sqrt{r/d} = 0.043.$

air density correctn factor $\delta = \frac{3.92 h}{273 + t}$

$\delta = \frac{3.92 \times 415}{273 + 32°} = ~~5.38~~ \; 0.918$

$Vd = 21.1 \delta m_0 r \ln(d/r)$

$= 21.1 \times 0.918 \times 0.88 \times 5.64 \times 10^{-3} \times 6.28$

Critical disruptive voltage.

$$= 21.1 \times \delta \times m_v \times \ln(d/r)$$
$$= 0.515\ kV/m.$$

Corona Loss.

$$P_{loss} = 24 \times 10^{-5} \left(\frac{f+25}{\delta} \right) \sqrt{\frac{r}{d}} \left\{ (V_{ph} - V_d)^2 \right\}$$

$$= 24 \times 10^{-5} \left(\frac{75}{0.918} \right) \times 0.043 \times \left\{ \frac{220}{\sqrt{3}} - 0.604 \right)^2$$

$$= 13.47\ kV/km/ph$$

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 destruptive voltage do not exceed 250KV b/w the line. the breakdown strength is 35KV/cm (max^m)

$V_d \rightarrow 250\ KV$

$m = 0.93$

$\delta = 0.9$

$r = 20 \times 10^{-3}$.

$V_d = 21.1\ r \ln(d/r)$

8

critical disruptive voltage $\frac{35}{\sqrt{2}}$ cm/rms

$\frac{35}{\sqrt{2}} = 21.1 \times 0.9 \times 0.93 \times \ln(d/2.0) \times 20$

$\ln(d/r) = 1.4$

$d/r = e^{1.4}$

$d = 4.05 \times 2$

$= 8.110$ cm.

$V_d = (24.75)\, m \cdot \delta \cdot r \cdot \ln(d/r)$ KV/cm.

$250/\sqrt{3} = (24.75)(0.95 \times 0.9 \times 2 \times \ln d/r)$

$d/r = 32.46$

$d = 32.46 \times 2$

$= 64.92$ cm.

5) find the corona characteristic of ~~bundle~~ 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 = 50Hz

r = 0.4cm

t = 28°C

h = 75cm

N = 0.84

Nr = 0.75

d = 2.8N.

$r/d = \frac{0.4}{0.28} = 1.19 cm.$

$V_{02} \ \ln\left(\frac{d}{r}\right) = \ln\left(\frac{2.8}{0.4}\right) = 4.24.$

$V_0 = 21.1 \cdot 8 \cdot 0.4 \times 0.84 \ \ln\left(\frac{28}{2.4}\right)$

$\delta = \frac{3.92 \times 75}{273 + 28} = 0.976$

$V_0 = 21.1 \times 0.976 \times 0.4 \times 0.84 \times 4.24$

= 233KV/cm/ph

critical disruptive voltage

$21.1 \times 0.976 \times 0.75 \times 4.24$

= 65.42 KV/cm/ph.

$P_{loss} = 241 \times 10^{-5} \times \left(\frac{50+25}{0.976}\right) \times \sqrt{1.19} \times \left\{\frac{110}{\sqrt{3}} - 29.3\right\}^2$

= 25.67

INSULATOR

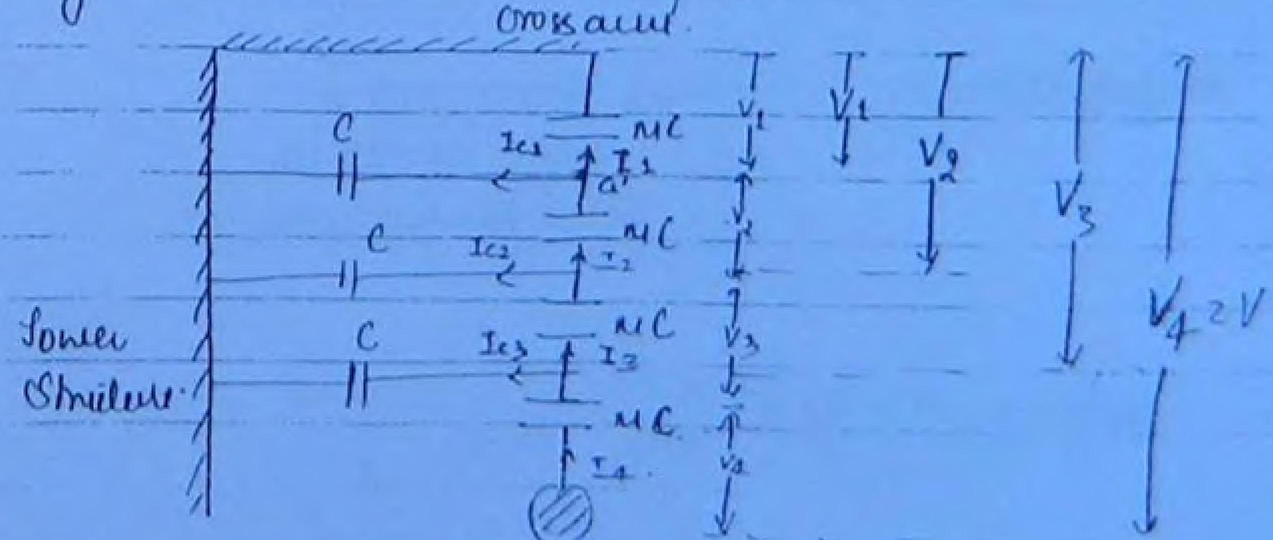
- Insulator provide insulation to the power conductor from the ground.
- Material used:

  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 ~~sov~~ 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 → 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'

$$\Sigma I_{in} = \Sigma I_{out}$$

$$I_2 = I_1 + I_{c1}$$

$V_2 \omega(MC) \cancel{V_2} = V_1 \omega(MC) + V_1(\omega C)$

$\Rightarrow V_2 \cancel{\omega} . M\cancel{C} = V_1 \cancel{\omega C}(M+1)$

$$\boxed{V_2 = V_1\left(\frac{1+M}{M}\right)} \quad \text{--- (1)}$$

- applying at 'b'.

$I_3 = I_{C_2} + I_2$

$V_3 \omega(MC) = (V_1 + V_2)\omega C + V_2 \omega(MC)$

$$\cancel{\boxed{V_3 = V_2\left(\frac{M+1}{M}\right)}} \quad \text{--- (2)}$$

$V_3 M = V_2 M + V_1 + V_2$

$V_3 . M = V_1 + V_2(1+M)$

$V_3 = \frac{V_1}{M} + V_2\left(\frac{1+M}{M}\right)$

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'

$$\Sigma I_{in} = \Sigma I_{out}$$

$$I_4 = I_3 + I_{c3}$$

$$V_4 \cancel{\omega} MC = V_3 \cancel{\omega}(MC) + (V_1 + V_2 + V_3) \cancel{\omega C}$$

$$V_4 = \frac{V_1}{M} + \frac{V_2}{M} + V_3\left(\frac{1+M}{M}\right)$$

$$\boxed{V_4 = V_1 \left\{ \frac{M^2 + 3M + 1}{M^2} + \frac{3M^2 + 4M + 1}{M^3} \right\}} \quad \text{- (3)}$$

Let $M = 5$

$$V_2 = V_1\left(\frac{1+M}{M}\right) = V_1\left(\frac{1+5}{5}\right) = 1.2V_1$$

$$V_3 = V_1\left(\frac{M^3 + 3M + 1}{M^2}\right) = V_1\left(\frac{125 + 15 + 1}{25}\right) = \frac{41V_1}{25} = 1.64V_1$$

$$V_4 = 2.408 V_1$$

$$\boxed{V_1 < V_2 < V_3 < V_4}$$

• string efficiency = $\frac{V_1 + V_2 + V_3 + V_4}{4 \times V_4} \times 100$.

$$= \frac{V_1 + 1.8V_1 + 1.64V_1 + 2.408V_1}{4 \times 2.408 V_1}$$

$$= \cancel{6.408}\ 54.4\%.$$

Important

$$I_4 = I_3 + I_{3C}$$

$$I_n = I_{(n-1)} + I_{(n-1)C}.$$

$$V_{n+1}(\omega m C) = V_n.(\omega m C) + V_n(\omega C)$$

$$\boxed{V_{n+1} = \frac{V_n}{m} + V_n.}$$

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 maximum 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.

$$I_{n+1} = I_n + I_{cn} \quad \cdots (1)$$

$$\boxed{I_{n+1} = V \cdot [\omega m C_{n+1}]}$$

$$I_{c_3} = 3V \cdot \omega C$$

$$V_1 = V_2 = V_3 = V_4 = V.$$

$$\boxed{I_n = V(\omega m C_n)}$$

so equation

$$V[\omega m C_{n+1}] = V(\omega m C_n) + nV\omega C.$$

$$\boxed{m C_{n+1} = C_n + \frac{nC_n}{m}}$$

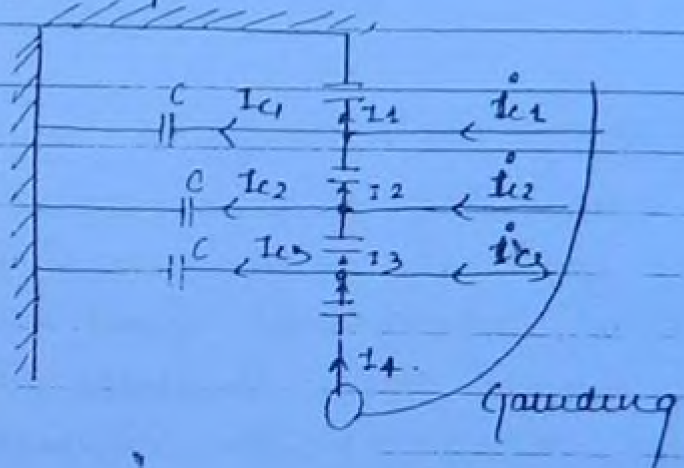
DISADVANTAGES:-

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 the 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

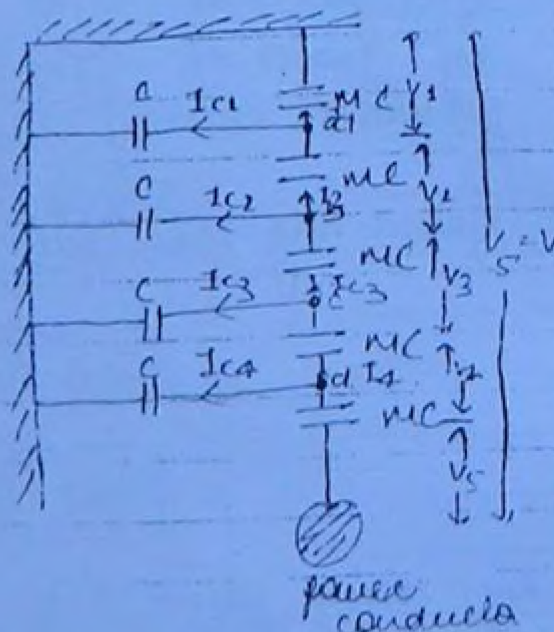
$$\boxed{C_n = \frac{n}{K-n} \cdot C}$$

• K → total no of disc
• n → no of disc upto which gaurding can be utilized.

Date
9 Oct 2010

Question:

In transmission tower 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 gre 1

• Pin to earth capacitance = C
Mutual capacitance

$$MC = 6C$$
$$\therefore \boxed{M = 6}$$

$$I_5 = I_4 + I_{c4}$$

$$V_5 \times \omega m C = V_4 \omega m C + V_4 \omega C.$$

$$= \quad V_5 \cdot m = V_4 m + V_4$$

$$\boxed{V_5 = V_4 + \frac{V_4}{m}} \quad \text{------} \; (1)$$

Imp formula

$$\boxed{\text{for } n = 4 \quad = \quad V_{n+1} = V_n + \frac{V_n}{m}.}$$

n is no of insulator from top tower the structure.

• ($n = 1$)

$$V_{n+1} = V_1 + \frac{V_1}{m}.$$

$$V_2 = V_1 + \frac{V_1}{m} \qquad \text{as } \boxed{V_1 = V_1}$$

$$V_2 = V_1\left(1 + \frac{1}{6}\right)$$

$$\boxed{V_2 = V_1 \cdot 7/6} \quad \text{----} \; (2)$$

• ($n = 2$)

$$V_3 = V_2 + \frac{V_2}{m}.$$

$$V_3 = V_2 + \frac{V_1 + V_2}{m}$$

$$V_3 = \frac{V_1}{m} + V_2\left(1 + \frac{1}{6}\right) \qquad \text{substitute value of } V_2 \text{ from } (2)$$

$$V_3 = \frac{V_1}{6} + V_1\left(7/_6\right)\left(7/_6\right)$$

$$\boxed{V_3 = V_1\left(\frac{55}{56}\right)}$$

n=3 :

$$V_4 = V_3 + \frac{V_3}{N}$$

$$V_4 = V_3 + \frac{V_1 + V_2 + V_3}{N}$$

$$V_4 = V_3\left(1 + \frac{1}{N}\right) + \frac{V_1 + V_2}{N}$$

$$V_4 = \frac{55 V_1}{36} \cdot \frac{7}{6} + \frac{V_1}{6} + \frac{87 V_1}{6 \cdot 6}.$$

$$\frac{385}{216} V_1 + \frac{V_1}{6} + \frac{7 V_1}{36}$$

$$\boxed{V_4 = \frac{463}{216} V_1}$$

n=4

$$V_5 = V_4 + \frac{V_4}{N}.$$

$$V_5 = \frac{463}{216} V_1 + \frac{V_1 + V_2 + V_3 + V_4}{N}$$

$$V_5 = \cancel{\frac{463}{216} V_1} + \frac{V_1}{N} + \frac{6\,7 V_1}{6 \cdot 6} + \frac{5}{3}\,\frac{V_1}{6} + \frac{463}{216} \cdot \frac{7}{6} V_1$$

$$\frac{V_1}{6} + \frac{7 V_1}{36} + \frac{55 V_1}{216} + \frac{3\,3 \times V_1}{1296}$$

$$\boxed{V_5 = 311 V_1}$$

voltage across string

$$V = V_1 + V_2 + V_3 + V_4 + V_5$$

$$= V_1\left(1 + \frac{7}{6} + \frac{55}{36} + \frac{463}{216} + 3.11\right)$$

$$\therefore V = V_1 \times 8.94.$$

%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

- $V_3 = 17.05\%$ of V

- $V_4 = \frac{463}{216} \times 11.16$ of $= 25.92\%$ of V.

$V_5 = 3.11 \times 11.16$ of V

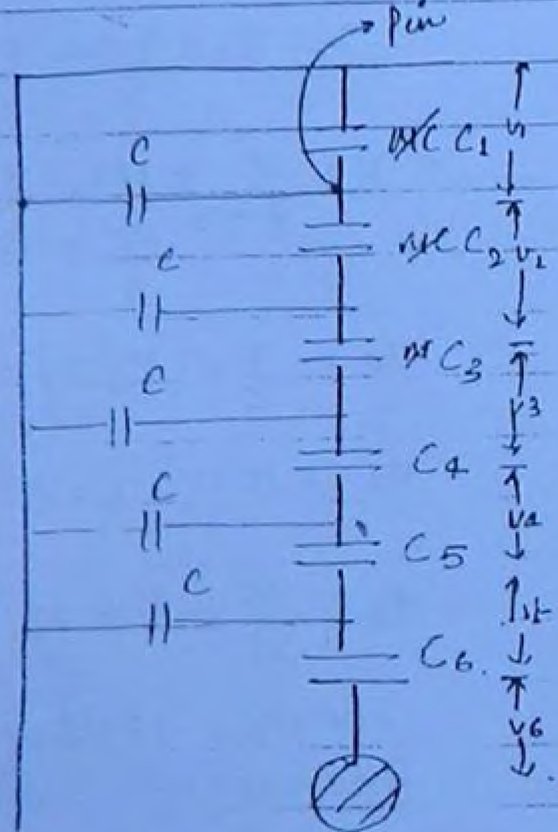
- $V_5 = 34.07\%$ of V

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 $\boxed{N \neq 1}$,

$\therefore$ $C_{n+1} = \; n+1C$

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) $n=4$

$$C_5 = C_4 + 4C$$

$$16C + 4C$$

$$\boxed{C_5 = 20C}$$

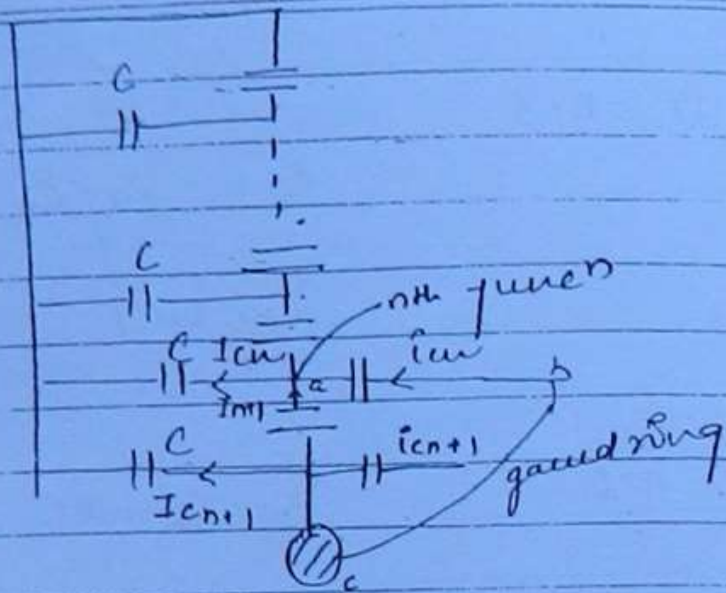
5) $n=5$

$$C_6 = C_5 + 5C$$

$$\boxed{C_6 = 25C}$$

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 gaurd 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 eqn (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.

$$C_n = \left(\frac{n}{K-n}\right)C.$$

$$C_2 = \left(\frac{6-1}{5}\right)$$

$$C_2 = \frac{1}{?}C.$$

$n_3 = \frac{3}{4} C = C_3$

$n_4 = \frac{4C}{3} = C_4$

$n_5 = \frac{5C}{2} = C_5$

$n_6 = 6C = C_6$.

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 juncn 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

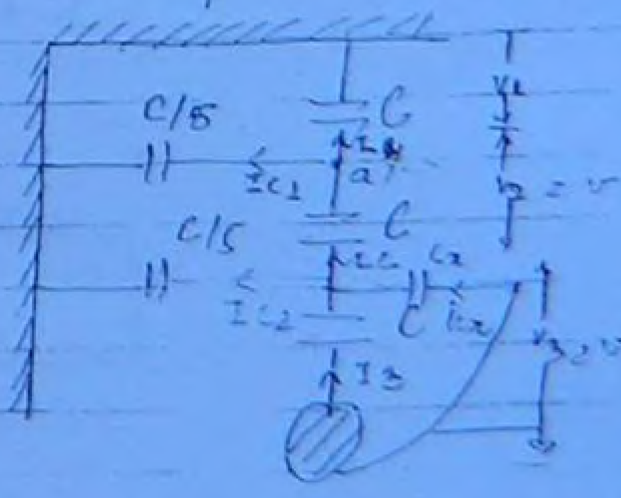
2) the value of capacitance C_x required.

Solut^n $v_2 = v_3$ (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'

$$I_1 + I_{C_1} = I_2$$

$$\Rightarrow \cancel{\omega C} . V_2 = V_1 . \cancel{\omega C} + V_1 . \frac{C \omega}{5}$$

$$\boxed{V_2 = \frac{6}{5} . V_1} \text{ ——— (2)}$$

substituting on (1)

$$C_x = \left(\frac{V_1}{V} + 1\right) \times \frac{C}{5}$$

$$C_x = \left(\frac{5 \cancel{V_1}}{6 \cancel{V_1}} + 1\right) \times \frac{C}{5}$$

$$C_x = \frac{11}{5} \times \frac{C}{5} =$$

$$\boxed{C_x = \frac{11}{30} C}$$

→ voltage across line end unit $V_2 = V_3 = V =$

$$V_1 + V_2 + V_3 = 20$$

$$V_1 + 2V = 20$$

$$V_1 + 2 \times \frac{6}{5} V_1 = 20$$

$$\frac{5+12}{5} V_1 = 20$$

$$\frac{17}{5} V_1 = 20$$

$$V_1 = \frac{100}{17}$$

$$\text{So} \quad V = \frac{6}{5} \times \frac{\cancel{100}^{20}}{17} = \frac{120}{17} \text{ kV}$$

$$\boxed{V = 7.05 \text{ kV}}$$

TYPES OF INSULATOR

1) Pin insulator: (upto 25 KV)

- A pin insulator operate upto 25KV
- multipin insulators operate upto 55KV
- vertical 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 configuratn $\boxed{132/11 = 12.\ \text{disc.}}$

) Strain insulator: (mechanically strong).

Strain insulator is mechanically strong, it is used when T.L directn is changed. or when T.L is laid across a river or at the dead end. of
(vertical configuratn)

) 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:

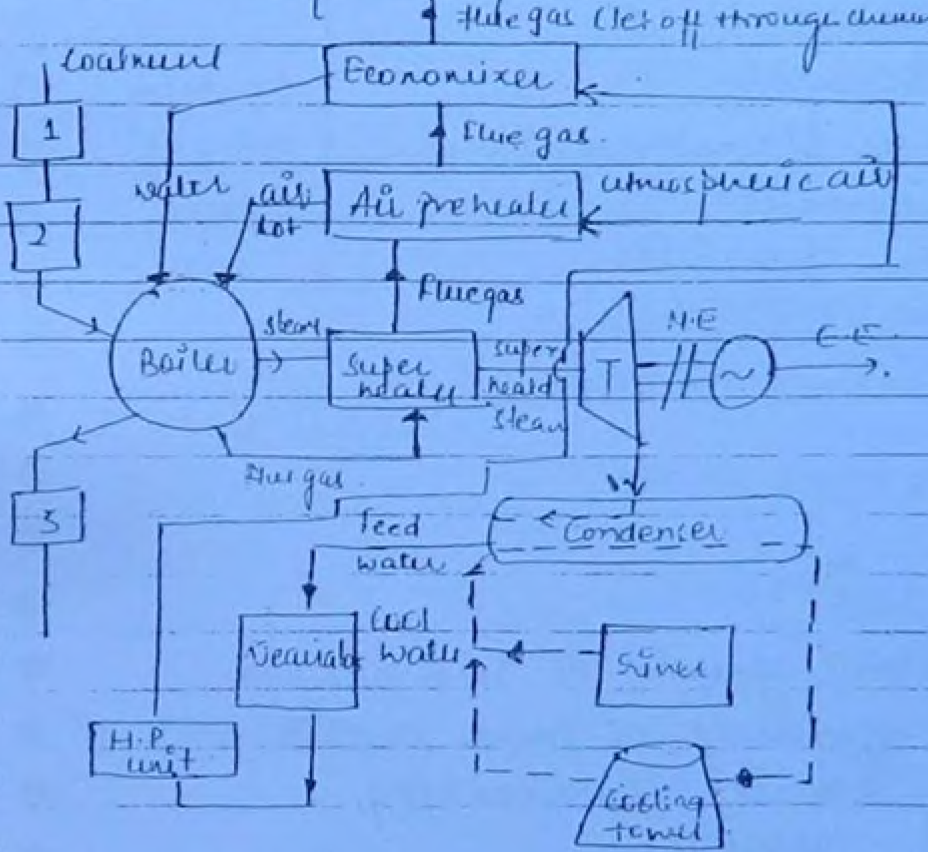
) Synthetic Resin:-
Used in the region where rainfall is mor.
(17% costlier)

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.

Avg thermal stat^n 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 stat^n spends Rs 10.6 lakh/yr for utilization of coal. the efficiency of power stat^n 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 stat^n.

Sol^n

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

$= 5000 \times 21200 \times 1000$

$= 1.06 \times 10^{10}$ kcal/year.

3) Heat output

$= 0.30 \times 1.06 \times 10^{10}$

$= 3.18 \times 10^{9}$ 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.

$$= \frac{\text{Energy gen/year}}{\text{no. of hour/year}}$$

$$= \frac{3.69 \times 10^6}{365 \times 24}$$ ~~0.422 KW~~ 0.42 MW

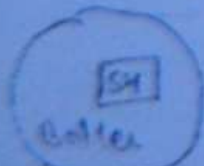
(i) BOILER:-
- → Water tube Boiler
- → Fire tube Boiler

• 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.

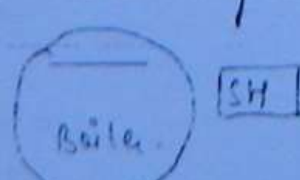
(ii) SUPER HEATER:

In the super heater the temperature of steam is increase by ~~increasing~~ absorbing heat of flue gases.

• Radiant Super heater

• 

• Convection Super heater

• 

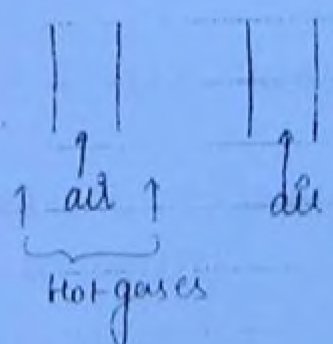
- more efficient
- less efficient

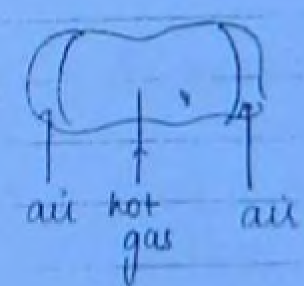
(v) AIR PREHEATER:

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
- explosion donot occur

- less efficient
- explosion may occur when temp hot gases increases

Questn:

A thermal power stath 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 generat^n.

Solut^n:

capacity = 100 MW

power output = 100 MW
= 100×10^3 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 utilised for generatⁿ = $\frac{2.8 \times 10^6 \text{ Kal/hr}}{6400}$

= 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

- Steam is expanded completely
- Pressure on moving plates is constant
-

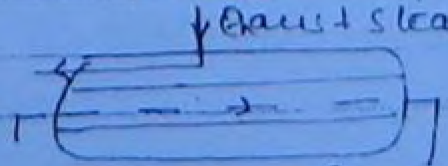
REACTION TURBINE

- Steam is expanded partially.
- 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

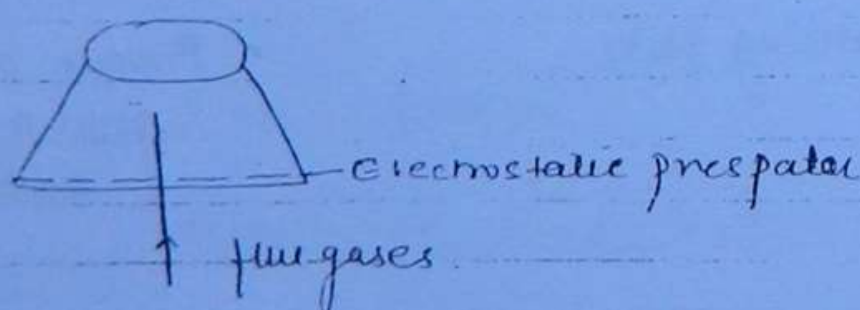
- less efficiency

- 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 50 KV

Induced draft fan forces the flue gases from the bottom surface to top surface

Quesn

A thermal power staⁿ has efficiency 21%. 0.75 Kg of coal is utilized to generate 1 KWh of energy calculate

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 :

1KWh = 860 Kcal/kg.

Heat output = 860 Kcal.

2) calorific value of coal.

=

$$1\,KWh \begin{cases} \rightarrow 860\,Kcal \\ \rightarrow 0.75 \end{cases}$$

$$= \frac{860}{0.75}\frac{Kcal}{Kg} = 1.146 \times 10^3\ Kcal/Kg$$

3) Heat i/p $= \frac{860}{0.21} = 4.1 \times 10^3$ Kcal

7) A thermal power station utilizes 0.7 kg of coal to generate electrical energy of 1 kWh. 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.

Solution

1 kWh ⟶ 860 kcal.

heat input C.V = ~~7421~~ CV × coal.

7421 × 0.7 kg

= 5194.7 kcal

$$\% \eta_T = \frac{860}{5194.7 \times 0.95 \times 0.6}$$

$\eta_T = 0.18$

$\eta_T = 18\%$

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:
   a) Low head HEPS (0-70) Ex Propeller
   b) Medium HEPS (70-300) Kaplan
   c) High HEPS (>300) Pelton

3) 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.

$$\boxed{P = \frac{736}{75} Q.w.} \quad K.W$$

$$\boxed{P = 9.81 Qh} \quad KW.$$

- 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 ~~~~ reservoir at a rate of $50 m^3/sec$. The head of water $h = 50m$. 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) Evaporation
3) Stream flow or Runoff (m^3/sec)

$$\boxed{\text{Runoff} = \text{Precipitation} - \text{Evaporation}}$$

Precipitatⁿ: the volume of water available (m^3) or water discharged from the river to HE generating statⁿ.

Evaporation: the volume of water evaporated during its normal flow is evaporation

Run-off: the ~~to~~ volume of water available at HE G/r station is known as run off

numericals:
day-sec-meter - $1m^3$/sec in day
month-sec meter → $1m^3$/sec in month
year-sec meter → $1m^3$/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 evaporatⁿ. 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 =

Avg rainfall $\times 200 \times 10^6$

$= \cancel{0.420}\ 0.420 \times 200 \times (10^3)^2\ m^3/year.$

$= \cancel{88}\ 840 \times 10^6\ m^3/year$

Available water for station $= 0.7 \times 840 \times 10^6$

$= 588 \times 10^6\ m^3/year$

Volume of water discharge/sec = 18.64 m^3/sec

$P = 9.81 \times 18.64 \times 75 \times (.8) \times (.85)$

9.3MW

Ques A hydro-electric g/r station has the following data

1) Operating head → 30m.
2) reservoir area → 400 km^2
3) Avg rain/year → 125 cm/year
4) yield factor = 75% (available)
5) $\eta_{t} = 86\%$
6) $\eta_{Penstock} = 90\%$
9) $\eta_{a\,tr} = 95\%$

the power generated is ?

$$P_{tr} = \cancel{12.5}\ 12.5 \times 400 \times 10^6 \times$$
$$= 5 \times 10^8 \, m^3/year.$$

$$\text{Available water} = \frac{5 \times 10^8}{365 \times 24 \times 60 \times 60}$$

$$Q = 11.89 \, m^3/sec$$

$$P_t = 11.89 \times 30 \times 9.81 \times \cancel{0.75} \times .85 \times .90 \times 0.95$$
$$=$$

can be obtained for voltage and current equatⁿ.

from eqⁿ (1)

$$\frac{1}{z}\frac{dV}{dx} = I.$$

$$\Rightarrow I = \frac{1}{z}\left[\frac{d}{dx}\left\{Ae^{\sqrt{yz}\cdot x} + Be^{-\sqrt{yz}\cdot x}\right\}\right]$$

$$I = \frac{1}{z}\left[\sqrt{yz}\cdot Ae^{\sqrt{yz}\cdot x} - \sqrt{yz}\,e^{-\sqrt{yz}\cdot x}\right]$$

$$I = \sqrt{\frac{y}{z}}\left[Ae^{\sqrt{yz}\cdot x} - Be^{-\sqrt{yz}\cdot x}\right]$$

$$I = \frac{1}{\sqrt{z/y}}\left[Ae^{\sqrt{yz}\cdot x} - Be^{-\sqrt{yz}\cdot x}\right] \quad -(6)$$

Applying initial condition.
$V = V_R$, $I = I_R$ when $x = 0$.

Now from equation (6) we get

$$I_R = \left[\frac{1}{\sqrt{z/y}}\left\{Ae^{0} - Be^{0}\right\}\right]$$

$$I_R = \frac{1}{\sqrt{z/y}}\left[A - B\right] \quad -(7)$$

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 impedence 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.

$$V = \overbrace{\left(\frac{V_R + Z_C \cdot I_R}{2}\right)}^{\text{incident wave}} e^{\gamma x} + \overbrace{\left(\frac{V_R - Z_C I_R}{2}\right)}^{\text{reflected wave}} e^{-\gamma x} \quad \text{--- (9)}$$

$$= V_R\left(\frac{e^{\gamma x} + e^{-\gamma x}}{2}\right) + I_R Z_C \left(\frac{e^{\gamma x} - e^{-\gamma x}}{2}\right)$$

$$\boxed{V \Rightarrow V_R \cosh\gamma x + I_R Z_C \sinh\gamma x \quad \text{--- } 10}$$

Similarly:

$$I = \frac{1}{Z_C}\left[\left(\frac{V_R + Z_C \cdot I_R}{2}\right) e^{\gamma x} - \left(\frac{V_R - Z_C I_R}{2}\right) e^{-\gamma x}\right]$$

$$\boxed{I = \frac{1}{Z_C}\left[V_R\left\{\frac{e^{\gamma x} - e^{-\gamma x}}{2}\right\} + Z_C I_R \left\{\frac{e^{\gamma x} - e^{-\gamma x}}{2}\right\}\right]} \quad (11)$$

$$\boxed{I = \frac{1}{Z_C}\{\sinh\gamma x\} V_R + I_R\{\cosh\gamma x\} \quad \text{--- } (12)}$$

when $x = l$, $V = V_S$ $I = I_S$

$$\boxed{\begin{aligned} V_S &= V_R \cosh\gamma l + I_R Z_C \sinh\gamma l \quad \text{--- } (13) \\ I_C &= \frac{V_r}{Z_C} \sinh\gamma l + I_R \cosh\gamma l \quad \text{--- } (14) \end{aligned}}$$

$A = \cosh\gamma l = D$ — $B = Z_C \sinh\gamma l$; $C = \frac{1}{Z_c} \sinh\gamma l$.

Main points :-

Equation (9) is combination of incident voltage wave and reflected voltage wave.

Incident voltage Vi 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>:

$$\cosh\gamma l = \cosh(\alpha - j\beta) l = \cosh(\alpha l + j\beta l)$$

$$= \left\{ \frac{e^{(\alpha l + j\beta l)} + e^{-(\alpha l + j\beta l)}}{2} \right\}$$

$$= \frac{1}{2}\left\{ \cancel{e^{\alpha l}}\; e^{\alpha l} . e^{j\beta l} + e^{-\alpha l} e^{-j\beta l} \right\}$$

$$\boxed{\cosh\gamma l = \frac{1}{2}\left[e^{\alpha l} [\beta l + e^{-\alpha l} \angle -\beta l \right\}}$$

$$\sinh\gamma l = \sinh(\alpha l + j\beta l)$$

$$= \left\{ \frac{e^{\alpha l + j\beta l} - e^{-(\alpha l + j\beta l)}}{2} \right\}$$

$$\boxed{\sinh \gamma l = \frac{1}{2} \left\{ e^{\alpha l} \angle \beta l - e^{-\alpha l} \angle -\beta l \right\}}$$

	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 loadin

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 eqn (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 $\quad$ Z_c $\quad$ R.E

$\frac{V_s}{I_s} = Z_c$ $\qquad$ $\frac{V_R}{I_R} = Z_c$

$$Z_c = \sqrt{\frac{B}{C}} = \sqrt{\frac{Z_{sc}}{Y_{oc}}}$$

$$\boxed{Z_c = \sqrt{Z_{sc} Z_{oc}}}$$

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.

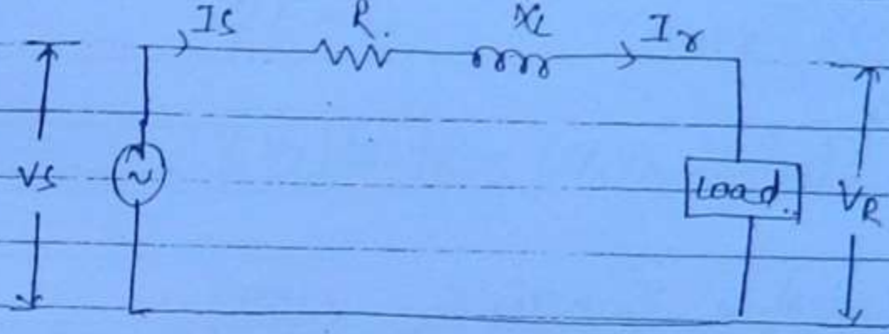
2) load impedence (Z_L) > Z_c

3) As $\frac{1}{2}Li^2 < \frac{1}{2}CV^2$, so the power factor is leading

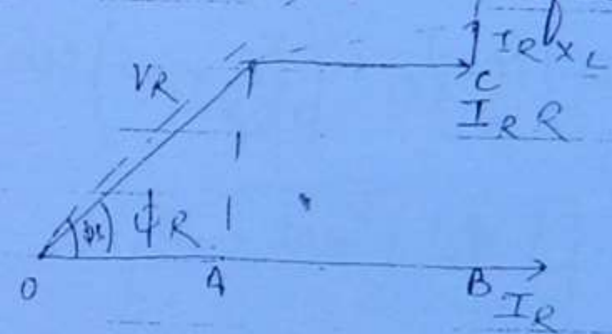
4) $V_R > V_S$.

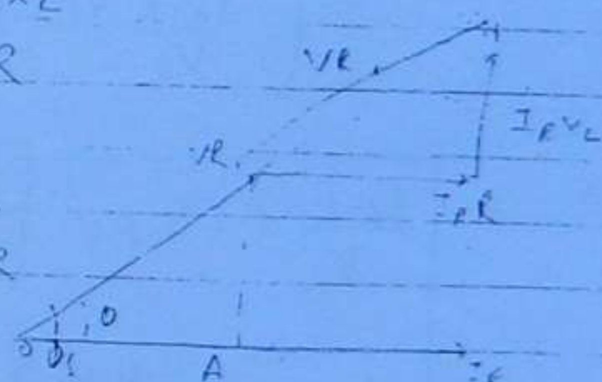
In general T.L is loaded more than surge impedence loading. Surge impedence also called Natural impedence.

CONDITION FOR ZERO REGULATION OF T.L :-



consider R.E current I_R as reference vector.





$$V_S^2 = OD^2 = OB^2 + BD^2$$

$$V_S^2 = (OA + AB)^2 + (BC + CD)^2$$

$$OB = V_S \cos\phi_S = OA + AB.$$

$$= V_R \cos\phi_R + I_R . R \quad \text{— (1)}$$

$$BD = V_S \sin\phi_S = BC + CD.$$

$$= V_R \sin\phi_R + I_R X_L \quad \text{— (2)}$$

$(1)^2 + (2)^2$

$$V_S^2 = V_R^2 + I_R^2 (R^2 + X_L^2)$$

$$V_S - V_R \cong I_R R \cos\phi_R + I_R X \sin\phi_R.$$

$$\%E = \frac{V_S - V_R}{V_R} \times 100$$

$$\frac{I_R R \cos\phi_R + I_R X \sin\phi_R}{V_R} \times 100$$

$$= \left(\frac{I_R \cdot R}{V_R} \times 100\right) \cos\phi_R + \left(\frac{I_R}{V_R} \times 100\right) \sin\phi_R.$$

$$\boxed{\begin{gathered} \frac{I_R R}{V_R} = V_R \text{ p.u} \\ \frac{I_R \cdot R}{V_R} \times 100 = \% V_R. \end{gathered}}$$

$$\boxed{\%E = (\% V_R)\cos\phi_R + (\% V_R)\sin\phi_R.}$$

--- 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

$$\% E = 0$$

$$(\% V_r)\cos\phi_R - (\% V_x)\sin\phi_R = 0$$

$$\% V_r \cos\phi_r = \% V_x \sin\phi_r$$

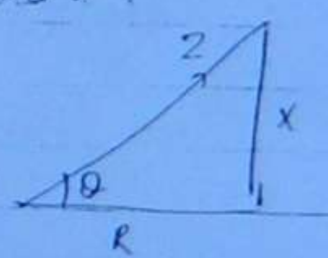
$$R\cos\phi_R = X\sin\phi_R$$

$$\tan\phi_R = R/x.$$

$$\boxed{\phi_R = \tan^{-1}(R/x)}$$

when phases are quired i.e. between R and x.

$$\cot\theta = R/x.$$



$$Z = R + jX$$

$$\therefore \tan\phi_R = \frac{R}{x} = \cot\theta.$$

$$\tan\phi_R = \tan(\pi/2 - \theta)$$

$$\boxed{\phi_R = \pi/2 - \theta}$$

*. Phase angle of load at which regulat^n is maximum

For lagging p.f, percentage regulat^n is max^m.

$$\%E = (\%V_R)\cos\phi_R + (\%V_X)\sin\phi_R$$

$$\frac{d(\%E)}{d\phi_R} = (\%V_r)(-\sin\phi_R) + (\%V_x)\cos\phi_R.$$

$$\frac{d(\%E)}{d\phi_R} = 0 \Rightarrow (\%V_r)(-\sin\phi_R) + (\%V_x)\cos\phi_r = 0$$

$$\Rightarrow \left(\frac{I_R \cdot R}{V_R} \times 100\right)\sin\phi_R = \left(\frac{I_R}{V_R} \times 100\right)\cos\phi_R.$$

$$R\sin\phi_R = X\cos\phi_R$$

$$\boxed{\tan\phi_R = X/R}$$ regulat^n is max^m

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 maxm ratio $\uparrow X/R$

	Zero Regulatn	Maxm Regulation
$\tan \phi_R$	R/X	X/R
ϕ_R	$\frac{\pi}{2}-\theta$	θ

When both zero

Zero Regulatn = Maxm Regulation

when pf is 0.707 (lagging or leading)

as

$$\tan \phi_R = R/X \;(=)\; \tan\phi_R = X/R$$

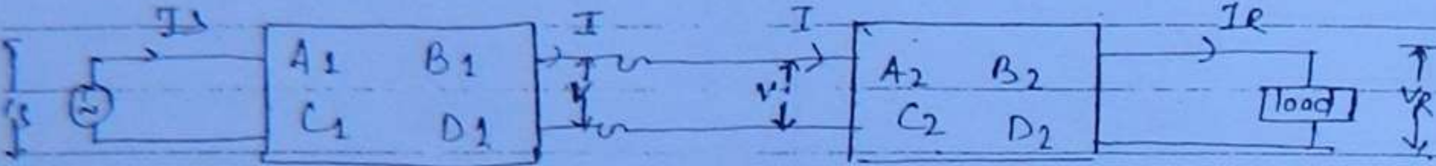
$$\boxed{X = R}$$

$$\phi_R = \tan^{-1}(1) = 45^\circ.$$

$$\boxed{\cos \phi_R = \cos(45) = 0.707}$$

percentage regulation of T.L (practically) around 6-7%

T.L CONNECTED IN SERIES OR CASCADE OR TANDOM:



$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} V \\ I \end{bmatrix}$$

$$\begin{bmatrix} V \\ I \end{bmatrix} = \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_2 \end{bmatrix} \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A_1 A_2 + B_1 C_2 & A_1 B_2 + B_1 D_2 \\ A_2 C_1 + D_1 C_2 & C_1 B_2 + D_1 D_2 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

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.

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A^2+BC & AB+BD \\ AC+DC & BC+D^2 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}.$$

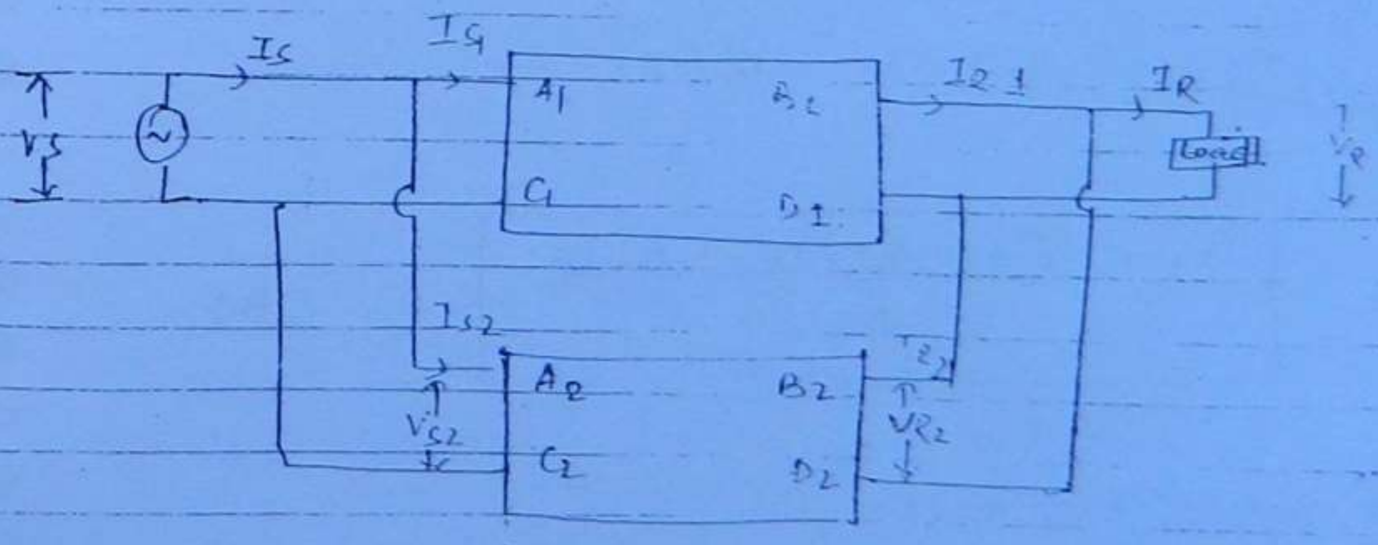
$A \longrightarrow A_1A_2 + B_1C_2 = A^2+BC$

$B \longrightarrow A_1B_2 + B_1D_2 = AB+BD$

$C \longrightarrow A_2C_1 + D_1C_2 = AC+DC$

$D \longrightarrow B_2C_1 + D_1D_2 = BC+D^2.$

T.L CONNECTED IN PARALLEL :-



$I_s = I_{s1} + I_{s2}$

$I_R = I_{R1} + I_{R2}$

POWER SYSTEM-1

$V_S = V_{S_1} = V_{S_2}$

$V_{R_1} = V_R = V_{R_2}$

$V_S = V_{S_1} = A_1 V_{R_1} + B_1 I_{R_1} = A_1 V_R + B_1 I_{R_1}$ —— (1)

$V_S = V_{S_2} = A_2 V_{R_2} + B_2 I_{R_2} = A_2 V_R + B_2 I_{R_2}$ —— (2)

$I_{S_1} = C_1 V_{R_1} + D_1 I_{R_1} = C_1 V_R + D_1 I_{R_1}$ — (3)

$I_{S_2} = C_2 V_{R_2} + D_2 I_{R_2} = C_2 V_R + D_2 I_{R_2}$ — (4)

equating eqn (1) and (2)

$$A_1 V_R + B_1 I_{R_1} = A_2 V_R + B_2 I_{R_2}$$

$$\Rightarrow \quad B_1 I_{R_1} - B_2 I_{R_2} = V_R (A_2 - A_1)$$

$$\boxed{I_{R_1} = \frac{(A_2 - A_1) V_R + B_2 I_R}{B_1 + B_2}} \quad \text{---} \quad (5)$$

Substituting eqn (5) in (1)

$$V_S = A_1 V_R + B_1 \left\{ \frac{(A_2 - A_1) V_R + B_2 I_R}{B_1 + B_2} \right\}$$

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-: HAND WRITTEN NOTES:-

OF

ELECTRICAL ENGINEERING

-: SUBJECT:-

POWER SYSTEM IInd - IV

- Components of HEPS :-

1. Reservoir: Reservoir stores water during rainy season and utilizes the stored water during summer season

2. Dam: Provides the necessary head of water for generation.

3. Trashrack: Trashrack prevents the flow of tree leaves or any other material to reach the turbine of Generating station. Trashrack is made of steel bars.

4. Spillway: During rainy season when the water reaching dam is very high the excess water may over the dam. this result the damage to the dam. Spillway is provided at the upper layer of the dam where the excess water flows through it.

5. Gates: the water stored in the reservoir is supplied to the generating station by opening the gates. Gates can be arranged in four different configuration

1. Radial
2. Axial
3. Horizontal
4. Vertical.

6. Inta[redacted]

When the spillway fails to operate the excess water can be send to the turbine through the intake. Intake is provided with gates operating on principle of gravity.

7. Forebay:

It is the additional reservoir provided to ensure that the water stored in the main reservoir doesnot flow over the dam.

8. Surge Tank:

Surge tank is located near the turbine of HEGS when the load demand decreases, generatⁿ decreases, quantity of water to be supplied to the generating statⁿ must decrease. Before signal & reaches operator the quantity of water discharged is high. In order to supply less water to turbine, the excess water is stored in surge tank. When the load demand increases or decreases the volume of water supplied to the generating station increases or decreases the water channel has to withstand. The sudden variations in the load. This is known as 'water hammer'.

Penstock:

The water channel through which the water is flowing from dam to generating statⁿ is known as Penstock.

For low discharges penstock is made of 'STEEL'. For high discharges penstock is made of "reinforced concrete".

Question:

A hydroelectric power station is supplied water from a reservoir having storage capacity 50 km^2 across a dam. where the head of water is maintained at 50m. the efficiency of turbine-g/r set 60% calculate the rate of fall of water when hydro-electric power station is generating power at 30,000 kW.

Solution:

$A = 50\,km^2$

$h \rightarrow 50\,m.$

$\eta_{t+g/r} = 60\%$

$P_t = 30{,}000\,kW.$

$$\boxed{\text{Rate of fall of water } m/sec = \frac{Q\,(m^3/sec)}{A\,(m^2)}}$$

- Electrical power generated

$$P_t = 9.81 \times Q \times 50 \times 0.6$$

$$Q = \frac{30{,}000}{9.81 \times 50 \times 0.6} = 101.93\,m^3/sec$$

$$\Rightarrow \text{Rate of fall} = \frac{101.93}{50 \times (10^3)^2} = 2.038 \times 10^{-6}\,m/sec$$

2) The quantity of water stored across the reservoir is $3\times10^7 m^3$. The head of the water $h = 150m$. If over all $\eta_{g/r} = 70\%$ calculate the energy generated.

Soln:

$V = 3\times10^7 m^3$ $\qquad Q = m^3/sec \quad P_t \rightarrow KW$

$h = 150m$ $\qquad Q = m^3 \quad P_t \rightarrow KW sec$

$\eta = 70\%$.

$P_t = 9.81 \times Q \times h \times \eta$

$P_e = 9.81 \times 3 \times 10^7 \times 150 \times 0.70 \quad KW sec.$

- electrical power output in KWsec = 3.089×10^{10} KWsec

electrical power o/p in KWh = $\frac{3.089\times10^{10}}{3600}$

$$\boxed{P_e = 8.58\times10^6 \text{ KWh}}$$

CLASSIFICATION OF TURBINE

1) Based on discharge of water:

1. High discharge
2. Medium discharge
3. low discharge

• 2. Based on pressure of water:

a) Impulse : Pelton,

b) Reaction: Francis, Kaplan.

• 3. Based on direction of water flow:

a). Axial

b) Radial

c) Diagonal: → Deriaz → used in pumpstored plant

d) Tangential

Deriaz turbine pumps water in diagonal direction and used in used in pumped storage plant.

• 4. Based on output power:

a) Low : 0 - 150000 Hp

b) Medium: 150000 - 350,000 Hp

c) High: > 350,000 Hp.

• 5. Based on specific speed:

($N \rightarrow \frac{1m^2}{sec}$, P

the speed at which turbine rotates to develop 1 MHP, when water is discharged at 1m with the head of water maintain at 1m.

$$\boxed{\text{Specific speed } N_s = \frac{N \cdot P^{1/2}}{h^{5/4}}}$$

P → power output in HP

h → head of water

N → actual speed in rpm.

Question:

A ~~AA~~ HEPS has average water discharge in a year as given below.

MONTH	DISCHARGE (m^3/sec)
Jan	200
Feb	400
March	600
April	2400
May	1800
June	1800
July	1600
Aug	1200
Sept	2000
Oct	1200
Nov	800
Dec	400

Calculate the average water flow and power generated when head of water is 50m and η of g/r stat^n being 90%. Draw the Hydrograph, flow duration curve and mass curve for given data. Estimate the total storage capacity of the reservoir

Solution

1) $Q = \frac{\text{water discharged}}{\text{no. of month in year}} = \frac{1380}{12} = 1150\, m^3/sec.$

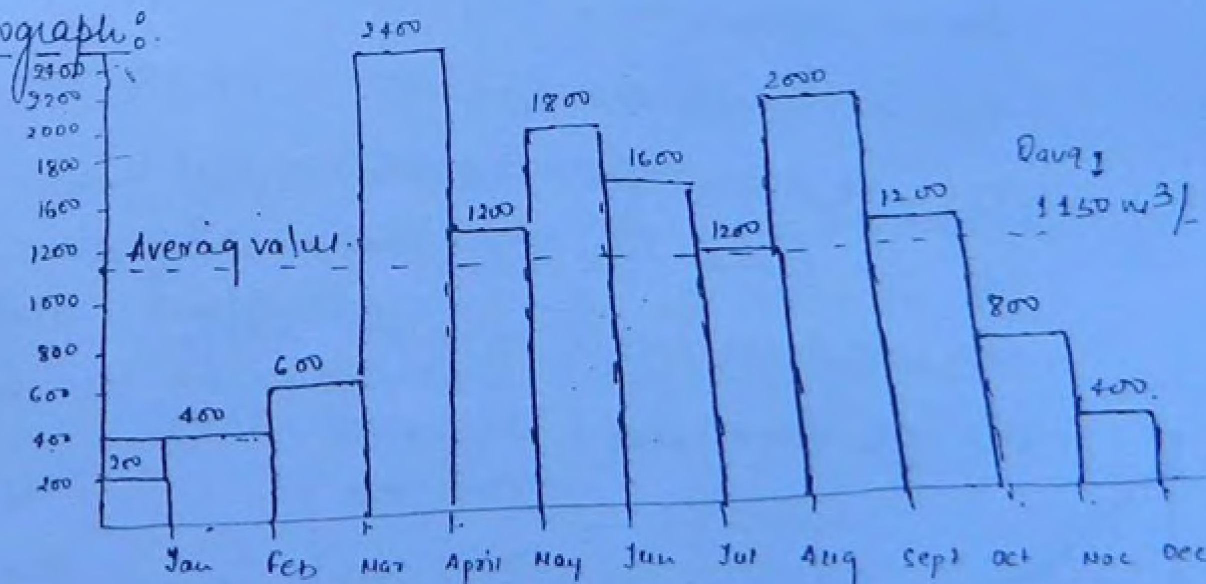
2) To electrical power generated

$P_t = 9.81 \times 1150 \times 0.9 \times 50$

$P_t = 507.6 \times 10^3\ KW$

$P_t = 507.6\ MW.$

3). Hydrograph:

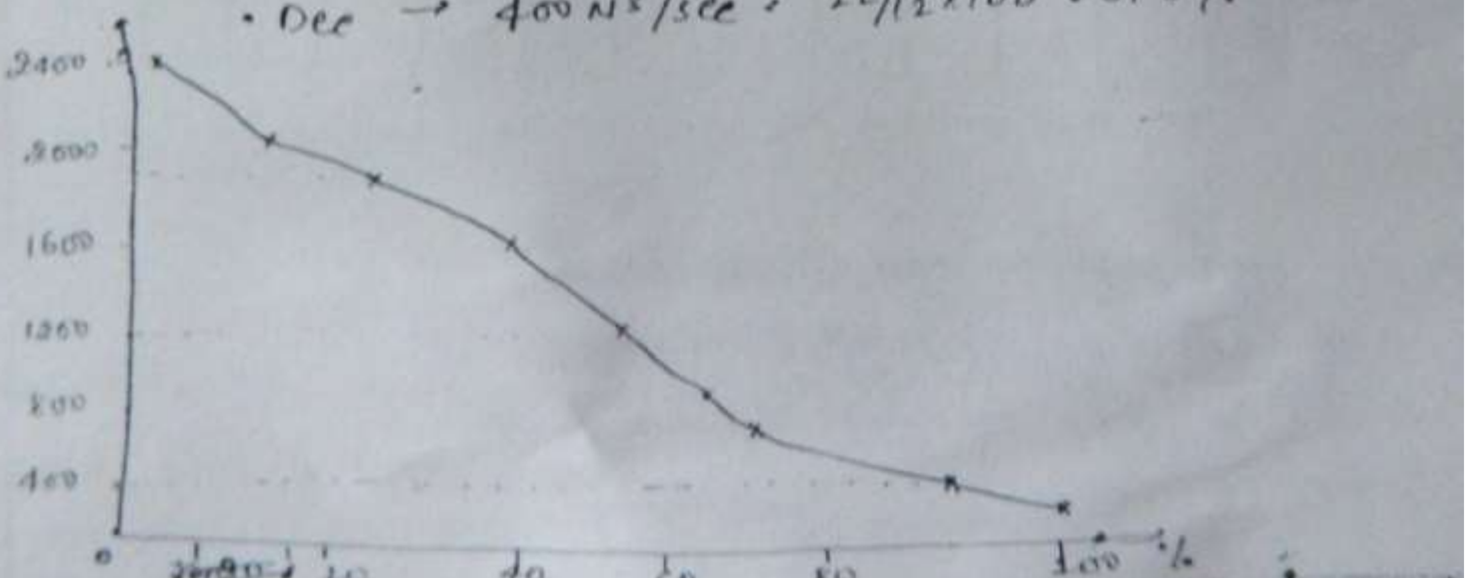


- From the hydrograph we can determine
  1) the duration of max^m discharge.
  2) the duration of minm discharge
  3) Average discharge.

5). <u>Flow duration curve</u>: It gives the relation b/w the discharge in m^3/sec represented along Y-axis and percentage of time represented ~~a~~ along X-axis.

(10)

- Jan → 2600 m^3/sec = $\frac{12}{12} \times 100$ = 100%
- Feb → 400 m^3/sec = $\frac{11}{12} \times 100$ = ~~75%~~ 91.6%
- March → 600 m^3/sec = $\frac{9}{12} \times 100$ = 75%
- April → 2400 m^3/sec = $\frac{1}{12} \times 100$ = 8.33%
- May → 1200 m^3/sec = $\frac{7}{12} \times 100$ = 58.3%
- June → 1800 m^3/sec = $\frac{3}{12} \times 100$ = 25%
- Jul → 1600 m^3/sec = $\frac{4}{12} \times 100$ = 33.3%
- Aug → 1200 m^3/sec = $\frac{7}{12} \times 100$ = 58.3%.
- Sept → 2000 m^3/sec = $\frac{2}{12} \times 100$ = 16.67
- Oct → 1200 m^3/sec = $\frac{7}{12} \times 100$ = 58.3%
- Nov → 800 m^3/sec = $\frac{9}{12} \times 100$ = ~~78~~ 66%
- Dec → 400 m^3/sec = $\frac{11}{12} \times 100$ = 91.6%



4) Total storage capacity:

- we store when water available > 1150 m^3/sec.

- water is stored in the reservoir when quantity of water available is gr8 than quantity water sent to generating statn.

Total storage capacity

$= \cancel{(2400-1150)+(1200-1150)}$

$= 1250+50+650+450+50+1850+50$

$= 5350 \, m^3/sec.$

$= \frac{5350 \times 24 \times 60 \times 60 \times 30}{\cancel{1000}}$

$= 8.7 \times 10^5 \, m^3/month$

5) MASS CURVE:

- find cumulative discharge.

- Mass curve gives the relation b/w cumulative discharge and time.. cumulative discharge is obtained by adding all discharges upto end of that month

Jan - 200

feb = 600

March → 1200

April → 3600

May → 4800

June → 6600

July → 8200

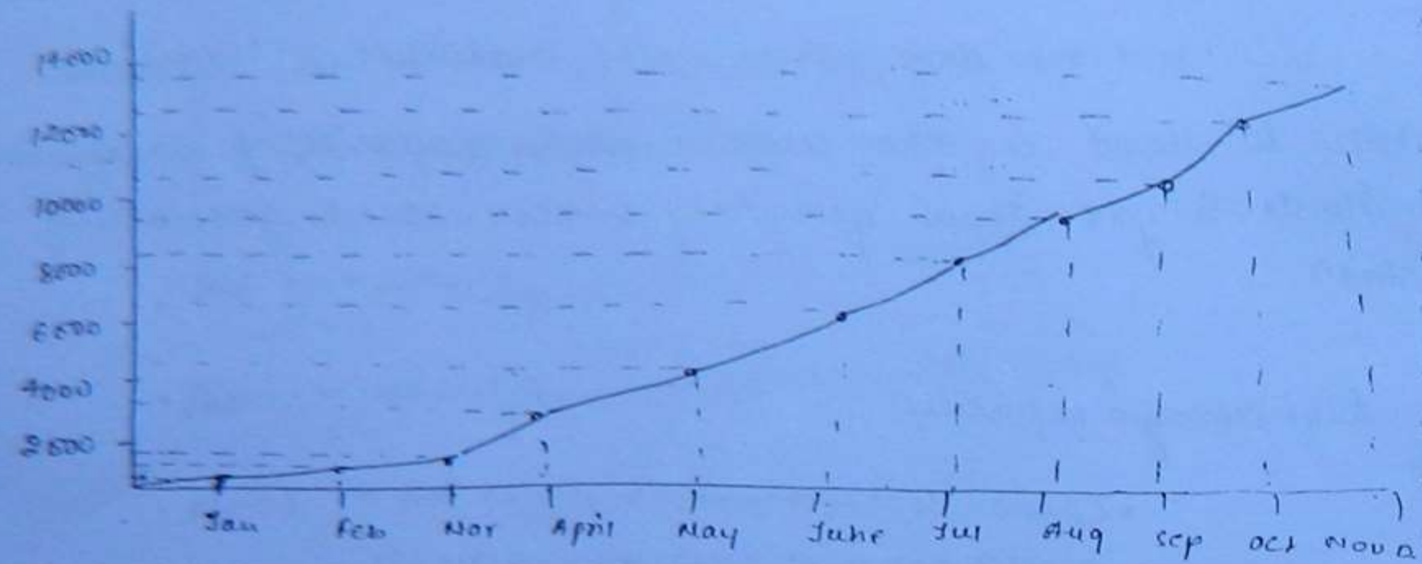
Aug → 9400

sept 11400

oct · 12600

Nov 13400

Dec 13800



NUCLEAR GENERATING STATION

Nuclear fission:

When neutron collides with uranium isotope enormous amount of energy is released.

$$ {}_{92}U^{235} + n^1 \longrightarrow {}_{56}Ba^{139} + {}_{36}Kr^{94} + 3\,{}_0n^1 + \text{Energy} $$

$$ {}_{92}U^{235} + {}_0n^1 \longrightarrow {}_{42}Mb^{106} + {}_{50}Sn^{128} + 2\,{}_0n^1 + 11 $$

Critical Mass:

The minimum amount of mass required for nuclear chain reaction to continue is known as critical mass. For an uranium isotope, the critical mass require 10kg. The energy generated by 1kg of uranium is ~~250~~ 3500kg of coal.

- The process of chain reaction can be increased by following.

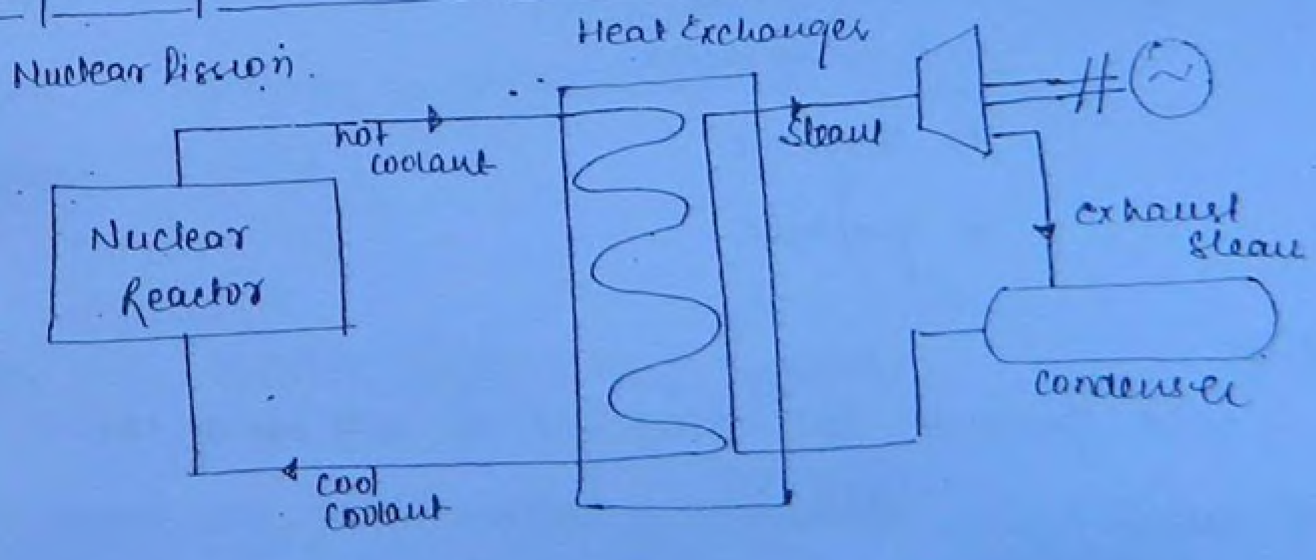
1. Conversion

- $_{92}U^{238} + {_0}n^1 \longrightarrow {_{92}}U^{239} + \gamma$
- $_{92}U^{239} \longrightarrow {_{93}}Np^{239} + {_{-1}}e^0$
- $_{93}Np^{239} \longrightarrow {_{94}}Pu^{239} + {_{-1}}e^0$

2. Breeding

- $_{90}Th^{232} + {_0}n^1 \longrightarrow {_{90}}Th^{233} + \gamma$
- $_{90}Th^{233} \longrightarrow {_{91}}Pa^{233} + {_{-1}}e^0$
- $_{91}Pa^{233} \longrightarrow {_{92}}U^{233} + {_{-1}}e^0$.

- Layout of Nuclear Power station:



- On nuclear reactor heat transfer takes place during the heat b/w heat generated during nuclear reaction. Water from the condenser is converted into steam by absorbing heat of coolant.

COMPONENTS OF NUCLEAR POWER STATION

1. Reactor Core:

• In the reactor core nuclear fission take place and the energy is released

• Reactor core consist of fuel rods in the form of thin plates made of stainless steel for low capacity reactor and Zirconium for high capacity reactors.

2. Moderator:

• Moderator slows down the neutrons before they collide with uranium isotope

• Types of Moderators are.

a) Heavy water

b) Beryllium

c) Graphite

3. Reflector:

• It prevents the neutrons to come out of the reactor core

• Reflector surrounds the reactor core.

4) Control Rod :

• Control rod ensures the safety of nuclear reactor

• During earth-quakes control rod trips the nuclear-reactor and ensure safe operation.

• Material → high grade gho graphite

5. Coolant:

• Coolant is used as heat transfer

• the cool water from condenser is converted into steam by absorbing the heat from the hot coolant

6. Multiplication factor (K):

$$\boxed{K = \frac{\text{no. neutron released}}{\text{Neutron absorbed.}}}$$

• 'K' determines the performance of nuclear reactor

• when no of neutrons released during fission is greater than no. of neutron absorbed. $(K>1)$

• Alway $1<K<\infty$

LOAD FREQUENCY CONTROL

• To control the power output of alternators several generating station are connected into a grid

• Grid connected s/m ensures frequency to be constant.

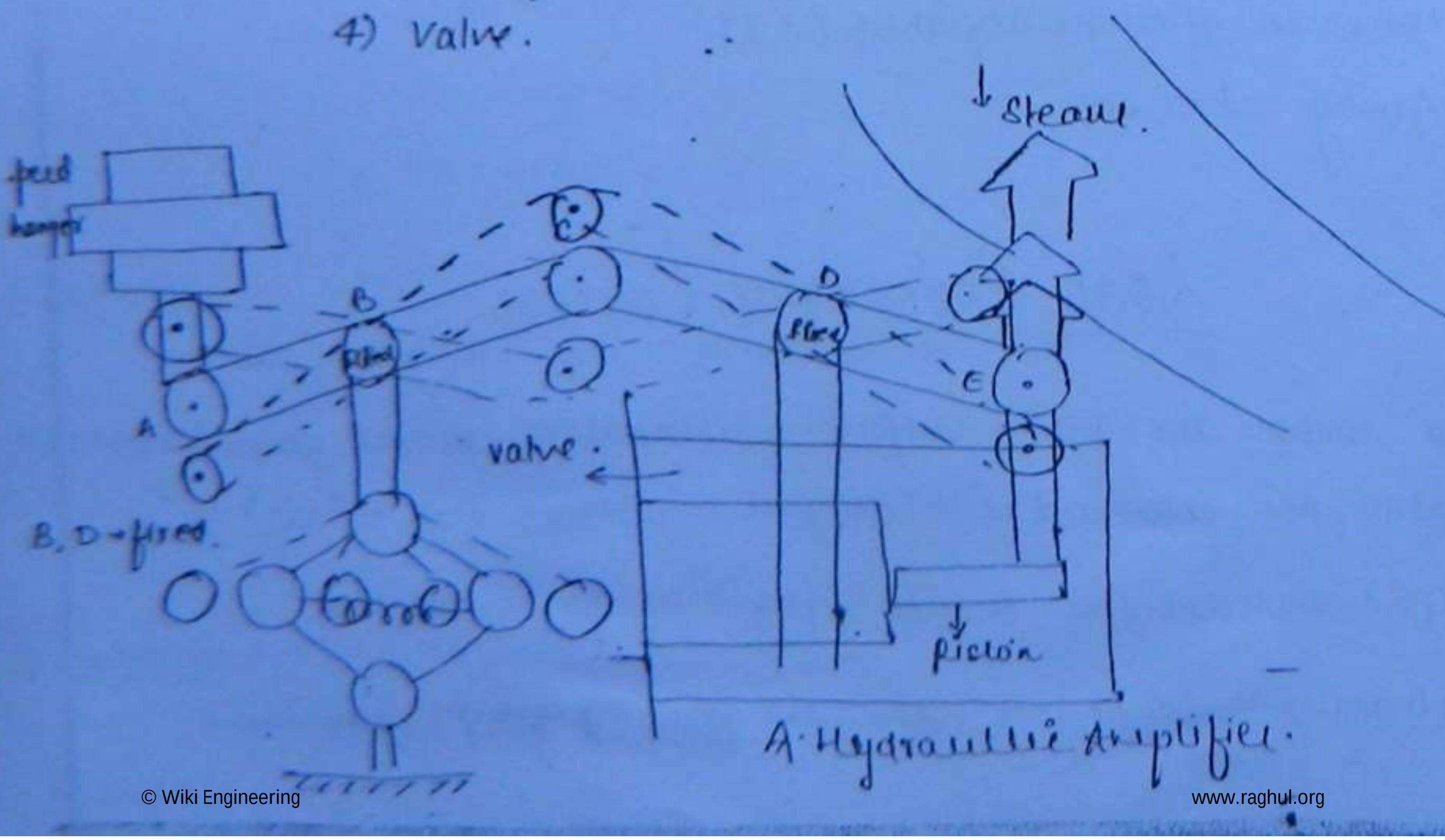
• Alternators connected in the form of group maintains constant frequency.

- When load demand increases, power ~~as~~ generation must be increase, alternator must generate more electrical power, turbine has to supply more mechanical energy to the alternator, the steam supply to turbine must increase. and SPEED GARNER. must identify the increase in the load demand.

Design of speed Governer :.

- It components are:

1) speed changer
2) Hydraullic Amplifier
3) Linkage Mechanism
4) Valve.



A Hydraullic Amplifier.

• condition 1: Increase in load Demand

Generation must increase

speed of turbine must increase.

speed changer is pulled in downward directn

Point A moves in downward direction depends on speed governor signal.

Point 'C' moves in upward direction

Point 'E' moves in downward direction

the inlet to the steam is increased.

Mechanical energy at the I/P alternator increase

Electrical energy genrated by alternator increa

• condition 2: Decrease in load demand

Generation must decrease

speed of turbine must decrease

speed changer is pulled in upward directn depending on signal of speed governor

Point 'A' moves upward depending on speed governor signal

Point 'C' moves in downward direction

Point 'E' moves in upward direction

the inlet to steam is decreased

Mechanical energy at the I/P alternator

decreases

Electrical energy generated by alternator decreases

- The load frequency control depends on:

  1. The movement of fly ball governor and there after the speed changer

- Hydraulic amplifier determines actual steam input to the turbine

DESIGN EQUATIONS:

- Point 'A' and 'C' moves in opposite direction
- Let $\Delta(P_c)$ be the command signal given by the speed governor to the speed changer

A ↓ downward direct^n

speedchanger ↓ ''

← governor → (expansion)

$\therefore$ $y_A \propto \Delta P_c$

$$\boxed{y_A = K_c \Delta P_c}$$

- The extent to which point 'C' moves in upward direction is equal to extent to point 'A' move in downward directⁿ.

$$y_C \propto (-y_A)$$

$$y_C \propto (-K_C \cdot \Delta P_C)$$

$$\boxed{y_C = -K_1 K_C \Delta P_C} \quad \text{---- (1)}$$

- Assume that volume of oil sent to hydraulic amplifier is increased. therefore point E moves in downward directⁿ resulting in movement of point C in of upward directⁿ

$$y_C \propto (-y_E) \qquad C\uparrow \text{ when } E\downarrow.$$

$$\propto (\Delta f) \quad \text{---> as steam inlet} \uparrow.$$

$$\boxed{y_C = K_2 \Delta f} \quad \text{---- (2)} \quad \text{generatⁿ} \uparrow. \ \text{frequency} \uparrow.$$

- the movement of point 'A' is related w.r.t to frequency,

$$\boxed{y_C = -K_1 K_2 \Delta P_C + K_2 \Delta f} \quad \text{---- (5)}$$

Δy_D :-

- point 'D' is located at the middle of the the second section. the movement of point D is affected by the position 'C' and 'E'

$$\Delta y_C = -K_1 K_C \Delta y_A + K_2 \Delta f \quad \cdots \quad (3)$$

$$\Delta y_D = K_3 \Delta y_C + K_4 \Delta y_E \quad \cdots \quad (4)$$

$$\Delta y_E =$$

the volume of oil in hydraulic amplifier determine the movement point 'E'. For 'Δy_E' to be positive, oil is taken from the hydraulic cylinder.

depending on the position of point 'D', Δy_E is determined.

$$\Delta y_E \propto -\int (\Delta y_D)\,dt$$

since oil is stored in cylinder the integral is applied.

$$\boxed{\Delta y_E = -K_5 \int (\Delta y_D)\,dt} \quad \cdots \quad (5)$$

applying laplace transform to the equations (3), (4), (5)

$$\Delta Y_C(s) = -K_1 K_C \Delta Y_A(s) + K_2 \Delta f(s) \quad \cdots \quad (6)$$

$$\Delta Y_D(s) = K_3 \Delta Y_C(s) + K_4 \Delta Y_E(s) \quad - \quad (7)$$

$$\Delta Y_E(s) = -\frac{K_5}{s} \Delta Y_D(s) \quad \cdots \quad 8$$

substituting eqn (7) in (8)

from the equation (7) and (8)

$$\Delta Y_D(s) = K_3 \Delta Y_C(s) + K_4 \left\{ -\frac{K_5}{s} \Delta Y_D(s) \right\}$$

8 → 7

$$\Delta Y_D(s) + \frac{K_4 K_5}{s} \Delta Y_D(s) = K_3 \Delta Y_C(s)$$

$$= \Delta Y_D(s) \left\{ 1 + \frac{K_4 K_5}{s} \right\} = K_3 \Delta Y_C(s)$$

$$\Rightarrow \Delta Y_C(s) = \Delta Y_D(s) \left\{ \frac{1}{K_3} + \frac{K_4 K_5}{s K_3} \right\} \quad \text{----} \quad (9).$$

9 → 6

$$\Delta Y_D(s) \left\{ \frac{1}{K_3} + \frac{K_4 K_5}{s K_3} \right\} = -K_1 K_C \Delta P_G(s) + K_2 \Delta F(s) \quad \cdots \quad (10).$$

equaⁿ 10 represents the change in position in terms of frequency.

From eqⁿ 8 we have:

$$\cancel{\Delta Y_E(s) = \frac{-K_5}{s}} \quad \Delta Y_D(s) = \frac{-s}{K_5} \Delta Y_E(s) \quad \cdots \quad (11)$$

11 → 10

$$= \frac{-s}{K_5} \Delta Y_E(s) \left\{ \frac{1}{K_3} + \frac{K_4 K_5}{s K_3} \right\} = -K_1 K_C \Delta P_C(s) + K_2 \Delta F(s)$$

$$= -\Delta Y_E(s) \left\{ \frac{s}{K_3 K_5} + \frac{K_4}{K_3} \right\} = -K_1 K_C \Delta P_C(s) + K_2 \Delta F(s)$$

$$= \Delta Y_E(s) \left\{ \frac{s + K_4 K_5}{K_3 K_5} \right\} = K_1 K_C \Delta P_C(s) - K_2 \Delta F(s)$$

$$\Rightarrow \Delta Y_E(s) = \left(\frac{K_3 K_5}{s + K_4 K_5} \right) \left(K_1 K_2 \Delta P_C(s) \right) - \left(\frac{K_3 K_5}{s + K_4 K_5} \right) K_2 \Delta F(s)$$

Dividing $K_4 K_5$

$$\Rightarrow \Delta Y_E(s) = \left[\frac{\frac{K_3 K_5}{K_4 K_5}}{1+\frac{s}{K_4 K_5}}\right](K_1 K_c \Delta P_c(s)) - \left[\frac{\frac{K_3 K_5}{K_4 K_5}}{1+\frac{s}{K_4 K_5}}\right](\Delta f(s))$$

$$\Delta Y_E(s) = \left[\frac{\frac{K_1 K_c K_3}{K_4}}{1+\frac{s}{K_4 K_5}}\right](\Delta P_c(s)) - \left[\frac{\frac{K_2 K_3}{K_4}}{1+\frac{s}{K_4 K_5}}\right]\Delta f(s)$$

$$\Rightarrow \Delta Y_E(s) = \left[\frac{\frac{K_1 K_c K_3}{K_4}\Delta P_c(s) - \frac{K_2 K_3 \cdot \Delta f(s)}{K_4}}{1+\frac{s}{K_4 K_5}}\right]$$

$$\Rightarrow \frac{\left(\frac{K_1 K_c K_3}{K_4}\right)\left\{\Delta P_c(s) - \left(\frac{K_2 K_3}{K_4}\right)\left(\frac{K_4}{K_1 K_c K_3}\right)\Delta f(s)\right\}}{1+s\frac{1}{K_4 K_5}}$$

$$\boxed{G(s) \Rightarrow \frac{\left(\frac{K_1 K_c K_3}{K_4}\right)}{\left(1+s\frac{1}{K_4 K_5}\right)}\left\{\Delta P_c(s) - \frac{1}{K_1 K_c / K_2}\Delta f(s)\right\}}$$

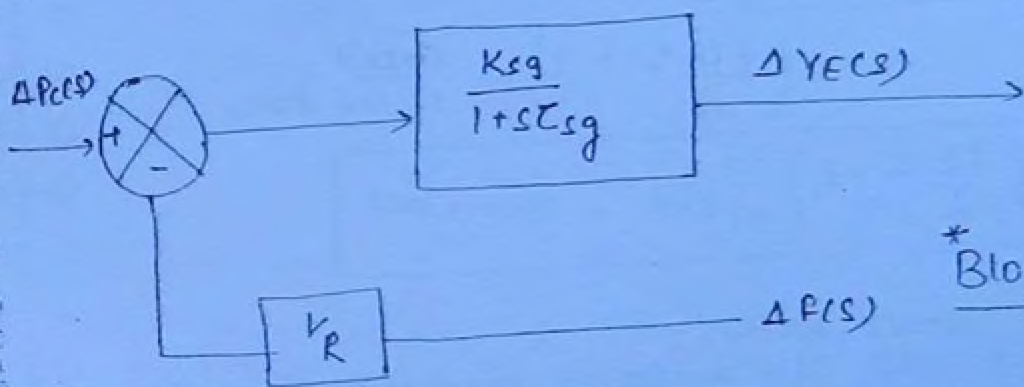
- gain constant speed governor s/m

$$\boxed{K_{sg} = \frac{K_1 K_c K_3}{K_4}}$$

$$\boxed{\tau_{sg} = \frac{1}{K_4 K_5}}$$

- Regulation of speed governor is $\boxed{R = \frac{K_1 K_c}{K_2}}$

$$\boxed{\Delta Y_E(s) = \left\{ \Delta P_c(s) - \frac{1}{R} \Delta F(s) \right\} \frac{K_{sg}}{1 + sT_{sg}}}$$



*Block Diagram

$$\boxed{\frac{\Delta Y_E(s)}{\Delta P_c(s) - \frac{1}{R}\Delta F(s)} = \frac{K_{sg}}{1 + sT_{sg}}}$$

- **DESIGN OF TURBINE:**

1. INPUT:- change in position 'E', $\Delta Y_E(s)$
2. OUTPUT:- Change in power developed by turbine ΔP_t.

$$\boxed{\frac{\Delta P_t}{\Delta Y_E(s)} = \frac{K_t}{1 + sT_t}}$$

• Block diagram:

$$\Delta Y_E(s) \longrightarrow \boxed{\frac{K_t}{1+sT_t}} \longrightarrow \Delta P_t(s)$$

$\Delta Y_E(s)$ = input to the turbine aswell as output of speed governor.

Dated
11 Oct 2010

DESIGN OF ALTERNATOR

• the design of alternator deals with:-

1) Kinetic Energy stored by rotor of alternator

At the operating frequency $f_0 = 50Hz$. the K.E stored by alternator

$$W_{KE_0} \propto f_0^2 \quad \text{-----} \quad (1)$$

let Δf be the change in frequency

$$\therefore \quad f_{new} = (f_0 + \Delta f)$$

$$W_{KE(new)} \propto f_{new}^2$$

$$\Rightarrow \quad W_{KE(new)} \propto (f + \Delta f)^2 \quad \text{-----} \quad (2)$$

The K.E stored by the alternator due to change in frequency is $W_{KE}(new)$.

from the equat^n (1) and (2)

$$\left(\frac{2}{1}\right) \rightarrow \quad \frac{W_{KE(new)}}{W_{KE_0}} = \frac{(f_0+\Delta f)^2}{f_0^2}$$

$$= \frac{f_0^2 + \Delta f^2 + 2 f f_0}{f_0^2}$$

$$= \frac{f_0^2}{f_0^2} + \underbrace{\frac{\Delta f^2}{f_0^2}}_{\text{neglected as } (2/50)^2 = \text{very small}} + \frac{2 f_0 \Delta f}{f_0^2}.$$

$$\left(1 + 2\frac{\Delta f}{f_0}\right)$$

$$\boxed{W_{KE(new)} = W_{KE_0}\left(1 + 2\frac{\Delta f}{f_0}\right).} \quad \text{-----} (3)$$

According to dynamics rotating m/c the K.E stored by alternator

$$W_{KE_0} = H \times P_{rated} \quad \text{......} \quad (4)$$

$$= \underbrace{H \times P_r}_{\text{inertia constant}}$$

$\underline{\underline{4 \rightarrow 3}}$.

$$W_{KE(new)} = (H \times P_r)\left[1 + 2\frac{\Delta f}{f_0}\right]$$

$$\boxed{W_{KE(new)} = H P_r + \frac{2 H P_r}{f_0} \Delta f} \quad \text{----} (5)$$

By differentiating the above equat^n the electrical power developed by alternator is obtained:

$$\frac{d(W_{KE(new)})}{dt} = \frac{2 H . P_r}{f_0} \cdot \frac{d(\Delta f)}{dt} \quad \text{.....} \quad (6)$$

The change in the load demand w.r.t change in the frequency is represented as:

The change in load demand due to all factors $\rightarrow \Delta P_D$

The change in frequency due all factor $\rightarrow \Delta f$.

Since the load demand changes not only due to frequency, the total change in load demand.

$$= \left(\frac{\partial P_D}{\partial f}\right) \Delta f.$$

$$= (B)\Delta f \quad \cdots \quad (7) \quad \text{unit } W/Hz$$

According to the power balance equation

$$\Delta P_G - \Delta P_D = \frac{2HP_r}{f_0}\frac{d}{dt}(\Delta f) + B\Delta f.$$

By considering rated capacity of alternator 'P_r' as the reference/Base value the power balance equat^n can be expressed in terms P.U

$$\Rightarrow \frac{\Delta P_G}{P_r} - \frac{\Delta P_D}{P_r} = \frac{\frac{2HP_r}{f_0}}{P_r}\frac{d(\Delta f)}{dt} + B_{p.u}\Delta f$$

$$\Rightarrow \boxed{\Delta P_{G\,p.u} - \Delta P_{D\,p.u} = \frac{2H}{f_0}\frac{d(\Delta f)}{dt} + B_{p.u}\Delta f.} \quad --- \quad (8)$$

* In numerical B is given as $B_{p.u}$ MW/Hz.

Applying Laplace transform:

$$\Delta P_{G_{p.u}}(s) - \Delta P_{D_{p.u}}(s) = \frac{2H}{f_0}\left[s\Delta f(s)\right] + B_{p.u}\Delta f(s)$$

$$\Rightarrow \Delta P_{G_{p.u}}(s) - \Delta P_{D_{p.u}}(s) = \Delta f(s)\left[\frac{s.2H}{f_0} + B_{p.u}\right]$$

$$\Rightarrow \boxed{\Delta f(s) = \frac{1}{\left[\frac{s.2H}{f_0} + B_{p.u}\right]}\left\{\Delta P_{G_{p.u}}(s) - \Delta P_{D_{p.u}}(s)\right\}} \quad \text{---- (10)}$$

Divide by $B_{p.u}$

$$\boxed{\Delta f(s) = \frac{1/B_{p.u}}{\left[\frac{s.2H}{f_0 B_{p.u}} + 1\right]}\left[\Delta P_{G_{p.u}}(s) - \Delta P_{D_{p.u}}(s)\right]} \quad \text{---- (11)}$$

- gain constant of alternator $\rightarrow \frac{1}{B_{p.u}}$

- time constant of alternator/powersys $\rightarrow \frac{2H}{f_0 B_{p.u}}$

**

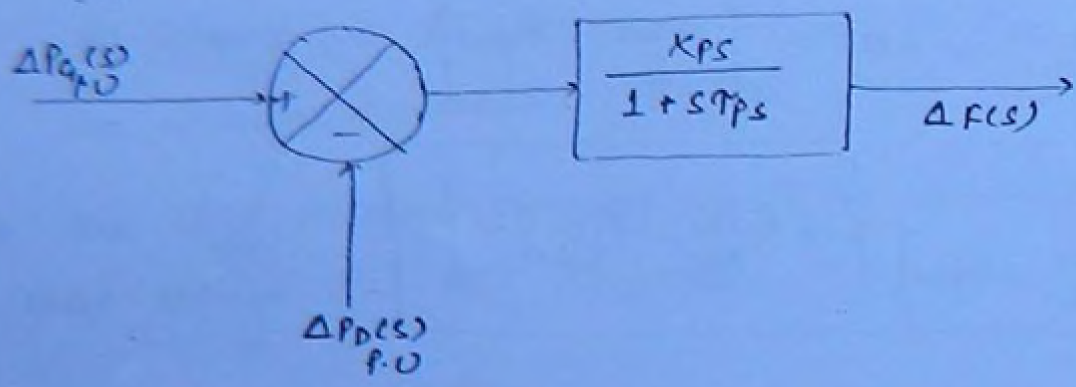
$$\boxed{\Delta f(s) = \frac{K_{ps}}{(1+sT_{ps})}\left\{\Delta P_{G_{pu}}(s) - \Delta P_{D_{pu}}(s)\right\}}$$

Transfer function of alternator is:

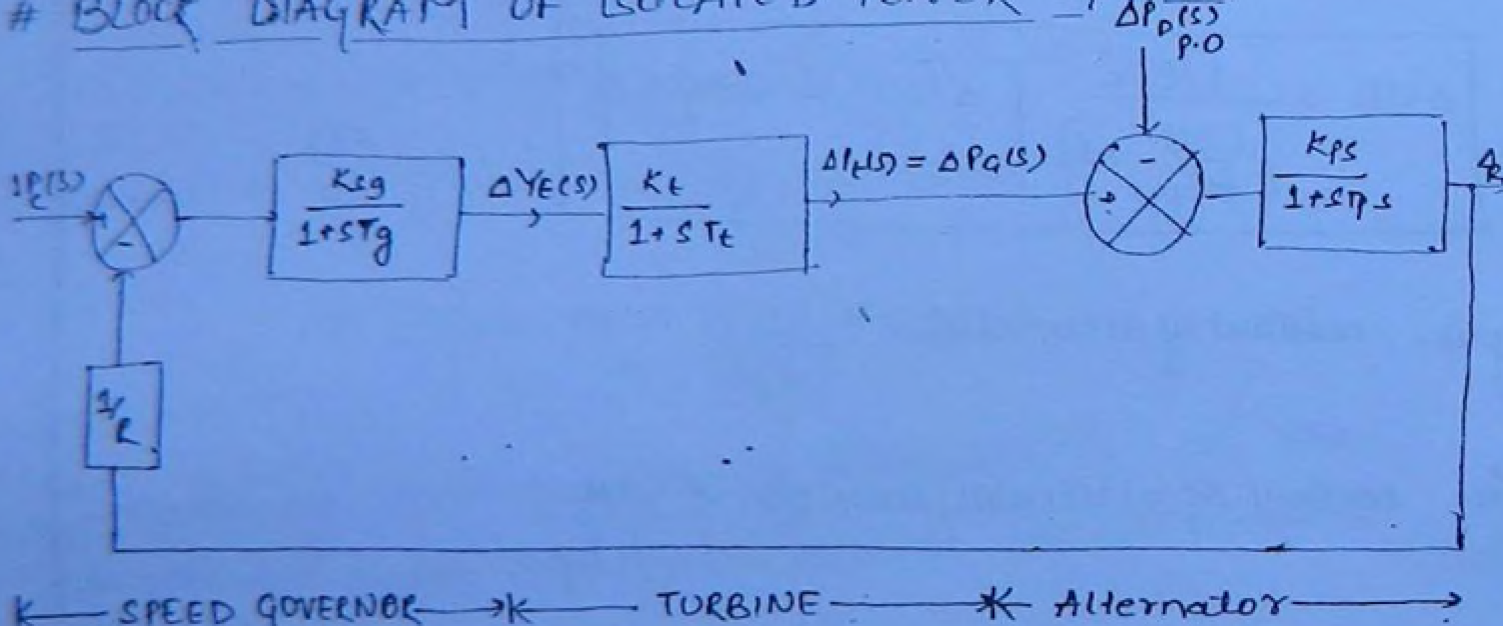
**

$$\boxed{\frac{\Delta f(s)}{\Delta P_{G_{pu}}(s) - \Delta P_{D_{p.u}}(s)} = \frac{K_{ps}}{1+sT_{ps}}}$$

* Block diagram:



BLOCK DIAGRAM OF ISOLATED POWER SYMTEM:



Question:

Determine the load frequency control loop parameters of a control area with following data.

1) Total rated capacity 2000 MW
2) Normal operating load 1000 MW
3) Inertia constant H = 5

Regulation $R = 2.4\ Hz/MW$
change in load demand w.r.t frequency is $16.67\ MW/Hz$

Soln

$$B = \frac{\partial P_D}{\partial f} = 16.67\ MW/Hz$$

$$B_{pu} = \frac{B}{P_r} = \frac{16.67}{2000} = 8.335 \times 10^{-3}\ pu\ MW/Hz.$$

- $K_{ps} = \frac{1}{B_{pu}} = 120\ Hz/MW$

- $\tau_{ps} = \frac{2H}{f_0 B_{pu}} = \frac{2 \times 5}{8.335 \times 10^{-3}} = 24\ sec.$

- Default values of time constant when not given in numericals:

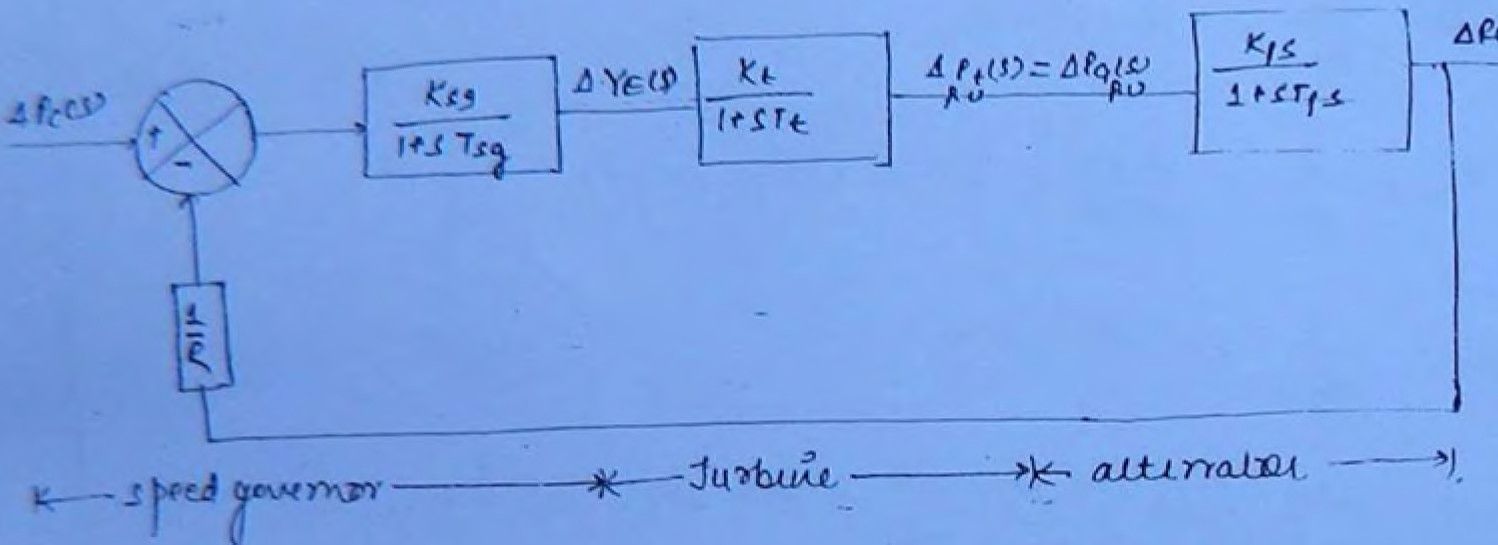
$$\boxed{\begin{aligned} T_{sg} &= 0.4\,sec \\ T_t &= 0.5\,sec \\ T_{ps} &= 20\,sec. \end{aligned}}$$

STEADY STATE ANALYSIS..

Steady-state analysis deals with determining 'Δf' due to ΔP_c and ΔP_D

- **Condition 1:** change in frequency Δf due to change in speed changer setting.

$\therefore \Delta P_D(s) = 0$



$$\left.\frac{\Delta F(s)}{\Delta P_c(s)}\right|_{\Delta P_D(s)=0} = \frac{\left(\frac{K_{sg}}{1+sT_{sg}}\right)\left(\frac{K_t}{1+sT_t}\right)\left(\frac{K_{ps}}{1+sT_{ps}}\right)}{1+\frac{1}{R}\left[\left(\frac{K_{sg}}{1+sT_{sg}}\right)\left(\frac{K_t}{1+sT_t}\right)\left(\frac{K_{ps}}{1+sT_{ps}}\right)\right]}$$

$$\Delta F(s) = \frac{\left(\frac{K_{sg}}{1+sT_{sg}}\right)\left(\frac{K_t}{1+sT_t}\right)\left(\frac{K_{ps}}{1+sT_{ps}}\right)}{1+\frac{1}{R}\left[\left(\frac{K_{sg}}{1+sT_{sg}}\right)\left(\frac{K_t}{1+sT_t}\right)\left(\frac{K_{ps}}{1+sT_{ps}}\right)\right]} \cdot \Delta P_c(s)$$

After taking L.C.M:

$$\left.\Delta F(s)\right|_{\Delta P_D(s)=0} = \frac{K_{sg} \cdot K_t \cdot K_{ps}}{(1+sT_{sg})(1+sT_t)(1+sT_{ps}) + \frac{1}{R} K_{sg} K_t K_{ps}} \cdot \frac{\Delta P_c(s)}{s}$$

error $e_{ss} = \underset{s \to 0}{lt}\ sE(s)$

the steady state change in the frequency Δf.

$$\Delta f = \underset{s \to 0}{lt}\ s \cdot \Delta F(s)$$

$$= \underset{s \to 0}{lt}\ \cancel{s} \left\{ \frac{K_{sg} \cdot K_t \cdot K_{ps}}{(1+sT_{sg})(1+sT_t)(1+sT_{ps}) + \frac{K_{sg} K_t K_{ps}}{R}} \right\} \frac{\Delta P_c}{\cancel{s}}$$

$$= \frac{K_{sg} \cdot K_t \cdot K_{ps}}{(1+0 \cdot T_{sg})(1+0 \cdot T_t)(1+0\, T_{ps}) + \frac{K_{sg} K_t K_{ps}}{R}} \cdot \Delta P_c$$

$$= \frac{K_{sg} \cdot K_t \cdot K_{ps}}{1 + \frac{K_{sg} K_t K_{ps}}{R}} \cdot \Delta P_c$$

consider $K_{sg} K_t = 1$

as in general
$K_{sg} = 0.7$
$K_t = 1.55$

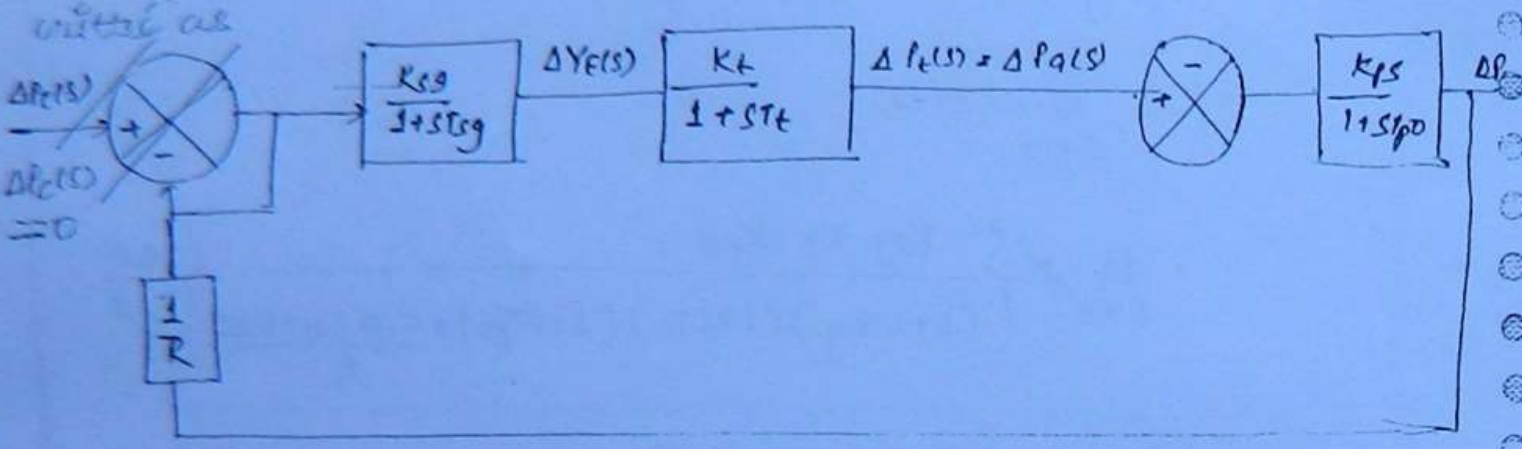
$$\Delta f \Big|_{\Delta P_D = 0} = \frac{K_{ps}}{1 + \frac{K_{ps}}{R}} \cdot \Delta P_c$$

$\div$ by K_{ps}.

$$\Delta f \Big|_{\Delta P_D = 0} = \frac{1}{\frac{1}{K_{ps}} + \frac{1}{R}} \cdot \Delta P_c$$

$$\boxed{\Delta f \Big|_{\Delta P_D = 0} = \frac{1}{B_{p.u} + \frac{1}{R}} \cdot \Delta P_c} \quad \text{- - - - -} \quad (1)$$

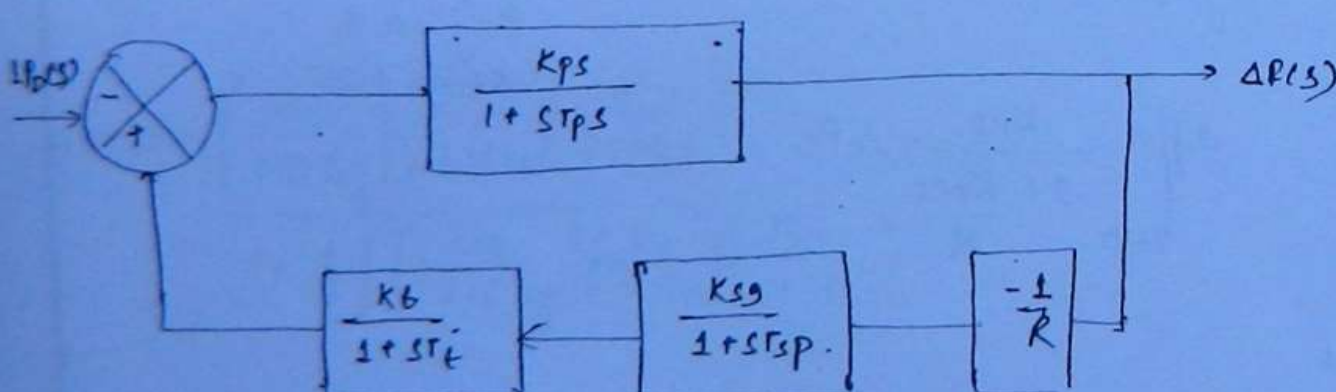
• condition 2: change in frequency Δf due to ΔP_D.



$\Delta P_c(s) = 0$

• ~~speed changer sett~~

• $\Delta P_c(s) = 0$ represents free governor operation (speed changer setting is constant)



$$\left.\frac{\Delta f(s)}{\Delta P_D(s)}\right|_{\Delta P_c(s)=0} = \frac{-\left(\frac{K_{ps}}{1+sT_{ps}}\right)}{1+\left\{\left(\frac{K_{ps}}{1+sT_{ps}}\right)\left(\frac{K_t}{1+sT_t}\right)\left(\frac{K_{sg}}{1+sT_{sg}}\right)\left(-\frac{1}{R}\right)\right\}}$$

Take L.C.M and Simplify:

$$\Delta F(s)\Big|_{\Delta P_c(s)=0} = \frac{-\left(\frac{K_{ps}}{1+sT_{ps}}\right)}{1+\left\{\left(\frac{K_{ps}}{1+sT_{ps}}\right)\left(\frac{K_t}{1+sT_t}\right)\left(\frac{K_{sg}}{1+sT_{sg}}\right)\left(\frac{+1}{R}\right)\right.} \cdot \Delta P_D(s)$$

$$\Delta f(s)\Big|_{\Delta P_c(s)=0} = \frac{-K_{ps}}{(1+sT_{ps})(1+sT_t)(1+sT_{sg})+\frac{K_{ps}K_{sg}K_t}{R}} \cdot \frac{\Delta P_D}{s}$$

Steady state change in frequency.

$$= \lim_{s\to 0} \cancel{s}\left[\frac{-K_{ps}(1+sT_t)(1+sT_{sg})}{(1+sT_{ps})(1+sT_t)(1+sT_{sg})+\frac{K_{ps}K_{sg}K_t}{R}}\right]\frac{\Delta P_D}{\cancel{s}}$$

$$\Delta f(s) = \frac{-K_{ps}}{1+\frac{K_{ps}K_gK_t}{R}} \cdot \Delta P_D$$

Taking $K_{sg}K_t = 1$.

$$\Delta f(s)\Big|_{\Delta P_c(s)=0} = \frac{-K_{ps}}{1+\frac{K_{ps}}{R}} \cdot \Delta P_D$$

$\div\ K_{ps}$

$$\boxed{\Delta f(s)\Big|_{\Delta P_c(s)=0} = \frac{-1}{B_{p.u}+\frac{1}{R}} \cdot \Delta P_D} \quad \text{----- (2)}$$

$\because \frac{1}{K_{ps}} = B_{p.u}$

total $\Delta f_{s.s} = \Delta f_{ss}\Big|_{\Delta P_D(s)=0} + \Delta f_{s.s}\Big|_{\Delta P_c(s)=0}$

$$= \frac{\Delta P_c}{B_{p.u} + \frac{1}{R}} - \frac{\Delta P_D}{B_{p.u} + \frac{1}{R}}.$$

$$\boxed{\Delta f_{s.s.} = (\Delta P_c - \Delta P_D)\left(\frac{1}{B_{pu} + \frac{1}{R}}\right)}$$ ---- steady state frequency change.

<u>Question:</u>

Consider the Block diagram of load frequency control. the following approximation is made regarding the analysis

$$(1+sT_{sg})(1+sT_t) = 1 + (T_{sg} + T_t)s = 1 + sT_{eq}$$

Determine $\Delta f(t)$ when $\Delta P_D = 0.01$

Solution:

the given data corresponds to free governor operation

when $\Delta P_c(s) = 0$

$$\frac{\Delta F(s)}{\Delta P_c(s)} = \frac{-\left(\frac{K_{ps}}{1+sT_{ps}}\right)}{1 + \left(\frac{K_{ps}}{1+sT_{ps}}\right)\left(\frac{K_{sg}}{1+sT_{sg}}\right)\left(\frac{K_t}{1+sT_t}\right)\frac{1}{R}}$$

⇒ Taking default value.

$$1+(T_{sg}+T_t)s = 1+(0.4+0.5)s = 1+0.9s.$$

$$\Delta f(s) = \frac{-\left[\frac{K_{ps}}{1+sT_{ps}}\right]}{1+\left(\frac{K_{ps}}{1+sT_{ps}}\right)\left(\frac{K_{sg}}{1+sT_{sg}}\right)\left(\frac{K_t}{1+sT_t}\right)\frac{1}{R}}$$

$$\Delta f(s) \frac{-\left(\frac{100}{1+20s}\right)}{1+\left(\frac{100}{1+20s}\right)\left(\frac{1}{1+0.9s}\right)\left(\frac{1}{3}\right)} \cdot \frac{0.01}{s.}$$

Since

$$K_{ps} = \frac{1}{B_{p.u}} = \frac{1}{0.01} \text{(default value)} = 100$$

$R = 3$ (default)

$K_{sg}K_t = 1$ (default)

$T_{ps} = 20$ (default)

$$\Delta f(s) = \frac{-100(1+0.9s)}{(1+20s)(1+0.9s)+\frac{100}{3}} \cdot \frac{0.01}{s}$$

$$\Rightarrow \frac{-100-90s}{1+20.9s+18s^2+\frac{100}{3}} \cdot \frac{0.01}{s}$$

$$\Delta F(s) = \frac{-(1+0.9s)}{s\left(18s^2+20.9s+\cancel{1}\frac{7}{3}+\frac{103}{3}\right)}$$

$$\Delta f = \lim_{s \to 0} sF(s)$$

$$= \frac{-\cancel{s}(1+0.9s)}{\cancel{s}\left(18s^2+20.9s+\frac{103}{3}\right)}$$

$$= \frac{-1}{103/3}$$

$$\Delta f = \frac{-3}{103} = 0.0289\ Hz$$

$$\boxed{\Delta f = 0.0289\ Hz}$$

DYNAMIC RESPONSE

Dynamic response of a s/m is obtained for the step changes in the load demand.

- Dynamic response deals with following assumption:

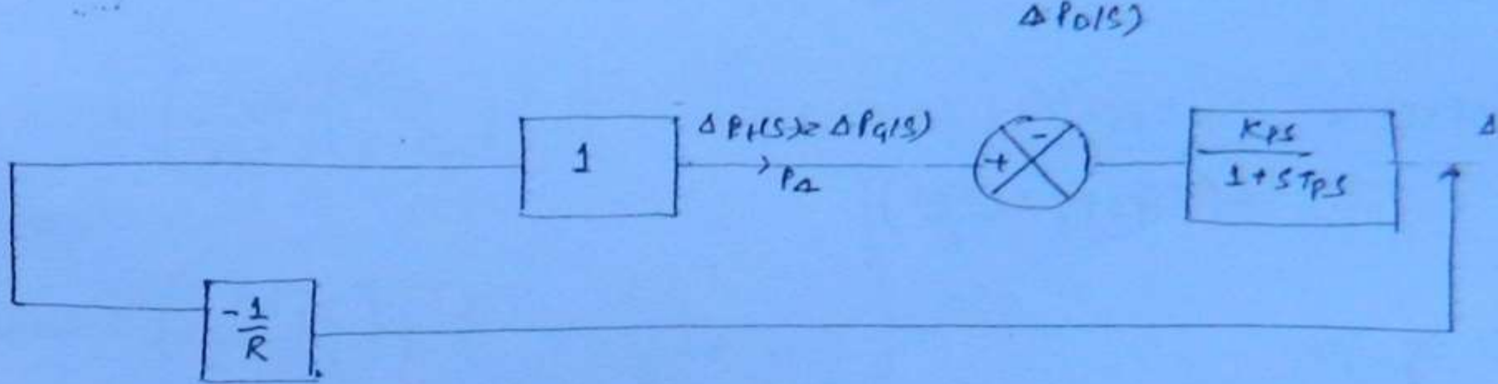
1) free governor operatn ($\Delta P_c(s) = 0$)

2) $K_{sg}K_t = 1$

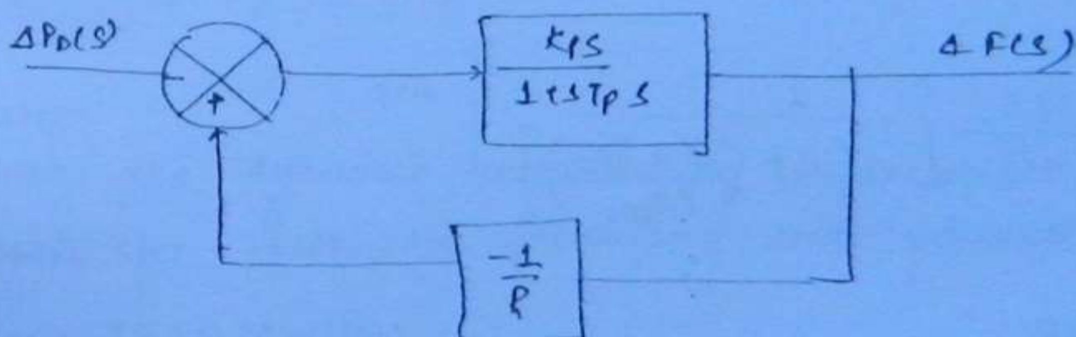
3) $T_{sg} \cong 0$, $T_t \cong 0$

So,

$$\left(\frac{K_{sg}}{1+sT_{sg}}\right)\left(\frac{K_t}{1+sT_t}\right) = \frac{1}{(1+s\cdot 0)(1+s\cdot 0)} = 1.$$



⇒



$$\Delta F(S) = \frac{-\left(\frac{K_{ps}}{1+sT_{ps}}\right)}{1 - \left\{\left(\frac{K_{ps}}{1+sT_{ps}}\right)\left(\frac{-1}{R}\right)\right\}} \cdot \Delta P_D(S)$$

$$\Delta F(S) = \frac{-\left[\frac{K_{ps}}{1+sT_{ps}}\right]}{\left[1 + \left\{\left(\frac{K_{ps}}{1+sT_p}\right)\left(\frac{1}{R}\right)\right\}\right]} \cdot \frac{\Delta P_D}{S}$$

$$= \frac{-K_{ps}}{\left[sT_{ps} + \left(1 + \frac{K_{ps}}{R}\right)\right]} \cdot \frac{\Delta P_D}{s}$$

$$\Delta F(s) = \frac{-K_{ps}}{s\left(sT_{ps} + \left(1 + \frac{K_{ps}}{R}\right)\right]} \Delta P_D.$$

Divide by T_{ps}

$$\Delta F(s) = \frac{-K_{ps}/T_{ps}}{s\left(s + \left\{\frac{1}{T_{ps}} + \frac{K_{ps}}{T_{ps} \cdot R}\right\}\right)} \cdot \Delta P_D.$$

$$\Delta F_s = \frac{-K_{ps}/T_{ps}.}{1} \left\{ \frac{1}{s\left[s + \left(\frac{R + K_{ps}}{RT_{ps}}\right)\right]} \right\} \Delta P_D.$$

Applying partial fraction:

$$\frac{1}{s\left[s + \left(\frac{R+K_{ps}}{RT_{ps}}\right)\right]} = \frac{A}{s} + \frac{B}{s + \left[\frac{R + K_{ps}}{RT_{ps}}\right]}$$

$$1 = A \cdot \left(\frac{R + K_{ps}}{RT_{ps}}\right) \qquad \therefore A + B = 0$$

$$\Rightarrow A = \frac{RT_{ps}}{R + K_{ps}}$$

$$B = -A = \frac{-RT_{ps}}{R + K_{ps}}$$

$$\Delta f(s) = \left(-\frac{K_{ps}}{T_{ps}}\right)\left[\frac{R T_{ps}/R+K_{ps}}{s} - \frac{R T_{ps}/R+K_{ps}}{s+\left(\frac{R+K_{ps}}{R T_{ps}}\right)}\right]\Delta P_D.$$

$$= \left(\frac{-K_{ps}}{T_{ps}}\right)\left(\frac{R T_{ps}}{R+K_{ps}}\right)\left\{\frac{1}{s} - \frac{1}{s+\left(\frac{R+K_{ps}}{R T_{ps}}\right)}\right\}\Delta P_D.$$

$$\Delta f(s) = \left(\frac{-R K_{ps}}{R+K_{ps}}\right)\left\{\frac{1}{s} - \frac{1}{s+\left(\frac{R+K_{ps}}{R T_{ps}}\right)}\right\}\Delta P_D.$$

Taking inverse laplace:

$$\Delta f(t) = \left(-\frac{R K_{ps}}{R+K_{ps}}\right)\left\{1 - e^{-\left(\frac{R+K_{ps}}{R T_{ps}}\right)t}\right\}\Delta P_D.$$

Question:

Obtain the dynamic response of uncontrolled isolated power s/m with the following loop parameters. Regulation R = 2

- $K_{ps} = 75$ p.u MW/Hz.
- $T_{ps} = 20$ sec
- $\Delta P_D = 0.02$ pu.

$$-\left(\frac{2\times75}{2+75}\right)\left\{1 - e^{-\left(\frac{2+75}{2\times20}\right)t}\right\} 0.02$$

$$-1.94\left\{1 - e^{-1.925t}\right\}0.02$$

$$\Delta f(t) - 0.038(1-e^{3.87t})$$

Dynamic responce is represented in 4th Quadrant dynamic response is always exponential increasing in the fourth quadrant.

- Dynamic response alway gives $\boxed{\Delta f \neq 0}$

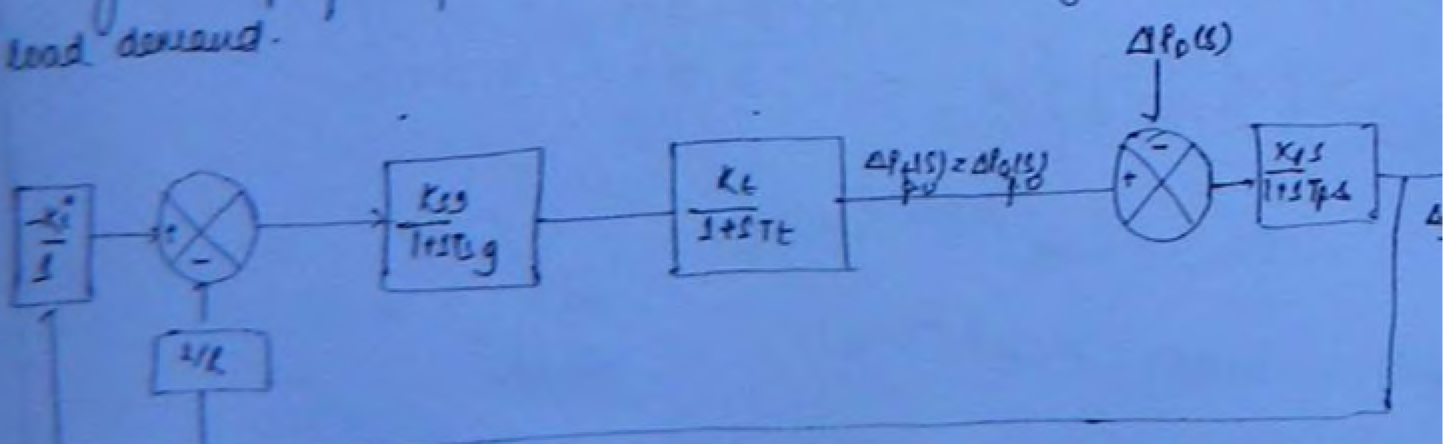
- The change in frequency Δf can be made equal to 0 by means of p proportional and integral controller.

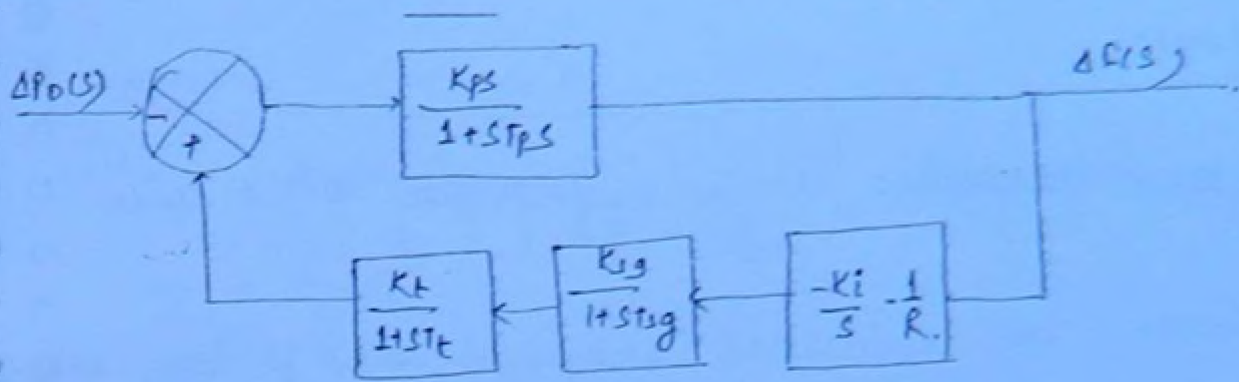
INTEGRAL CONTROLLER:-

- Integral controller is represented in the feedback path
- Let Ki be the gain constant of integral controller

negative sign indicates that for positive frequency error the speed changer should move in downward direction

- $\Delta f = 0$, can be made by replacing speed governor with integral controller. ie FREE GOVERNOR OPERATION.
- change in frequency is determined for the changes in the load demand.





$$\frac{\Delta f(s)}{\Delta P_D(s)} = \frac{-\left(\frac{K_{ps}}{1+sT_{ps}}\right)}{1-\left(\frac{K_{ps}}{1+sT_{ps}}\right)\left(\frac{K_t}{1+sT_t}\right)\left(\frac{K_{sg}}{1+sT_{sg}}\right)\left(\frac{-K_i}{s}-\frac{1}{R}\right)}$$

$$\Delta f(s) = \frac{-\left(\frac{K_{ps}}{1+sT_{ps}}\right)}{1+\left(\frac{K_{ps}}{1+sT_{ps}}\right)\left(\frac{K_t}{1+sT_t}\right)\left(\frac{K_{sg}}{1+sT_{sg}}\right)\left(+\frac{K_i}{s}+\frac{1}{R}\right)} \cdot \frac{\Delta P_D(s)}{s}$$

$$\Delta f_{s.s} = \lim_{s\to} s \cdot \Delta f(s)$$

$$\Delta f(s) = \frac{\cancel{s} \cdot -\left(\frac{K_{ps}}{1+sT_{ps}}\right)}{1+\left(\frac{K_{ps}}{1+sT_{ps}}\right)\left(\frac{K_t}{1+sT_t}\right)\left(\frac{K_{sg}}{1+sT_{sg}}\right)\left(+\frac{K_i}{s}+\frac{1}{R}\right)} \cdot \frac{\Delta P_D(s)}{\cancel{s}}$$

$$= \frac{-(K_{ps})(1+sT_{sg})(1+sT_t)}{(1+sT_{ps})(1+sT_{sg})+K_{ps}K_{sg}K_t\left(\frac{K_i}{s}+\frac{1}{R}\right)} \cdot \Delta P_D.$$

$$\boxed{\Delta f_{s.s}^{(i)} = \frac{1}{\infty} = 0}$$

Dynamic Response:

- Dynamic response determines change in frequency w.r.t time.
- Assumption:

1) $K_{sg} K_t = 1$

2) $T_{sg} = T_t \equiv 0$

3)

So,

$$\Delta F(s) = \frac{-(K_{ps})(1+sT_{sg})(1+sT_t)}{(1+sT_{ps})(1+sT_{sg})(1+T_t)+K_{ps}K_{sg}K_t\left(\frac{K_i}{s}+\frac{1}{R}\right)} \cdot \frac{\Delta P_D}{s}$$

$$= \frac{-K_{ps}(1+s\cdot 0)(1+s\cdot 0)}{(1+sT_{ps})(1+s\cdot 0)(1+s\cdot 0)+1\cdot K_{ps}\left(\frac{K_i}{s}+\frac{1}{R}\right)} \cdot \frac{\Delta P_D}{s}$$

$$= \frac{-K_{ps}}{\left[(1+sT_{ps})+K_{ps}\left(\frac{K_i}{s}+\frac{1}{R}\right)\right]} \frac{\Delta P_s}{s.}$$

$$\Delta F(s) = \frac{-K_{ps}}{\left(s+s^2T_{ps}+K_{ps}K_i+s\frac{K_{ps}}{R}\right)}$$

$$\Delta F(s) = \frac{-K_{ps}}{\left[s^2T_{ps}+s\left(1+\frac{K_{ps}}{R}\right)+K_{ps}K_i\right]} \Delta P_D.$$

$$\Delta f(s) = \frac{-K_{ps}/T_{ps}}{\left[s^2 + s\left(\frac{1}{T_{ps}} + \frac{K_{ps}}{RT_{ps}}\right) + \frac{K_{ps}K_i}{T_{ps}}\right]} \Delta P_D \quad \text{------} \quad (A)$$

- The roots of quadratic equatⁿ determines the nature of the integral controller.

CRITICAL GAIN: ($Ki_{critical}$)

Roots of above equation (A).

$$\frac{-\left(\frac{1}{T_{ps}} + \frac{K_{ps}}{RT_{ps}}\right) \pm \sqrt{\left(\frac{1}{T_{ps}} + \frac{K_{ps}}{RT_{ps}}\right)^2 - 4 \cdot 1 \cdot \left(\frac{K_{ps}}{T_{ps}} \cdot K_{ic}\right)}}{2 \cdot 1}$$

equating to 0.

$$\left(\frac{1}{T_{ps}} + \frac{K_{ps}}{RT_{ps}}\right)^2 - 4 \cdot \left(\frac{K_{ps}K_{ic}}{T_{ps}}\right) = 0$$

$$K_{ic} = \frac{T_{ps}}{4K_{ps}}\left(\frac{1}{T_{ps}} + \frac{K_{ps}}{RT_{ps}}\right)^2$$

$$= \frac{T_{ps}}{4 \cdot K_{ps}}\left[\frac{1}{T_{ps}^2} + \left(\frac{K_{ps}}{RT_{ps}}\right)^2 + \frac{2K_{ps}}{RT_{ps}^2}\right]$$

$$= \frac{\cancel{T_{ps}}}{4\cancel{K_{ps}}} \cdot \frac{K_{ps}^{\cancel{2}}}{T_{ps}^{\cancel{2}}}\left[\frac{1}{K_{ps}^2} + \frac{1}{R^2} + \frac{2}{RK_{ps}}\right]$$

$$4K_{ic} = \frac{K_{ps}}{T_{ps}}\left(\frac{1}{K_{ps}} + \frac{1}{R}\right)^2.$$

$$\boxed{K_{ic} = \frac{K_{ps}}{4T_{ps}}\left[\frac{1}{K_{ps}} + \frac{1}{R}\right]^2}$$ ---- Critical Gain.

In terms of inertia constant:

$$K_{ic} = \frac{1/B_{p.u}}{2 \times \frac{2H}{Bf_0}}\left[B_{p.u} + \frac{1}{R}\right]$$

$\therefore T_{ps} = \frac{2H}{Bf_0}$.

$$\boxed{K_{ic} = \frac{1}{8H/Bf_0}\left[B_{p.u} + \frac{1}{R}\right]}$$

Imp

$$\boxed{K_{ic} = \frac{f_0}{8H}\left(B_{p.u} + \frac{1}{R}\right)^2}$$

Question:

For an isolated integral controlled power s/m. find the value of critical gain the system parameters are given as follows

Total capacity = 1000 MW

Load demand = 600 MW

inertia constant H = 5 sec

Regulation R = 4%

The nominal operating frequency is 50Hz

the s/m load increases by 1% if s/m frequency increases by 1%

Solution :

$$B = \frac{\partial D}{\partial f}$$

$P_D = 600MW$

$f = 50 Hz$

$\frac{\partial D}{\partial f}$ load demand $\uparrow = \frac{1\% \text{ of } 600}{1\% \text{ of } 50} = 12 MW/Hz$

$$B_{p.u} = \frac{12}{1000} = 0.012 \text{ p.u}/MWHz$$

$$Ki_c = \frac{\overset{10}{\cancel{50}}}{8 \times \cancel{5}} \left(\frac{0.012 + \frac{1}{\cancel{2}}}{} \right)^2$$

$$Ki_c = \frac{10}{8}(0.012 + 0.\cancel{2}5)^2$$

~~$Ki_c = 0.085$~~

$Ki_c = 0.32768$

PERFORMANCE OF TRANSMISSION LINE

- the performance of overhead T.L can be obtained by

1) Efficiency
2) Regulation

• **Efficiency:-** $\dfrac{\text{Power O/P}}{\text{Power i/P}} \times 100$

$$= \frac{\text{Power O/P}}{\text{Power O/P} + \text{Power losses}} \times 100$$

$$= \frac{\text{Power i/P} - \text{Power losses}}{\text{Power i/P}}$$

the power losses are the active power losses

$1\phi = I^2R$

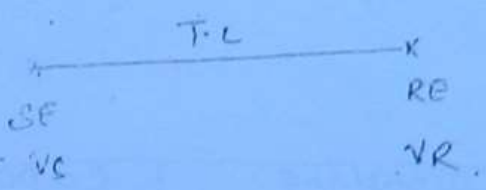
$3\phi = 3I^2R$

I = phase current

R = Resistance / phase.

• **Regulation** — for rotating M/C speed regulation is ~~of~~ obtained.

for static M/C or stationary M/C voltage regulation is measured.



$$\boxed{\% \epsilon = \frac{V_S - V_R}{V_R} \times 100}$$

• condition :-

When the receiving end is open circuited current I=0, voltage drop across TL = 0 &

$$V_S = V_R$$

$$\therefore \quad \boxed{\% \epsilon = \frac{V_{RO} - V_R}{V_R} \times 100}$$

the change in receiving end voltage from no-load to full load expressed w.r.t receiving end voltage at full load is V_R.

for a better T.L %η must be high & %ε must be ON.

CLASSIFICATION OF TL

TL are classified based on —

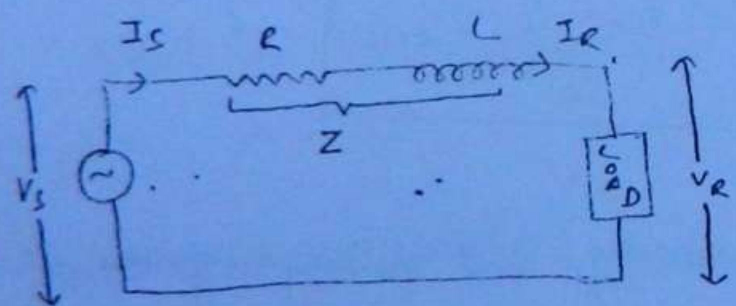
1) length.

ii) operating voltage
iii) effect of capacitance

	Length	operating voltage	capacitance
Short T.L	(0-80) km	(0-20) KV	Neglected
Medium T.L	(80-200) km	(20-100) KV	Lumped or Concentrated
long T.L	(>200 km)	> 100 KV	uniformly distributed

• SHORT TRANSMISSION LINE :-

• Equivalent ckt



• Mathematical Relations :

• $I_S = I_R = I$ (say)

• Resistive voltage drop = IR

• Reactive voltage drop = $j X_L (I)$

• Total voltage drop = $I(R + jX_L)$

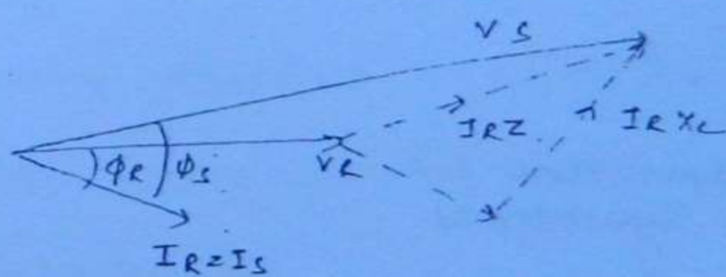
- Sending end voltage $V_S = V_R + I_R + j\,IX_L$

$$= V_R + I\underbrace{(R + jX_L)}$$

$$V_S = V_R + IZ.$$

5) Vector diagram –

- consider Recieving end voltage 'V_R' as the reference vector.
- Assume that the load is R-L load ∴ I_R lags V_R by an angle ϕ_R where ϕ_R lies b/w 0 to 90°.



Imp.

- $\phi_s > \phi_R$
- $\cos\phi_s < \cos\phi_R$.

4) 2-port network parameter:

$$V_s = AV_R + BI_R \quad \text{- - - - (i)}$$

$$I_s = CV_R + DI_R \quad \text{- - - - (ii)}$$

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \quad -$$

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

B → Impedence
C → Admittance.

$A = D = 1$ $\quad B = Z$

$C = 0$

alter →

$V_s = V_R + Z I_R$

$= 1 \cdot V_R + Z \cdot I_R$

$\therefore A = 1, \quad B = Z$

$I_s = I_R$

$= 0 \cdot V_R + 1 \cdot I_R$

$\therefore C = 0, \quad D = 1$

$A = D$ $\therefore$ Short line line Symmetrical.

Short line is Reciprocal because $\boxed{AD - BC = 1}$

$1 \times 1 - 0 \times Z = 1$

$1 = 1$

Questn

A 1-ϕ T.L is transmitting 1.1 MW power to factory at 11 KV & 0.8 PF lagging. It has total resistance of 2 Ω & reactance of 3 Ω

Determine:

1) voltage at the sending end

2) Sending end P.f

3) %age regulation

4) %age efficiency.

unless specified by default take all data as recieving end data.

$P_R = 1.1$ MW

$V_R = 11$ kV

$\cos\phi_R = 0.8$ lag

R/phase $= 2\Omega$

X/phase $= 3\Omega$

$P_R = I_R V_R \cos\phi_R$

$$I_R = \frac{1.1\times10^6}{0.8\times11\times10^3}$$

$I_R = 125$ A

$I_R = |I_R|\angle\phi_R$

$I_R = 125\angle -36.8^\circ$

Z/phase $= 2+j3$

$= 3.6\angle 56.3$

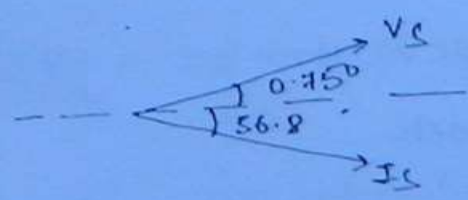
$V_S = V_R + I_R Z$

$= 11\times10^3 + 125\angle -36.8^\circ \times (2+j3)$

$= 11000\angle 0^\circ + (125\angle -36.8^\circ)(3.6\angle 56.5)$

$= 11.42\angle 0.75^\circ$ kV

(ii) $\cos\phi_S = \cos\angle V_S . I_S$



$\phi_S = 36.8 + 0.75$

$= 37.55$

$\cos\phi_S = \cos(37.55)$

$\cos\phi_S = 0.79$ lag

) $\eta = \frac{\text{Power o/p}}{\text{Power o/p + losses}} \times 100$

$= \frac{1.1 \times 10^6}{1.1 \times 10^6 + I^2R} = \frac{1.1 \times 10^6}{1.1 \times 10^6 + (125)^2 \times 2}$

$\eta = 97.24\%$

7) $\% \epsilon = \frac{V_S - V_R}{V_R} \times 100$

$= \frac{11420 - 11000}{11000} \times 100$

$= 3.86\%$

If asked A, B, C, D

$A = 1$

$B = Z = 3.6$

$C = 0$

$D = 1$.

Quest?

An overhead 3-ϕ T.L deliver 5MW at 22kV at 0.8 lagging. The resistance & reactance of each conductor are 4Ω & 6Ω. Determine

1) Sending end voltage
2) % Regulation
3) %age η

Solutⁿ

$P_R = 5MW$

$V_R = 22kV$

$\cos\phi_R' = 0.8 lag$

$\rightarrow$ in 1-ϕ

$P_R = V_R I_R \cos\phi_R$

$\rightarrow$ in 3-ϕ

$P_R = 3 V_{Rph} I_{Rph} \cos\phi_R$

$= \sqrt{3} V_{RL} I_{RL} \cos\phi_R$

until & unless specified all the value given is line value only

$P_R = \sqrt{3} V_{RL} I_{RL} \cos\phi_R$

$I_{RL} = \dfrac{5\times10^6}{22\times10^3 \times 0.8} = 164 A.$

$\boxed{V_{ph} \rightarrow V_L/\sqrt{3}}$

$I_R = 164 \angle -\cos^{-1}0.8$

$= 164 \angle -36.8\,°A$

$Z = 4 + 6j$

$= 7.21 \angle 56.31$

$\hat{V_s} = \dfrac{22000\angle 0°}{\sqrt{3}} + (164 \angle -36.8 (7.2 \angle 56.31°)$

$V_s = 13.817 \angle 1.63° kV$

$V_{sL} = \sqrt{3} V_s$

$= 25.94 kV$

$\% E = \dfrac{V_s - V_R}{V_R} \times 100$

$$= \frac{25940 - 22000}{22000} \times 100 = 8.82\%$$

$$\%\eta = \frac{o/p}{o/p + \text{losses}}$$

$$\text{losses} = 3 \cdot I^2 R$$

$$= 3 \times (164)^2 \times 4$$

$$= 322.75\,kW$$

$$\%\eta = \frac{5 \times 10^6}{5 \times 10^6 + 322.75 \times 10^3}$$

$$\%\eta = 93.9\%$$

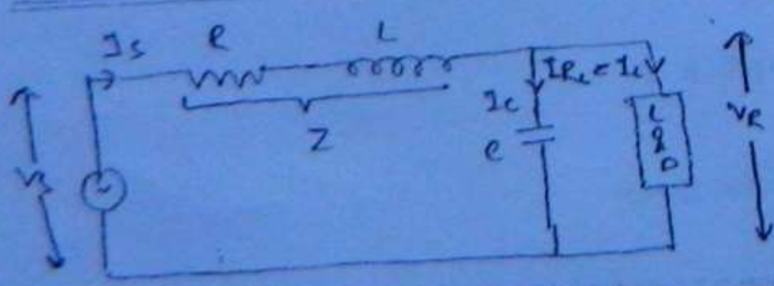
MEDIUM TRANSMISSION LINE

A medium T.L can be represented in 4 - method.

1) Load condenser method
2) Source condenser method
3) Nominal - T method
4) Nominal - π method

LOAD CONDENSER METHOD

Equivalent ckt:-



2) Mathematical Relation

- $I_s = I_R + I_C$
- Resitive voltage drop $= I_s R$
- Reactive voltage drop $= I_s(jX_L)$
- Total voltage drop $= I_s R + I_s(jX_L)$

$$= I_s(R + jX_L)$$

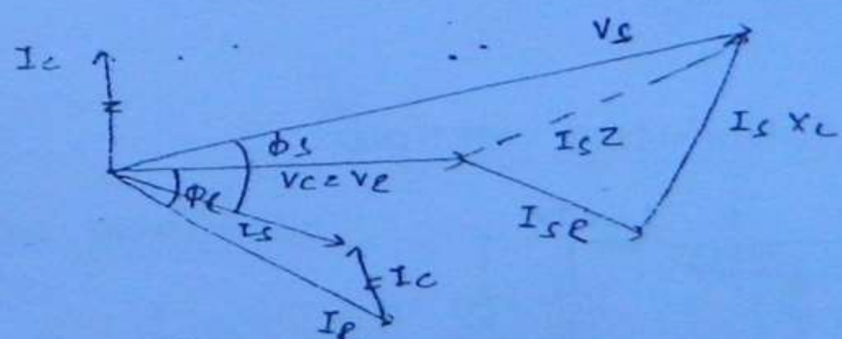
$$= I_s \cdot Z$$

- $V_s = V_R + I_s R + I_s(jX_L)$

$$V_s = V_R + I_s Z$$

- voltage across capacitor $(V_C) = V_R$

3) Vector diagram:



- for RL load I_R lags V_R by an angle ϕ_R

2) 2-port Network Parameters:-

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

$$= \begin{bmatrix} 1+YZ & Z \\ Y & 1 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

$A = 1 + YZ$

$B = Z$

$C = Y$

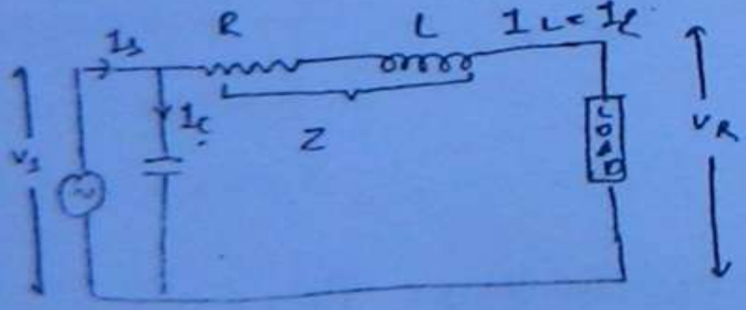
$D = 1$

- $A \neq D$ $\therefore$ Not symmetrical
- $AD - BC = (1+YZ) \cdot 1 - Z \cdot Y = 1$

  $\therefore$ It is reciprocal

Load condenser method is not symmetrical
$\because$ capacitor is not symmetrical in the equivalent ckt.

2) SOURCE CONDENSER METHOD



$I_s = I_R + I_c$

1) Mathematical Relation:-

- ~~Mathematical~~ $I_s = I_R + I_c$
- Resistive voltage drop $I_R R$

- Reactive voltage drop $= I_R(jX_L)$

- Total voltage drop $= I_R R + I_R(jX_L)$

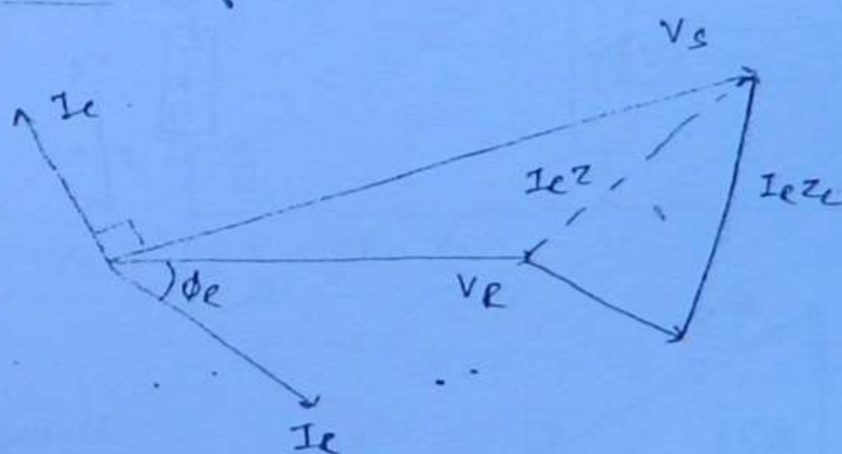
$$= I_R(R + jX_L)$$

$$= I_R Z$$

- Sending end voltage $V_s = V_R + I_R R + I_R(jX_L)$

$$V_s = V_R + I_R Z$$

Vector diagram



2-port N/w parameters:

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix} \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

→ see from the sending end, the branch that come first fill those values in 1st matrix.

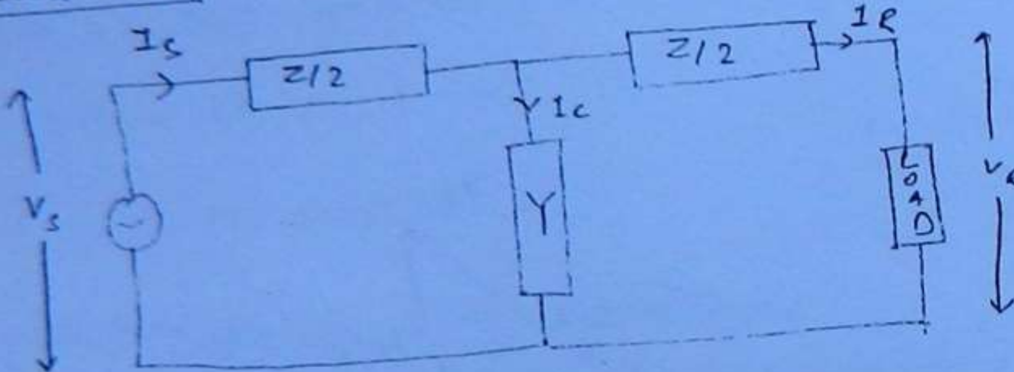
$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} 1 & Z \\ Y & 1+YZ \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

$A = 1$ $B = Z$ $C = Y$ $D = 1 + YZ$

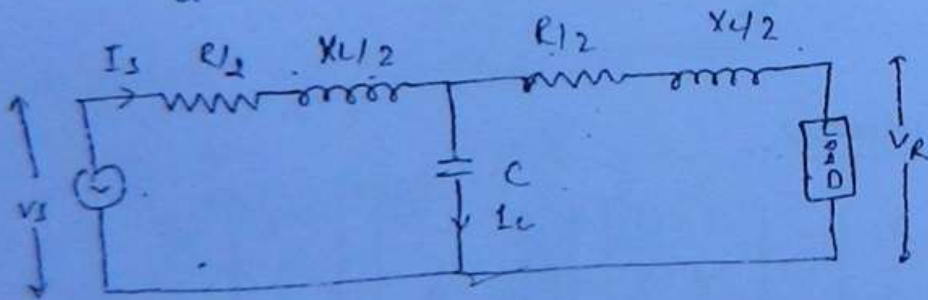
- $A \neq D$ So not symmetrical
- $AD - BC = 1$ ∴ Reciprocal

5) NOMINAL T-METHOD / MIDDLE CONDENSOR METHOD:

Equivalent ckt:



$$\frac{Z}{2} = \frac{R}{2} + j\frac{X_L}{2}$$



- $I_s = I_R + I_c$
- Resistive voltage drop $= I_s \cdot \frac{R}{2} + I_R \cdot \frac{R}{2}$

$$\frac{R}{2}(I_s + I_R)$$

- Total reactive drop $= I_s\left(j\frac{X_L}{2}\right) + I_R\left(j\frac{X_L}{2}\right)$

$= j\frac{X_L}{2}(I_S + I_R)$

- total voltage drop $= \left(\frac{R}{2} + j\frac{X_2}{2}\right) I_S + I_R\left(\frac{R}{2} + j\frac{X_L}{2}\right)$

$$= I_S \cdot \frac{Z}{2} + I_R \cdot \frac{Z}{2}.$$

- $V_C = V_R + I_R \cdot Z/2$

$$= V_R + I_R\left(R/2 + j\frac{X_L}{2}\right)$$

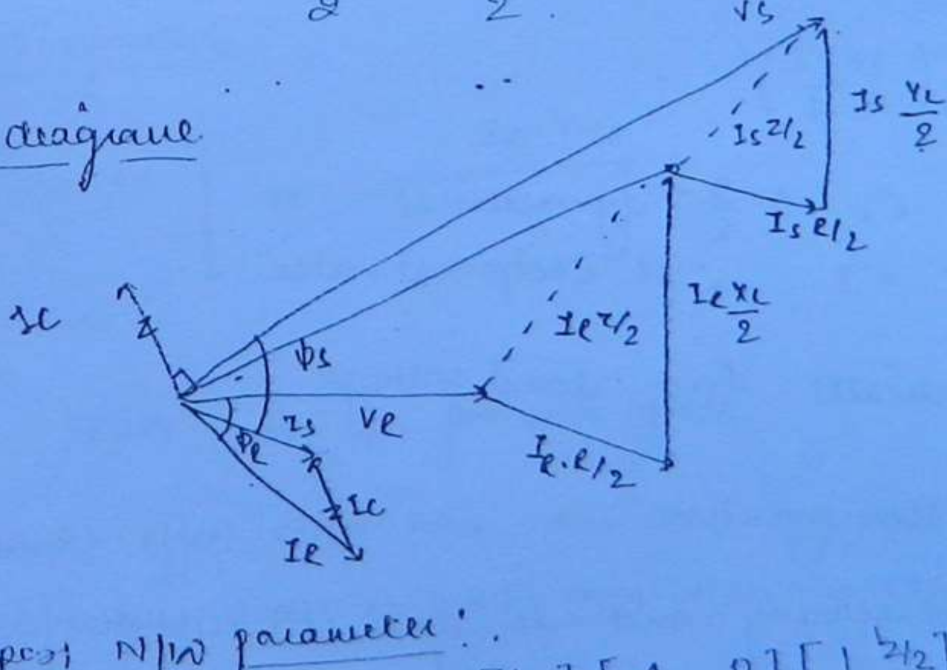
$$V_C = V_R + I_R \cdot \frac{R}{2} + j\, I_R \frac{X_L}{2}$$

$\boxed{V_R = V_C}$

- $V_S = V_C + I_S \frac{Z}{2}$

$$= V_C + I_S \cdot \frac{R}{2} + j I_S \cdot \frac{X_L}{2}.$$

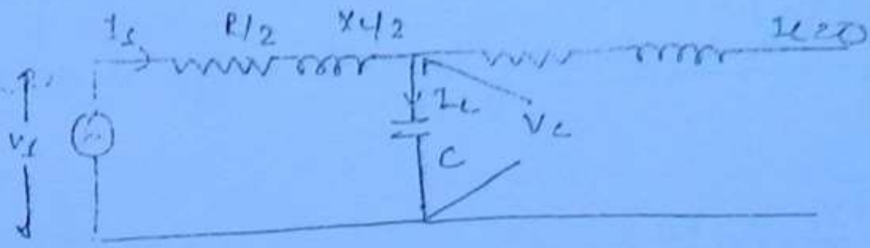
vector diagram



∴ 2-port N/W parameter :

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} 1 & Z/2 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix} \begin{bmatrix} 1 & Z/2 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V \\ R \end{bmatrix}$$

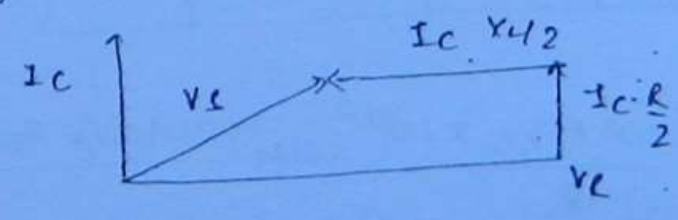
$$\boxed{I_s = I_c.}$$



- Total resistive drop $= I_c \cdot R/2$
- Total reactive drop $= I_c j \frac{X_L}{2}$
- $V_c = V_R$
- Sending end voltage $V_s = V_c + I_c \frac{R}{2} + I_c j \frac{X_L}{2}$

or $V_s = V_R + I_c \frac{R}{2} + I_c \frac{jX_L}{2}$.

Vector diagram:



$V_R > V_s$ is the Ferranti effect.

- Ferranti effect occur when the receiving end of T.L is operating under no-load condition or very light load condition

or $V_{R0} > V_s$

V_{RD} = Voltage across Capacitor

$= I_C \cdot (-jX_C)$

& $I_C = \dfrac{V_S}{R/2 + j\dfrac{X_L}{2} - jX_C}$

$= \dfrac{V_S}{\dfrac{R}{2} + j\dfrac{\omega L}{2} - j\dfrac{1}{\omega C}}$

Imp

$$\boxed{V_{RD} = \left(\frac{V_S}{R/2 + j\frac{\omega L}{2} - j\frac{1}{\omega C}}\right)\left(-j\frac{1}{\omega C}\right)}$$

Example

The %age rise in the voltage at the recieving end of a TL of length 200 km operating at 50 Hz is

Increase in voltage $= \dfrac{\omega^2 l^2 V_r \times 10^{-10}}{18}$ volts

%age ↑ in voltage $= \dfrac{\dfrac{\omega^2 l^2 V_R \times 10^{-10}}{18}}{V_R} \times 100$

$= \dfrac{\omega^2 l^2 \times 10^{-10} \times 100}{18}$ (l → km)

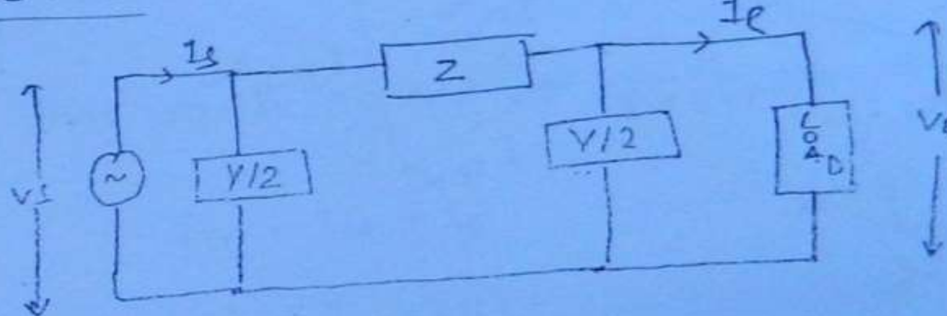
$= \dfrac{(2\pi \times 50)^2 \times (200)^2 \times 10^{-8}}{18}$

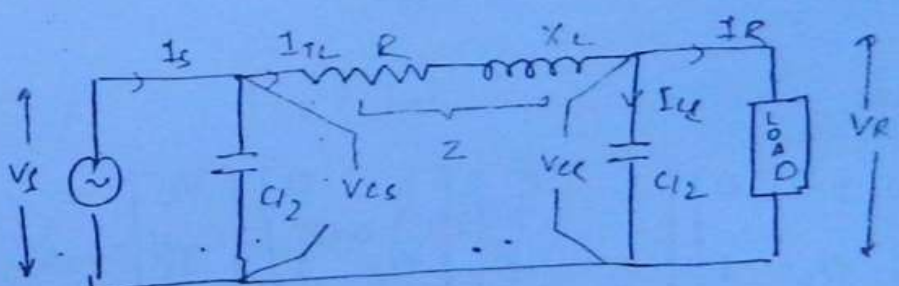
$= 2.18\%$

* Ferranti effect is more severe in long T.L when compared with medium T.L
* Ferranti effect is negligible in short T.L

4) NOMINAL-π METHOD / SPLIT CONDENSER METHOD

i) Equivalent ckt —



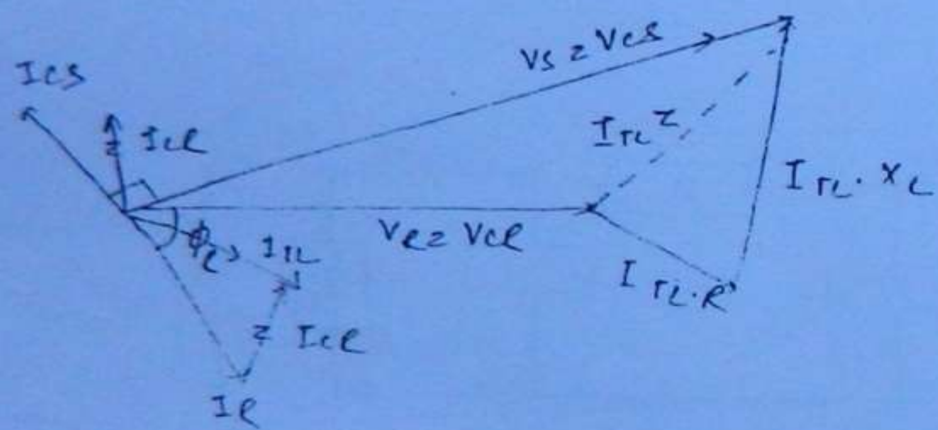


Mathematical Relations:

- $I_{TL} = I_R + I_{CR}$; $I_S = I_{CS} + I_{TL}$
- $V_{CR} = V_R$
- $V_{CS} = V_S$
- Total resistive drop = $I_{TL} \cdot R$
- Total reactive drop = $I_{TL} j X_L$
- Total voltage drop = $I_{TL}(R + jX_L)$

• Sending end voltage $(V_s) = V_R + I_{TL}R + I_{TL}jX_L$

Vector diagram:-



2 port N/W parameters —

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ Y/2 & 1 \end{bmatrix} \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ Y/2 & 1 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} 1 + \frac{ZY}{2} & Z \\ \frac{Y}{2} + \left(\frac{ZY}{2} + 1\right)\frac{Y}{2} & 1 + \frac{YZ}{2} \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

$A = 1 + \frac{ZY}{2}$ $\quad A = D$

$B = Z$

$C = \frac{Y}{2} + \frac{ZY^2}{4} + \frac{Y}{2}$

$$= Y + \frac{ZY^2}{4}$$

$$\therefore C = Y\left(1 + \frac{ZY}{4}\right)$$

- $A = D$ ∴ It is symmetrical

$AD = BC = 1$ also so Reciprocal also

<u>condition</u> -

Assume that receiving end of T.L is open circuited

$$I_{TL} = I_{cR} + I_R$$

$$= I_{cR} + 0$$

$$I_{TL} = I_{cL}$$

$$V_{R0} = V_{cR} = I_{cR}\underbrace{\left(-j\frac{X_c}{2}\right)}_{\alpha} \text{ this is wrong}$$

$$V_{R0} = I_{cR}\left(-j X_{c1/2}\right)$$

where $X_{C1} = 2/\omega C$

$= 2/\omega C$

$$I_{cR} = V_S / R + jX_L - jX_{C1/2}$$

$$V_{RO} = \left(\frac{V_c}{R + jX_L - jX_{C\,1/2}}\right)(-jX_{C\,1/2})$$

$$\boxed{V_{Ro} = \left(\frac{V_c}{R + j\omega L - j\frac{2}{\omega C}}\right)\left(-j\frac{2}{\omega C}\right)}$$

NOTE:

- Load condenser method is used to *improve the P.F of the load.
- Source condenser method is used to *improve the p.f of the source
- *Nominal π - method is used to improved the p.f of both source & load
- *Nominal T-method is used to improve the P.F to T.L

Quesn

A 220KV T.L represented as π-method has the following parameter

$A = 0.9\angle 5^\circ \qquad B = 80\angle 65^\circ \Omega$

The sending end voltage is maintained at 220kV the ↑ in voltage at the receiving end & the line losses on no-load condn are?

$V_s = 220\,KV$

$V_S = AV_R + BI_R$

No-load so $I_R = 0$

$V_S = AV_{R0}$

$\therefore V_{R0} = \frac{V_S}{A} = \frac{220}{0.9} = 244.4\ KV$

↑ in voltage = $(244.4 - 220)$ KVolts
$= 24.4\ KV$

Line losses = 0 (∵ the system is under no load)

Questn

A 3-φ T.L, 120km long, 50Hz delivers a connected load of 30 MVA, 110 KV & 0.8 p.f lagging. The resistance is 10Ω/phase & reactance is 40Ω/phase. & capacitive, susceptance is 6×10^{-4} S. Find the voltage regulation by nominal π method.

\# From the capacitive susceptance

$$I_{CR} = V_R/(-j X_{C1/2}) = V_R(j B_{C1/2})$$

$$= \left(\frac{110000}{\sqrt{3}}\right)(j\, 3 \times 10^{-4})$$

$$= (0 + j\, 11\sqrt{3})\ A$$

$$11\sqrt{3} \angle 90^\circ\ A$$

$I_{TL} = I_c + I_{ce}$

$= (157.46 \angle -36.8) + (11\sqrt{3} \angle 90^\circ)$

$I_{TL} = 146.8 \angle -30.9$ A.

voltage drop across $T_L = I_{TL} (R + jX_L)$

$= (146.8 \angle -30.9)(10 + j40)$

$= 6052.49 \angle 45.12^\circ$ V.

Sending end voltage $V_s = V_R +$ voltage drop

$= \frac{11000}{\sqrt{3}} + (6052.49 \angle 45.12)$

$= 67990.74 \angle 3.6^\circ$ V

$V_{SL} = \sqrt{3} \times V_s$/phase

$= \sqrt{3} \times 67990.74$

$= 117.6$ kV

$\% \epsilon = \frac{V_S - V_R}{V_R} \times 100$

$= \frac{117.6 - 110}{110} \times 100$

$= 6.9\%$

Example

A 3-φ feeder having a resistance of 5 Ω & reactance of 10 Ω supplies a load of 2 MW, at 0.85 p.f lagging. The receiving end voltage is maintained at 11 kV by means of static condenser taking 2.1 MVAR from the line. Calculate sending end voltage, sending end p.f regulation & efficiency of feeder.

- The given data corresponds to load condenser method.

$$W = \sqrt{3} \cdot V_{RL} I_{RL} \cos\phi_R$$

$$2 \times 10^6 = \sqrt{3} \times 11 \times 10^3 \times I_{RL} \times 0.85$$

$$I_{RL} = 123.5 \text{ A}$$

$$I_R = 123.5 \angle -31.78° \text{ A}$$

$I_C = ?$

Capacitive current

$$VAR = \sqrt{3} V_{RL} I_C \sin\phi$$

$$2.1 \times 10^6 = \sqrt{3} \times 11 \times 10^3 \times I_C \sin 90°$$

$$I_C = 110.22 \text{ A}$$

$$I_C = 110.22 \angle +90° \text{ A}$$

$$I_S = I_R + I_C$$

$$= 123.5 \angle -31.78 + (110.22 \angle 90°)$$

Types of Conductors :-

1. Solid conductor
2. Stranded conductor
3. Composite conductor (≤ 220kV)
4. Bundled conductor (> 275kV)

Solid Conductor

- 

copper

- A solid conductor consists of single strand

- High electrical conductivity

- Due to solid mech. strength is ↑

- Transportation is difficult

- Stringing of solid conductor is very difficult

Stranded Conductor

- 

copper.

- Stranded conductor consists of 2 or more strands arranged such that the required mech strength is obtained & are connected in parallel to ↑ the current carrying capacity.

- High electrical conductivity

- The required mech strength can be obtained by selecting no of strands

- Transportation is easier

- Stringing of stranded conductor is easy

- for a solid conductor in ac s/m skin effect is more

for a stranded conductor in ac s/m skin effect is less

SAG AND TENSION.

1. parabolic method < 300km
2. catenary method > 300 km.
3. Effect of external factors on calculatn of Sag & Tens
4. calculation of sag and tension when Transmission towers are located at different height from ground level
5 calculation of basic terms involved with sags.

CALCULATION OF SAG AND TENSION BY PARABOLIC METHOD.

- Parabolic method is used to determine sag and tension for spans upto 300m and sag without exceeding 5% of the span length.

- CATENARY: A line conductor of uniform cross-section and material perfectly flexible but stretche inelastic b/w the two supports, hanging freely under [illegible] influence of its own weight takes the form of curve known as k catenary.

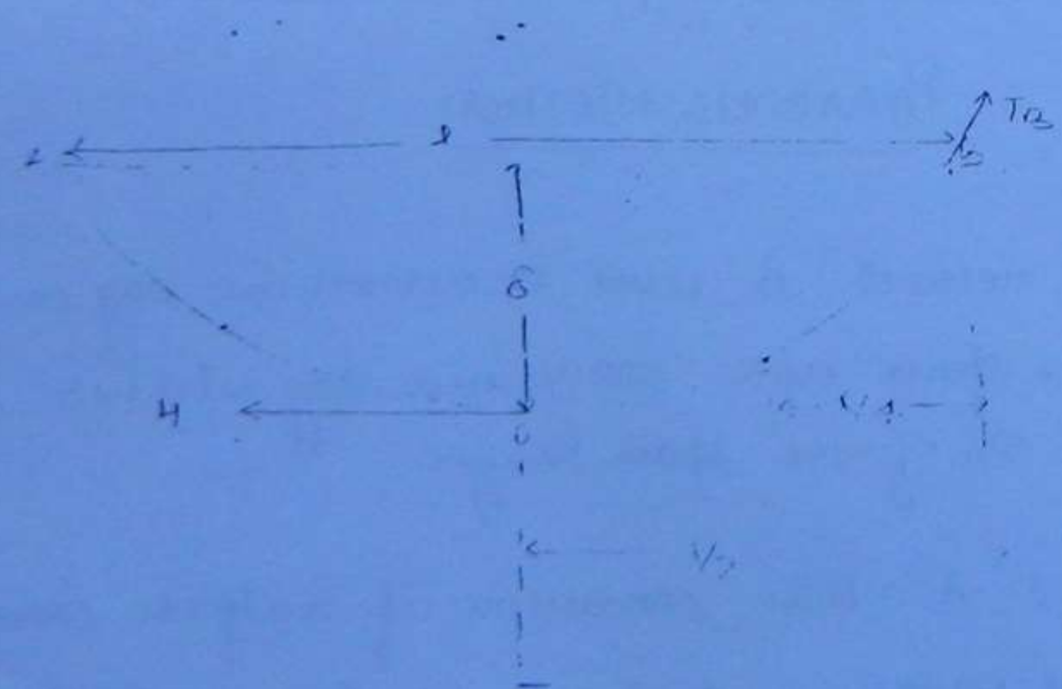
SPAN:

The horizontal distance b/w the adjacent supports is known as span.

SAG:

~~So~~ the vertical distance between the conductor at the midpoint and the ~~tér~~ line joining two adjacent level supports is known as sag.

- Sag is measured along the resultant load on the conductor.



- Consider a T.L 'AOB' freely suspended.

between the supports A and B. The lowest point is consider O.

- Let 'l' be span length

  $\omega \rightarrow$ weight/unit length of the conductor

  $\delta \rightarrow$ T.L line sag.

  $H \rightarrow$ Horizontal tension in T.L at the point of max^m sag.

  $T_B \rightarrow$ tension at the support B due to T.L.

- Consider the equilibrium of the portion 'OB' of the conductor. The force acting are :-

1) Horizontal tension 'H' at point O.
2) The weight of portion OB acting vertically downw through the center of gravity at a distance 'l/4' from the point 'B'.
3) Tension T_B at the support B.

- obtaining the moment at the point B

- $H \cdot \delta = \omega \times OB \times l/4$

$$H \cdot \delta = \omega \cdot \frac{l}{2} \cdot \frac{1}{4}$$

$$\Rightarrow \boxed{H = \frac{\omega l^2}{8\delta}}$$ .... horizontal tension.

and

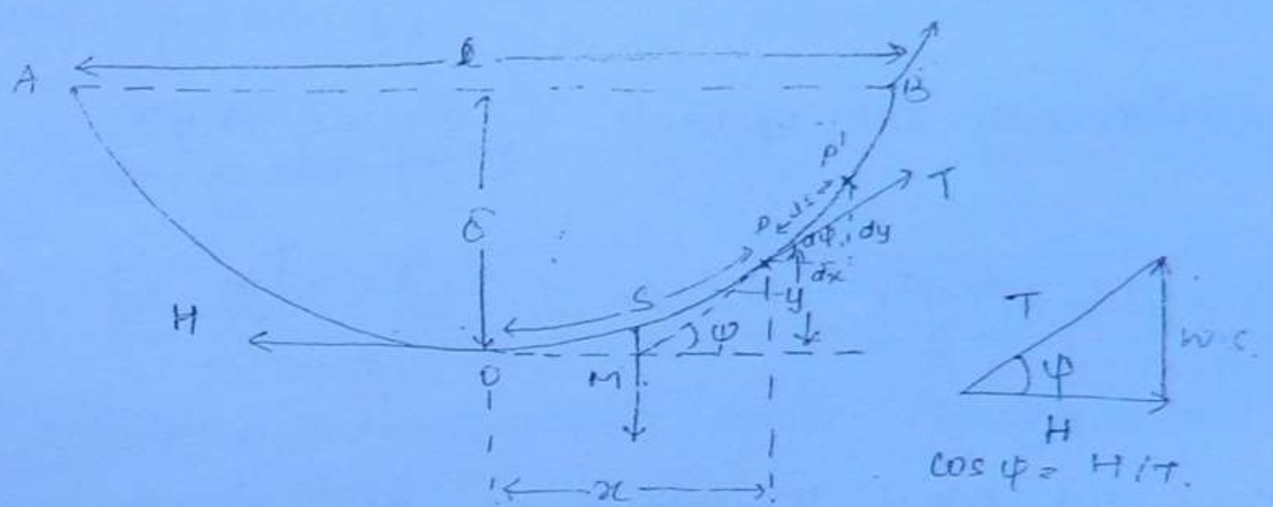
$$\boxed{\delta = \frac{\omega l^2}{8H}}$$ .... sag.

- The sag in a freely suspended conductor is directly proportional to weight/unit length of the conductor, square of span length and inversely proportional to horizontal tension (H).

CATENARY METHOD

- Catenary method is applicable when the length of span is greater than 300m and sag is more than 5% of the span length
- In catenary method a part of section OB is considered.
- Consider a point 'P' on the curve such that

$$OP = x_m.$$



$\cos\varphi = H/T$.

$\sin\varphi = w\cdot s/T$

- the three forces acting on point 'P' on the curve are:

1) Horizontal tension 'H' at lowest point

2) weight of section OP. acting through its center of gravity i.e $\boxed{w.OP = w.s}$

3) tension 'T' acting at point 'P' along the tangent to the curve at point 'P'

- Finding the intersection point of the three forces and the intersection point is 'M'.

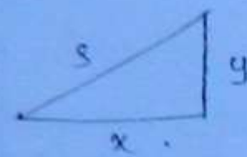
So

$$\boxed{\begin{aligned} H &= T\cos\varphi \\ ws &= T\sin\varphi \end{aligned}}$$

$$\boxed{\tan\varphi = \frac{ws}{H}}$$

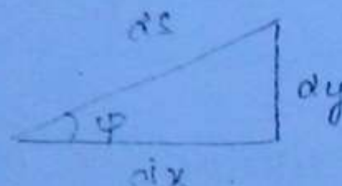
- Let (x, y) be the coordinates of point P.
- Considering the triangle involving (x, y).

$$\boxed{s^2 = x^2 + y^2}.$$



- Extend the point P upto point P' on the T.L such that $PP' = ds$.

$$\boxed{ds^2 = dx^2 + dy^2}.$$



divide by dx^2

$$\left(\frac{ds}{dx}\right)^2 = 1 + \left(\frac{dy}{dx}\right)^2$$

$\because \frac{dy}{dx} =$ slope of T.L $= \frac{w \cdot s}{H} = \tan\varphi$

$$\Rightarrow \left(\frac{ds}{dx}\right)^2 = 1 + \left(\frac{w \cdot s}{H}\right)^2$$

$$\frac{ds}{dx} = \sqrt{1 + \left(\frac{w \cdot s}{H}\right)^2}$$

$$\frac{dx}{ds} = \frac{1}{\sqrt{1 + (w \cdot s / H)^2}}$$

$$\Rightarrow \boxed{dx = \frac{ds}{\sqrt{1 + (w \cdot s/H)^2}}} \quad \text{---} \quad (1)$$

- Integrating equation (1)

$$\cancel{x = \frac{H}{\omega} \sinh^{-1}\left(\frac{\omega s}{H}\right)}$$

$$\boxed{x = \frac{H}{\omega} \sinh^{-1}\left(\frac{\omega s}{H}\right) + C_1} \quad --- (2)$$

$c_1 \rightarrow$ constant of integration which is evaluated from the condition at point O

At point O

$$x = 0 \; ; \; s = 0$$

so. eq^n (2)

$$0 = 0 + C_1$$

$$\boxed{C_1 = 0}$$

so equation (2) will be

$$\boxed{x = \frac{H}{\omega} \sinh^{-1}\left(\frac{\omega s}{H}\right)} \quad --- (3)$$

rearranging we get

$$\boxed{\frac{H}{\omega}\left(\sinh \frac{x\omega}{H}\right) = s} \quad --- (4)$$

- $$\frac{dy}{dx} = \tan\phi = \frac{\omega s}{H}$$

$$dy = \frac{\omega s}{H} \cdot dx \cdot$$

so

$$dy = \sinh\left(\frac{wx}{H}\right) dx \quad \because \frac{ws}{H} = \sinh\left(\frac{wx}{H}\right)$$

on integrating above equation we have.

$$\boxed{y = \frac{H}{w}\cosh\left(\frac{wx}{H}\right) + C_2} \quad \text{---- (5)}$$

now at $x=0$, $y=0$.

so $C_2 = -H/w$.

so

$$\boxed{y = \frac{H}{w}\cosh\left(\frac{wx}{H}\right) - \frac{H}{w}} \quad \text{---- (6)}$$

$\therefore$, vertical distance / catenary eqn.

- Equation '6' is known of <u>EQUATION OF CATENARY</u>
- Representing the parameter in terms of the tension 'T'.

using eqn

$$T\cos\varphi = \cancel{ws}\ H$$

$$T\sin\varphi = w \cdot s.$$

on squaring and adding we get.

$$(T\cos\varphi)^2 + (T\sin\varphi)^2 = H^2 + w s^2$$

$$\boxed{T = \sqrt{T^2 + (ws)^2}} \text{ - tangential tension } (7)$$

- The above equation represents the tension acting tangentially a point 'p' in terms of Horizontal tension and weight of the conductor for the section OP.

- Dividing the above equat^n with H or resubstitute (ws/H).

$$T = \sqrt{H^2 + H^2\left[\sinh\left(\frac{wx}{H}\right)^2\right]}$$

$$T = H\sqrt{1 + \sinh^2\frac{wx}{H}}$$

$$\boxed{T = H\cosh\frac{wx}{H}} \text{ --- } (8)$$

EVALUATION OF SAG(S) LENGTH OF CONDUCTOR(L) AND TENSION(T). AT SUPPORT B.

- At support B:-

$$x = l/2$$

$$s = L/2$$

$$y = \delta$$

the above relation are satisfied at the support B i.e transmission tower located at the point B:

now equation 6:

$$y = \frac{H}{\omega}\cosh\left(\frac{\omega x}{H}\right) - \frac{H}{\omega}.$$

$$\delta = \frac{H}{\omega}\cosh\frac{\omega l}{2H} - \frac{H}{\omega} \qquad x = l/2$$

$$* \boxed{\delta = \frac{H}{\omega}\left[\cosh\frac{\omega l}{2H} - 1\right]} \quad \text{---} (9)$$

now equation 8:

$$T = H\cosh\left(\frac{\omega x}{H}\right)$$

$$* \boxed{T = H\cosh\left(\frac{\omega l}{2H}\right)} \quad \text{---} (10)$$

equation 4:

$$\frac{H}{\omega}\sinh\left(\frac{\omega x}{H}\right) = S.$$

$$\frac{H}{\omega}\sinh\left(\frac{\omega l}{2H}\right) = L/2$$

$$* \boxed{L = \frac{2H}{\omega}\sinh\left(\frac{\omega l}{2H}\right)} \quad \text{---} (11)$$

Approximate Results: By expansion series

- from eqn (9). on expanding cosh we get

$$\delta = \left(\frac{H}{w}\right)\left[\cosh\left(\frac{wl}{2H}\right) - 1\right]$$

$$\delta = \left(\frac{H}{w}\right)\left[\cancel{1} + \left(\frac{wl}{2H}\right)^2\frac{1}{2!} + \left(\frac{wl}{2H}\right)^4\frac{1}{4!} - - - - \cancel{1}\right]$$

$$\delta = \frac{H}{w}\cdot\frac{w^2l^2}{2H}\cdot\frac{1}{2}. \quad \text{neglecting higher terms}$$

$$\boxed{\delta = \frac{wl^2}{8H}} \quad ---- (13)$$

- from equation (10)

$$T = H\cosh\frac{wl}{2H}.$$

$$T = H\left[1 + \left(\frac{wl}{2H}\right)^2\frac{1}{2!} + ---\right]$$

$$T = H + \frac{\cancel{H}w^2l^2}{4H^{\cancel{2}}}\cdot\frac{1}{2}$$

$$\boxed{T = H + \frac{w^2l^2}{8H}} \quad ---- (14)$$

$$T = H + w\cdot\left(\frac{wl^2}{8H}\right)$$

$$\boxed{T = H + w\cdot\delta} \quad --- (15)$$

• equation (31)

$$L = 2\left(\frac{H}{w}\right)\sinh\frac{wl}{2H}.$$

$$L = 2\left(\frac{H}{w}\right)\left[\left(\frac{wl}{2H}\right) + \left(\frac{wl}{2H}\right)^2\frac{1}{3!} + \cdots\right]$$

$$L = 2\left(\frac{H}{w}\right)\frac{\delta}{l}.$$

$$L = \frac{2H}{w}\cdot\frac{wl}{2H} + \frac{2H}{w}\cdot\frac{w^2 l^3}{8H^2}\cdot\frac{1}{6}.$$

$$\boxed{L = l + \frac{1}{24}\frac{w^2 l^3}{H^2}.} \quad \cdots\cdots (16)$$

$$L = l + \frac{1}{24}\frac{w^2 l^3}{\frac{w^2 l^4}{64\delta^2}} \qquad \because H, \ \delta = \frac{wl^2}{8H}.$$

$$L = l + \frac{64\delta^2}{24\cdot l}$$

$$\boxed{L = l + \frac{8}{3}\frac{\delta^2}{l}.} \quad \cdots\cdots (17)$$

Question:

The span b/w the two conductor/towers is 200m.
The ultimate tensile strength of conductor is 5758 Kg/f
The weight of the conductor is 604 KgF/km
The safety factor is 2. The sag is

Ans =

$$\delta = \frac{5758 \times 250 \times 10^{-3}}{}$$

Horizontal tension = $\frac{\text{tensile strength}}{2}$ $5758/2$.

$$\delta = \frac{604 \times (200 \times 10^{3})^2 \times 2}{5758 \times 8}$$

$$\delta = 1.048\,m$$

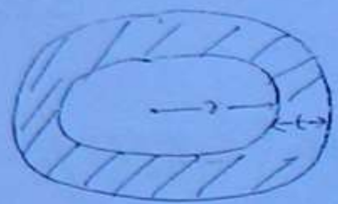
LOADING ON CONDUCTORS

- There are three forces acting on conductor.

    1) weight of conductor
    2) Ice loading
    3) Wind loading.

- The weight of conductor acts vertically downwards and depends on conductor type.
- The weight of conductor/unit length is obtained from mechanical characteristic of conductor.

Ice loading



r → radius of conductor

t → thickness of ice coating.

- Due to deposition of ice on the surface of conductor the weight/unit length of conductor increases.

- Area of cross-section of conductor. $\pi r^2 = \frac{\pi}{4} D^2$ --- ①

Area of cross-section of conductor $\bar{c}$ ice coating

$$A_{con+ice} = \frac{\pi}{4}(D+2t)^2 \quad \text{--- ②}$$

Area of cross section of ice coating

$$= \frac{\pi}{4}\left[D^2 - (D+2t)^2\right]$$

$$= \frac{\pi}{4}\left[\cancel{D^2} + \cancel{D^2} + 4t^2 + 4Dt\right]$$

$$= \frac{\pi}{\cancel{4}}\left[\cancel{4}t^2 + \cancel{4}Dt\right]$$

$$\boxed{A_{ice} = \pi t(t+D)\, m^2} \quad \text{--- ③}$$

- Volume of ice per unit length of conductor

$$\boxed{V = \pi t(t+D)\, m^3} \quad \text{--- ④}$$

• Let (ρ_i) be the weight density of ice the weight of the ice coating per unit length:

$$\boxed{\omega = \underbrace{\pi t(t+D)}_{\text{Volume}} \cdot \underbrace{\rho_i}_{\text{weight density}}}$$

→ where $\rho_i = 913.5 \text{ kgf/m}$
$= 8960 \text{ N/m}^3$.

• Due to ice coating the weight of the conductor increase and the vertical weight increases

5) WIND Loading:-

• Assume that conductor is covered with ice coating
• Let 'r' be the radius of conductor and
  't' be the thickness of ice coating
• Wind exterts horizontal pressure depending on velocity of wind acting ⊥.
Area projected per unit length of ice cover conductor.

- The wind pressure acts on area $\frac{\pi}{4}(D+2t)^2$

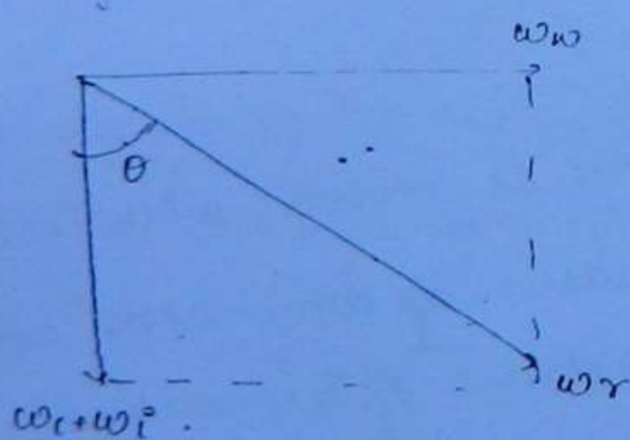
- $(D+2t)$ is surface exposed to wind pressure.
- Force exerted due to wind perpendicular to direcⁿ of span per unit length of conductor.

$$F = (D+2t)_m \times P \; (N/m)$$

$$\boxed{F = (D+2t) \times P}$$ meter Newton.

where P is the wind pressure acting in a direction ⊥ the direction of the span.

Resultant tension:-



- 'θ' represent the angle by which conductor is shifted from its original position due to wind pressure.

$$w_r = \left[(w_w)^2 + (w_c + w_i)^2 \right]^{1/2}$$

Question:-

A T.L has span of 275m between level supports the conductor has diameter of 19.53 mm, weighs 0.844 kgf/l with ultimate breaking strength 7950kgf. Each conductor has radial covering of ice 9.53 mm thick and is subjected to horizontal wind pressure 40kgf/m² of ice covered projected area. If the factor of safety is two. The deflected sag and vertical component of sag are.

Soln

$l = 275 mm$

$D = 19.53 mm.$

$\omega = 0.844 \frac{Kgf}{m}.$

· weight of ice per meter length of the conductor

$\omega i = \pi t (D+t) \rho i$

$= \pi t (D+t) \times 913.5$

1.54×10^{-1} ·

$= 3.14 \times 9.53 \times 10^{-6} (19.53 \times 10^{-6} + 9.53 \times 10^{-6}) \times 9$

$= 0.755 Kgf$

$\omega_w = (D+2t) \times P$

$\Rightarrow (3.859 \times 10^{-5}) \times 40$

$= 1.54 \times 10^{-3} kgf/km$

$= 1.54 kgf/m.$

- weight of conductor = 0.844 kgf

resultant weight

$$w_r = \left[(1.57)^2 + (0.795 + 0.844)^2\right]^{1/2}$$

$$w_r = 2.25\,kgf.$$

- working tension H. = $\dfrac{\text{ultimate strength}}{\text{safety facto}} = \dfrac{7950}{2}$

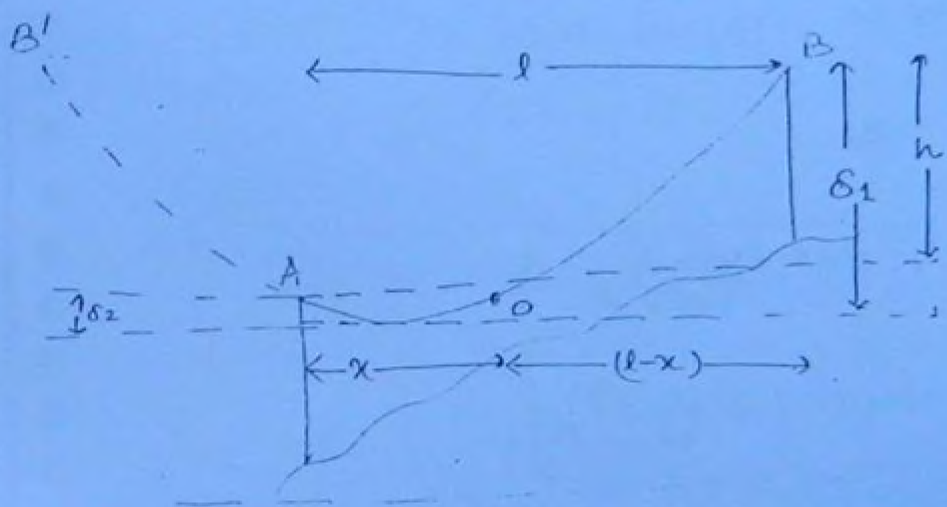
$= 3975$

$$\delta = \frac{wl^2}{8H}$$

→ deflected sag due to w_r. $\Rightarrow \dfrac{2.25 \times 275^2}{8 \times 3975} = 5.35\,m$

→ vertical sag δ. $\Rightarrow \dfrac{\overset{(w_c + w_i)}{1.639} \times 275^2}{8 \times 3975} = 5.89\,m.$

CALCULATION OF SAG WHEN TRANSMISSION TOWER ARE LOCATED AT DIFFERENT HIEGTH IN GROUND LEVEL.



- The transmission towers are not at the same level in hilly area

- Let

  l → horizontal span length b/w A and B

  h → difference in level b/w two supports A B

  x → horizontal distance of support A from lowest point O

  (l-x) → horizontal distance of B from lowest point O.

- B'OB. represents the entire catenary conductor AOB is portion of catenary B'OB. the portion

OA and OB may be treated as catenaries of sag δ_2 and δ_1.

- The vertical reaction at lower support ωx.
- vertical reaction at higher support $\omega(l-x)$.
- Tension at support A

$$\boxed{\begin{aligned} T_A &= H\cosh\left(\frac{\omega x}{H}\right) \quad \text{---} (1) \\ T_B &= H\cosh\left(\frac{\omega(l-x)}{H}\right) \quad \text{---} (2) \end{aligned}}$$

- sag b/w lowest point 'O' and the support 'A'

$$\boxed{\delta_2 = \frac{H}{\omega}\left[\cosh\left(\frac{\omega x}{H}\right) - 1\right]} \quad \text{---} (3)$$

- sag between lowest point and the support 'B'

$$\boxed{\delta_1 = \frac{H}{\omega}\left[\cosh\frac{\omega(l-x)}{H} - 1\right]} \quad \text{---} (4)$$

- In terms of tension T

$$\delta = \frac{\omega x^2}{2T} \quad ; \quad x = l/2 \text{ and } \delta = \frac{\omega l^2}{8T}$$

$$\boxed{\delta_2 = \frac{w(x)^2}{2T} \quad \text{--- (5)}}$$

$$\boxed{\delta_1 = \frac{w(l-x)^2}{2T} \quad \text{--- (6)}}$$

now

$$\boxed{h = \delta_1 - \delta_2}$$

$$= \frac{w}{2T}\left[(l-x)^2 - x^2\right]$$

$$h = \frac{w}{2T}\left[l^2 + \cancel{x^2} - 2lx - \cancel{x^2}\right]$$

$$h = \frac{wl}{2T}(l-2x)$$

$$\Rightarrow \quad (l-2x) = \frac{2hT}{wl}$$

$$2x = l - \frac{2hT}{wl}$$

Imp

$$\boxed{x = \frac{l}{2} - \frac{hT}{wl}} \quad \text{--- (7)}$$

so $(l-x) = l - \left[\frac{l}{2} - \frac{hT}{wl}\right]$

Imp

$$\boxed{(l-x) = \frac{l}{2} + \frac{hT}{wl}} \quad \text{--- (8)}$$

- If $\left[\frac{l}{2} < \frac{hT}{wl}\right]$ then x is negative i.e toward tower. A and B are located on the same side of the lowest point O.

Question:-

A TL conductor at a river crossing is supported by two towers at hieght 30m and 90m. above water level the horizontal distance b/w the tower is 270m. If the tension in conductor is 1800 kgf. and weight of conductor is 1kgf/m determine the clearance b/w conductor and the water at a point located at the center b/w the two towers.

Solution:

- Horizontal distance b/w the towers (span) $l = 270m$
- vertical distance b/w two supports.

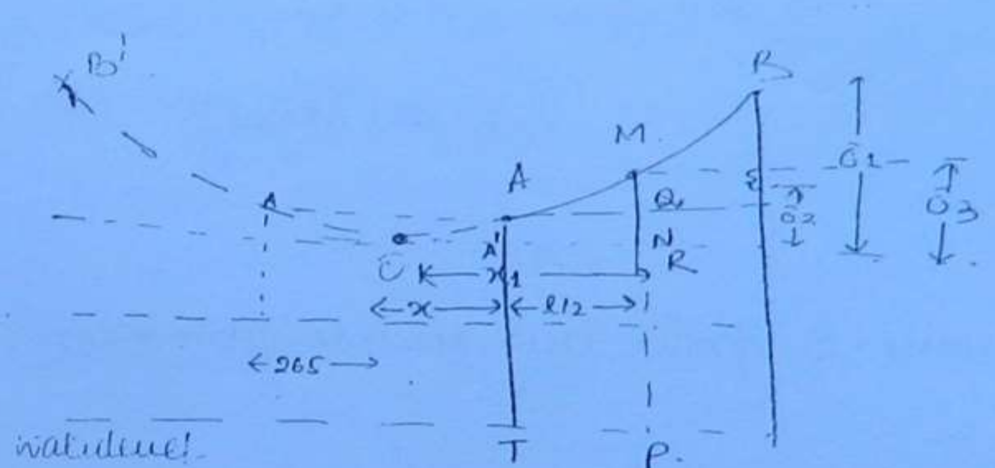
$$h = (90-30) = 60m$$

$$x = \frac{l}{2} - \frac{hT}{wl} = \frac{270}{2} - \frac{60 \times 1800}{1 \times 270}$$

$$= \frac{270}{2} - 400$$

$$= -265m.$$

negative value of x indicates that both towers are located on one side of lowest point O.



- let 'M' be the point located at the center between the two towers the horizontal distance of M from the lowest point 'O' is equal to

$$x_1 = OA' + A'N$$

$$= x + A'N.$$

$$= 265 + l/_2 .$$ (the sign as represented in other side)

$$= 265 + \frac{270}{2}$$

$$\boxed{x_1 = 400m}$$

- the height of point 'A' from the lowest point 'O'

$$\delta_2 = \frac{c\omega x^2}{2T} = \frac{1 \times 265^2}{2 \times 1800} = 19.50m.$$

• Height of point M from the lowest point O.

$$\delta_3 = \frac{w x_1^2}{2T} = \frac{1 \times 400^2}{2 \times 1800}$$

$$= 44.44 m.$$

• Height of point B from the lowest point O

$$\delta_1 = \frac{w (265 + 270)^2}{2T} = 79.50 m.$$

• The distance b/w the midpoint M b/w the supports A and B to the water level.

$$MP = MQ + QP.$$

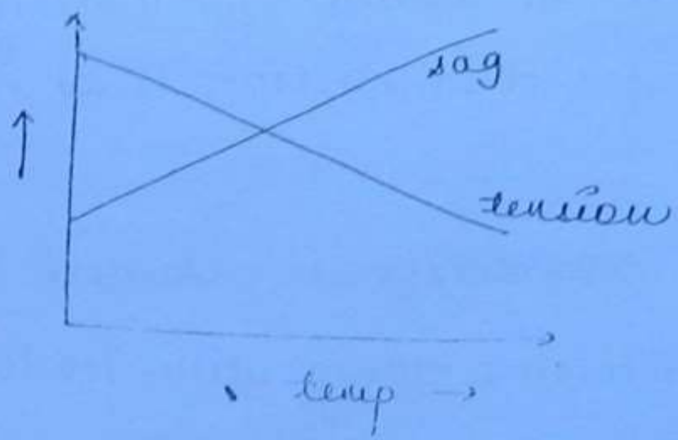
$$MP = (\delta_3 - \delta_2) + AT$$

$$MP = (44.44 - 19.5) + 30$$

$$MP = 54.94 m$$

STRINGING CHART

#. stringing charts gives the relation b/w tension and temp and sag and temp.



SAG TAMPLATE:

• Sag tamplate is used to allocate the position and ~~high~~ height of the supports.

• Sag tamplate is made of transparent ~~se~~ celluloid or other material perspex.

• Sag tamplate consist of 4 different characteristic

i) HOT template curve / HOT curve : hot curve is obtained between sag at maxm temp

• HOT curve determines the ground clearence.

2) Ground Clearance Curve:

Ground clearance curve is below the hot curve. and it is drawn parallel to hot curve

3) Support foot curve:

This curve is drawn for locating the position of supports for transmission lines

4) Cold curve / uplift curve:

Cold curve is obtained by plotting the sag at minimum temp with ice loading and wind loading with respect to span length.

POWER CABLES

- A cable consists of 3 component
  1) conductor
  2) Insulator / Dielectric
  3) Sheath.

* CONDUCTOR:

- A conductor provides a path of conduction for current.

* DIELECTRIC:

withstand service voltage and isolate conductor form other material.

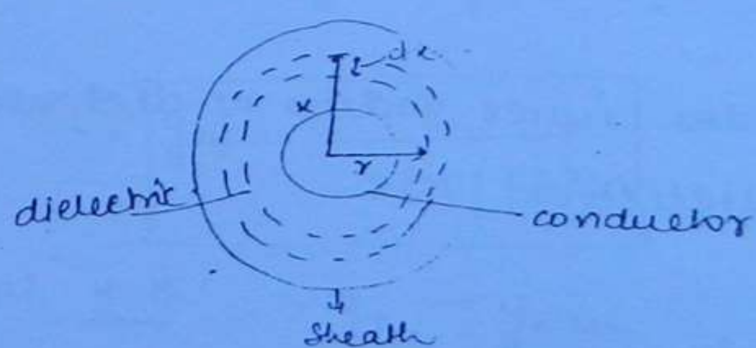
3) SHEATH:

sheath donot allow the moisture content into the cables and prevent cables from chemical forces.

DIELECTRIC STRESS

- When the electrostatic field is uniform, the stress of dielectric $= \dfrac{\text{Applied voltage (V)}}{\text{thickness of dielectric}}$

- In underground cables the electro-static field is not uniform. Therefore the dielectric stress at any point in a single-core cable can changes w.r.t distance x.



- r → radius conductor / inner radius of dielectric

  R → internal radius of sheath / outer radius of insulation

  ϵ_0 → permittivity of free space

Q → charge / unit of length of conductor

V → voltage b/w the phase and neutral

- Electric flux density at the distance x from centre of conductor

$$\boxed{D_x = \frac{Q}{2\pi x} \ C/m^2}$$

- dielectric stress

$$g_x = \frac{D_x}{\epsilon} = \frac{D_x}{\epsilon_0 \epsilon_r}$$

$$\boxed{g_x = \frac{Q}{2\pi \epsilon_0 \epsilon_r x}} \quad (1)$$

- total dielectric stress, is obtained by varying x from (r to R)..

- Potential difference b/w the inner radius of dielectric and outer radius of dielectric

$$V = \int_{x=r}^{x=R} g_x \, dx$$

$$V = \int_{r}^{R} \frac{Q}{2\pi \epsilon_0 \epsilon_r x} dx$$

$$V = \frac{Q}{2\pi\epsilon_0\epsilon_r} \ln(x)\Big|_r^R$$

$$\boxed{V = \frac{Q}{2\pi\epsilon_0\epsilon_r} \ln(R/r)} \quad \text{---- (2)}$$

from eqn (1)

$$\boxed{\frac{Q}{2\pi\epsilon_0\epsilon_r} = x \cdot g_x} \quad \text{---- (3)}$$

substituting in (2)

$$V = x \cdot g_x \ln(R/r).$$

$$\boxed{g_x = \frac{V}{x \ln(R/r)}} \quad \text{---- (4)}$$

at $\underline{x = r}$. $g_x \to g_{max}$.

$$\therefore \boxed{g_{max} = \frac{V}{r \ln(R/r)}} \quad \text{---- (5)}$$

at $\underline{x = R}$ $g_x \to g_{min}$

$$\boxed{g_{min} = \frac{V}{R \ln(R/r)}} \quad \text{---- (6)}$$

$\therefore$ now ~~g_{max}~~ $\boxed{\frac{g_{max}}{g_{min}} = R/r}$ ---- (7)

Economical size of cable.

- For g_{max} to be minimum $r\ln(R/r)$ has to max

- The condition for minimum g_{max} is

$$\frac{d}{dr}\left[r\ln(R/r)\right]=0$$

$$=\frac{d}{dr}\left[r\{\ln R-\ln r\}\right]=0$$

$$=\frac{d}{dr}\left[r\ln R-r\ln r\right]=0$$

$$\Rightarrow\left[\ln(R)\frac{d}{dr}(r)+r\frac{d}{dr}(\ln R)\right]-\frac{d}{dr}(r\ln r)=0.$$

$$=\left[\ln(R)+0-1-[\ln r]\right]=0$$

$$\Rightarrow \ln R-1-\ln r=0$$

$$\boxed{R/r=e=2.718}$$

Ques?

A single core cable for a working voltage of 6.5 kV (b/w core and sheath) has conductor of 10mm over all diameter, which is insulated to a thickness of

7.5mm. the max^{m} electric stress on insulation is

Sol^{n}

$r = \frac{10mm}{2}, 5mm$

$R = 5mm + 7.5 = 12.5mm.$
$(r+t)$

$$g_{max} = \frac{V}{r\ln(R/r)} = \frac{6.5\times10^3}{5\ln\left(\frac{12.5}{5}\right)} = 1.419\ KV/mm.$$

Qus$^{(7)}$

A single core cable is operating on a 3-φ phase 275KV 5/m.. the maximum. dielectric stress should not exceed. 15KV/mm. the overall diameter of single core cable and the most economical diameter of single core cable are.

Sol^{n}.

Rms value of phase voltage $= \frac{275}{\sqrt{3}} = 158.77\ KV$

$g_{max} = \frac{V}{\ } \ 15KV/mm.$

$$15KV = \frac{V}{r\ln(R/r)} = \frac{224.5}{r\ln R/r}.$$

Max^{m} value the phase voltage $= 158.77 \times \sqrt{2}$
$= 224.5\ KV$

$$\Rightarrow r\ln(R/r) = 0.01496$$

For most economical diameter.

$$R/r = e$$

$$\ln(R/r) = 1$$

$$r = \frac{224.5}{15} = 14.96\,mm.$$

economical diameter of conductor $= 2 \times r = 29.92$

economical diameter of ~~co~~ cables $= 2 \times R$
$= 81.38\,mm$.

GRADING OF CABLES

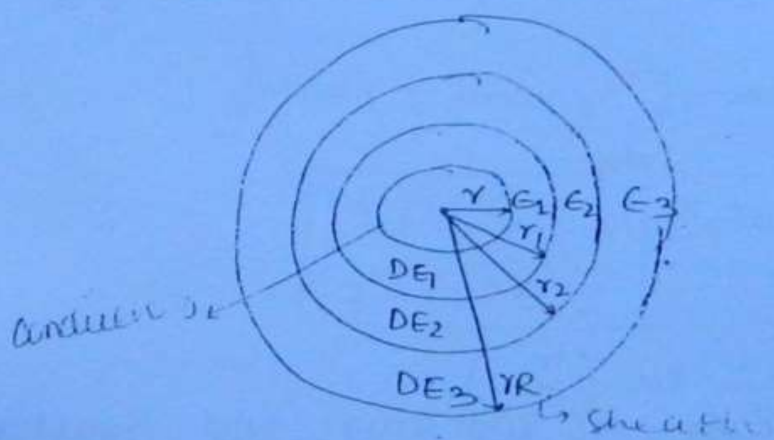
- The electrostatic stress in single core cable has maxm value at g_{max} and g_r decreases as we move towards sheath where electrostatic stress is minimum.

- For safe working of a cable having homogeneous dielectric, the strength of dielectric must be greater than g_{max}.

- If the dielectric of higher strength is used for cable. It is useful only near the conductance surface where the stress is maxm.

- As we move away from the conductor, electrostat stress decreases and dielectric unnecessarily strong therefore the cables must be graded such that the dielectric strength varies based on 'x'

1) Dielectric grading / Capacitance grading



- potential difference across inner layer.

$$V_1 = \int_{x=r}^{x=r_1} g_x \cdot dx$$

$$= \int_{x=r}^{x=r_1} \frac{Q}{2\pi \epsilon_0 \epsilon_1 x_1} dx$$

$$= \frac{Q}{2\pi \epsilon_0 \epsilon_1} \left[\ln(x_1) \right]_{r}^{r_2}$$

$$V_1 = \frac{Q}{2\pi\epsilon_0\epsilon_1} \ln\left(\frac{r_1}{r}\right).$$

$$\therefore\; g_{max} = \frac{Q}{2\pi\epsilon_0\epsilon_r r}$$

$$\boxed{V_1 = g_{max_1} \cdot r \ln\left(\frac{r_1}{r}\right)}.$$

$$g_{max_1} = \frac{Q}{2\pi\epsilon_0\epsilon_1 r}.$$

$$g_{max_2} = \frac{Q}{2\pi\epsilon_0\epsilon_2 r_1}$$

$$g_{max_3} = \frac{Q}{2\pi\epsilon_0\epsilon_3 r_2}$$

- Potential difference across middle layer

$$V_2 = \int_{r_1}^{r_2} g_x \cdot dx .$$

$$= \int_{r_1}^{r_2} \frac{Q}{2\pi\epsilon_0\epsilon_2 x} \cdot dx$$

$$= \frac{Q}{2\pi\epsilon_0\epsilon_2} \ln\left(\frac{r_2}{r_1}\right).$$

$$= \left[\frac{Q}{2\pi\epsilon_0\epsilon_2 r_1}\right] r_1 \ln\left(\frac{r_2}{r_1}\right).$$

$$\boxed{V_2 = g_{max_2} \cdot r_1 \ln\left(\frac{r_2}{r_1}\right)}.$$

- potential difference across outer layer.

$$V_3 = \int_{r_2}^{R} g_x \cdot dx .$$

$$\Rightarrow \int_{r_2}^{R} \frac{Q}{2\pi\epsilon_0\epsilon_3} \ln\left(\frac{R}{r_2}\right).$$

$$= \frac{Q}{2\pi\epsilon_0\epsilon_3 r_2} r_2 \ln\left[\frac{R}{r_2}\right].$$

$$\boxed{V_3 = g_{max_2} \cdot r_2 \ln(R/r_2).}$$

when $\epsilon_1 r = \epsilon_2 r_2 = \epsilon_3 r_2$.

$$g_{max_1} = g_{max_2} = g_{max_3}.$$

$$\boxed{\begin{array}{l} r < r_1 < r_2. \\ \epsilon_1 > \epsilon_2 > \epsilon_3 \end{array}}$$

- voltage b/w core and sheath.

$$\therefore V = V_1 + V_2 + V_3.$$

$$\boxed{V = g_{max}\left[r \ln\left(\frac{r_1}{r}\right) + r_1 \cdot \ln\left(\frac{r_2}{r_1}\right) + r_2 \ln\left(\frac{R}{r_2}\right)\right]}$$

- capacitance of the cable.

$$\therefore C = Q/V$$

$$C = \frac{Q}{V_1 + V_2 + V_3}$$

$$= \frac{Q}{\frac{Q}{2\pi\epsilon_0\epsilon_1}\ln\left(\frac{r_1}{r}\right) + \frac{Q}{2\pi\epsilon_0\epsilon_2}\ln\left(\frac{r_2}{r_1}\right) + \frac{Q}{2\pi\epsilon_0\epsilon_3}\ln\left(R/r_2\right)}$$

$$= \frac{Q}{\frac{Q}{2\pi\epsilon_0}\left[\frac{1}{\epsilon_1}\ln\left(\frac{r_1}{r}\right) + \frac{1}{\epsilon_2}\ln\left(\frac{r_2}{r_1}\right) + \frac{1}{\epsilon_3}\ln\left(\frac{R}{r_2}\right)\right]}$$

*

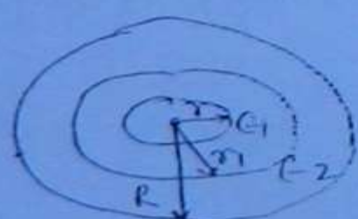
$$\boxed{C = \frac{2\pi\epsilon_0}{\left[\frac{1}{\epsilon_1}\ln\left(\frac{r_1}{r}\right) + \frac{1}{\epsilon_2}\ln\left(\frac{r_2}{r_1}\right) + \frac{1}{\epsilon_3}\ln\left(\frac{R}{r_2}\right)\right]}}$$

Date
26 m Oct 15

Questn

Single core cable has a conductor of 10mm diameter and 2 layers of different dielectric, each of 10mm thickness The relative permittivities are 5 and 2.5, determine the potential gradient at the surface of the conductor when the potential difference b/w conductor and sheath. is 60KV.

Solutn



Radius of conductor = $10/2$ = 5mm = 5×10^{-3}m.

$\epsilon_1 = 5$

$\epsilon_2 = 2.5$

$R = t + r = 15$ mm

$r_1 = r_1 + t = 15 + 10 = 25$ mm

~~now~~. max^m potential gradient at surface of conductor

$$g_{1max} = \frac{Q}{2\pi\epsilon_0\epsilon_1 \cdot r} = \text{---} \quad (1)$$

$$g_{2max} = \frac{Q}{2\pi\epsilon_0\epsilon_2 \cdot r_1} \quad \text{----} \quad (2)$$

on dividing.

$$\frac{g_{2max}}{g_{1max}} = \frac{\epsilon_1 r}{\epsilon_2 r_1}$$

$$\frac{r_1 \cdot g_{2max}}{r\, g_{1max}} = \frac{\epsilon_1}{\epsilon_2} \quad \text{-------} \quad (3).$$

· potential difference between conductor and sheath

$$V = V_1 + V_2$$

$$60 = g_{1max} \cdot r \ln\frac{r_1}{r} + g_{2max}\, r_1 \ln\frac{R}{r_1}$$

$$\Rightarrow 60 = g_{1max}\, r\left[\ln\frac{r_1}{r} + \frac{g_{2max}}{g_{1max}}\frac{r_1}{r}\ln\frac{R}{r_1}\right]$$

$$= g_{1max} \cdot r\left[\ln\frac{r_1}{r} + \frac{\epsilon_1}{\epsilon_2}\ln\left(\frac{R}{r_1}\right)\right]$$

$$60 = g_{1max} \cdot 5\left[\ln\frac{15}{5} + \frac{3}{2.5}\ln\frac{35}{15}\right]$$

$$g_{1max} = 7.01\, kV/mm$$

Question:-

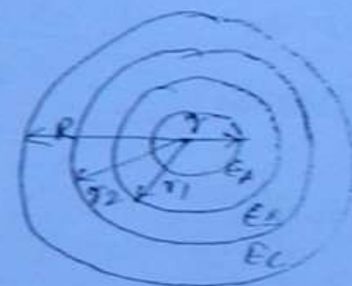
A single core cable is to be designed for 66KV to ground. The radius of conductor is 10mm. and insulating materials A, B and C have relative permittivities of 5, 4 and 3. and corresponding max^m stresses 3.8, 2.6 and 2 KV/mm. determine the minimum diameter of sheath.

Soln

$3.8 = g_{A max}$ | $\epsilon_A = 5$

$2.6 = g_{B max}$ | $\epsilon_B = 4$

$2 K = g_{C max}$ | $\epsilon_C = 3$



max^m ~~die~~ dielectric stress of dielectric A

$$g_{A max} = \frac{Q}{2\pi\epsilon_0\epsilon_A r}$$

$$3.8 = \frac{Q}{2\pi\epsilon_0 \times 5 \times 10 mm}$$

$$\Rightarrow \frac{Q}{2\pi\epsilon_0} = 190$$

max^m dielectric stress of dielectric B.

$$= \frac{Q}{2\pi\epsilon_0\epsilon_B r_1}$$

$$2.6 = \frac{190}{4 \times r_1}$$

$$r_1 = 18.26 mm.$$

- max^m dielectric stress of dielectric C

$$g_c\,max = \frac{Q}{2\pi\epsilon_0\epsilon_c r_2}$$

$$2 = \frac{190}{3 \times r_2}$$

$$r_2 = 31.67\ mm.$$

- Potential difference across inner layer.

$$V_1 = g_A\,max\ r \cdot \ln\left(\frac{r_1}{r}\right)$$

$$= 3.8 \times 10\ \ln\left(\frac{18.3}{10}\right)$$

$$V_1 = 22.96\ KV$$

$$V_2 = g_B\,max \cdot r_1 \ln\left(\frac{r_2}{r_1}\right)$$

$$= 2.6 \times 18.3 \cdot \ln\left(\frac{31.67}{18.3}\right)$$

$$V_2 = 26.1\ KV$$

as $V = V_1 + V_2 + V_3$

$$V_3 = g_c\,max \cdot r_2 \cdot \ln\left(\frac{R}{r_2}\right)$$

$$= 2 \times 31.67\ \ln\left(\frac{R}{31.67}\right)$$

$$V_3 = 63.34\ \ln\left(\frac{R}{31.67}\right)$$

$$66kV = 22.96 + 26.1 + 63.34 \ln\left(\frac{R}{31.7}\right)$$

$$\frac{16.91}{63.34} = \ln\left(R/31.7\right)$$

$$\cancel{0.29}\ 0.267$$

$$1.306 = \frac{R}{31.7}$$

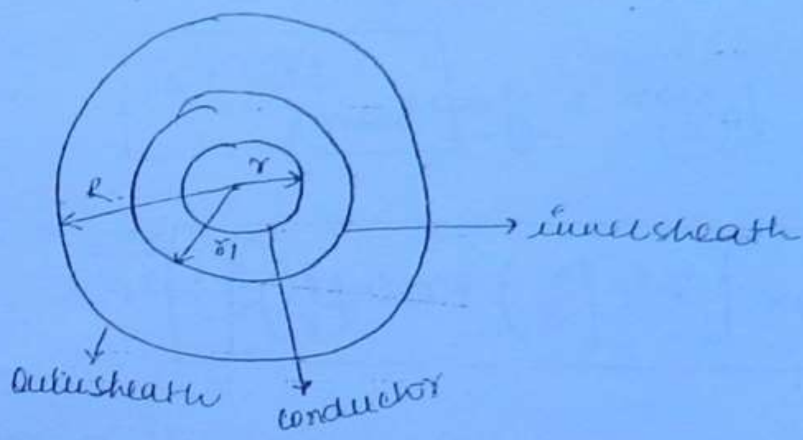
$$R = 41.40$$

$$\text{Diameter} = 2R = 82.8\,mm.$$

INTER-SHEATH GRADING

- In this method same insulating material is utilized through out the total thickness of the dielectric
- the dielectric is divided in two or more ~~sheaths~~ layers by providing intersheaths.
- Intersheaths are thin metallic cylindrical sheaths concentric with the conductor and placed b/w conductor and outside sheaths
- Inter sheath are maintained at suitable potentials by connecting them to the

tappings from the supply x^{mer}.



- Let $r \rightarrow$ radius of conductor

  $r_1 \rightarrow$ radius of intersheath

  $R \rightarrow$ radius of outer sheath.

  $V_1 \rightarrow$ voltage b/w conductor and intersheath.

  $V_2 \rightarrow$ voltage b/w intersheath and outer sheath.

  $V \rightarrow$ voltage b/w conductor and outer sheath.

- $$g_{1max} = \frac{V_1}{r \ln(r_1/r)} \Rightarrow \boxed{V_1 = r\, g_{max} \ln\left(\frac{r_1}{r}\right)} \text{ --- (}$$

$$g_{2max} = \frac{V_2}{r_1 \ln\left(\frac{R}{r_1}\right)} \Rightarrow \boxed{V_2 = r_1 g_{1max} \ln\left(\frac{R}{r_1}\right)} \text{ - (}$$

Potential difference b/w core and sheath

$$V = V_1 + V_2$$

$$= r g_1 max \ln\left(\frac{r_1}{r}\right) + r_1 g_2 max \left(R/r_1\right)$$

and $g_1 max = g_2 max = g max$.

$$\therefore \boxed{V = g max \left[r \cdot \ln\left(\frac{r_1}{r}\right) + r_1 \ln\left(\frac{R}{r_1}\right) \right]}$$

ECONOMICAL SIZE OF CABLE.

According to ~~di~~ dielectric grading

$$\boxed{\frac{r_1}{r} = e = \frac{\text{Sheath radius}}{\text{conductor radius}}} \quad \text{---} (1)$$

now

$$g_1 max = \frac{V_1}{r \ln\left(\frac{r_1}{r}\right)}$$

$$\boxed{g_1 max = \frac{V_1}{r}}$$

Since $g_1 max = g max = \dfrac{V_1}{r}$

$$\therefore \quad r = \frac{V_1}{g max}$$

Substituting in eqn. (1)

$$\Rightarrow \quad r_1 = e r = \frac{e V_1}{g_{max}}.$$

$$\boxed{r_1 = \frac{e V_1}{g_{max}}} \quad \text{--- (2)}.$$

• since '$g_2 max$' $= \dfrac{V_2}{r_1 \ln\left(\frac{R}{r_1}\right)}$

$$g_{max} = \frac{V_2}{r_1 \ln(R/r_1)}.$$

$$g_{max} = \frac{V_2}{r_1 \ln(R/r_1)}$$

$$\frac{V_1}{r} = \frac{V_2}{r_1 \ln(R/r_1)}$$

$$\Rightarrow \quad \ln(R/r_1) = \frac{V_2}{r_1} \times \frac{r}{r_1}.$$

$$\ln(R/r_1) = \frac{V_2}{V_1} \times \frac{1}{e} \qquad \because \frac{r_1}{r} = e.$$

since

$$V = V_1 + V_2$$

$$V_2 = V - V_1$$

thus

$$\ln(R/r_1) = \frac{(V - V_1)}{V_1} \times \frac{1}{e}.$$

$$\ln(R/r_1) = \frac{V}{e V_1} - \frac{1}{e}.$$

$$\Rightarrow \frac{R}{r_1} = e^{\left[\frac{V}{e r_1} - \frac{1}{e}\right]}$$

$$R = r_1 e^{\left[\frac{V}{e r_1} - \frac{1}{e}\right]}$$

substitute eqn (2) in above eqn

$$R = e\frac{V_1}{g_{max}} e^{\left[\frac{V}{e V_1} - \frac{1}{e}\right]}$$

$$R = \frac{V_1}{g_{max}} \cdot e^1 \cdot e^{V/eV_1} \cdot e^{-1/e}$$

$$R = \frac{V_1}{g_{max}} \cdot e^{1-\frac{1}{e}} \cdot e^{V/eV_1}$$

where $\boxed{A = \frac{e^{1-1/e}}{g_{max}}}$

$$\boxed{R = A \cdot V_1 \cdot e^{e^{V/V_1}}} \quad ---- (3)$$

Equation (3) represents the relation b/w the radius of intersheath in terms of the potential difference across the intersheath.

For minimum radius of outersheath differentiate eqn (3) w.r.t V_1 and equate to zero.

$$\frac{dr}{dV_1} = 0.$$

$$\therefore \frac{d}{dV_1}\left[A \cdot V_1 \cdot e^{e^{V/V_1}}\right] = 0$$

$$= A \cdot V_1 \frac{d}{dV_1}\left[e^{e^{V/V_1}}\right] = 0 + A \cdot e^{\frac{V}{eV_1}} \cdot \frac{d}{dV_1}(V_1) = 0$$

$$\Rightarrow A \cdot V_1 \cdot e^{V/V_1} \cdot e^{e^{V/V_1}} + A \cdot e^{V/eV_1} \cdot 1 = 0$$

$$\Rightarrow A \cdot e^{V/eV_1}\left\{\frac{-VV_1}{eV_1^2} + 1\right\} = 0$$

the above expression is equal to zero for the following condition.

$$1 - \frac{VV_1}{eV_1^2} = 0$$

$$1 = \frac{V}{eV_1}$$

$$\boxed{e = V/V_1.} \quad \text{and} \quad \boxed{V_1 = V/e.}$$

$$\boxed{\text{voltage across sheath} = \frac{\text{total voltage}}{e}}$$

- for economical size of cable the voltage across inner layer is $1/e$ times the voltage b/w conductor and sheath

• maxm dielectric stress across first layer.

$$g_{1max} = g_{max} = \frac{V}{r \ln(r_1/r)}$$

$$\Rightarrow g_{max} = V_1/r$$

$$g_{max} = \frac{V}{e \cdot r}$$

$$\boxed{r = \frac{V}{e \cdot g_{max}}} \quad \ldots (4)$$

this should be radius of conductor so that size of cable decrease

• now $\quad r_1/r = e$

$r_1 = r \cdot e$

$= V/\cancel{e}\, g_{max} \cdot \cancel{e}$

$$\boxed{r_1 = V/g_{max}} \quad ---: (5)$$

• the most economical size of cable.

$$R = A \cdot V_1 e^{-V/V_1 e}$$

$$R = \frac{V_1}{g_{max}} \cdot e^{(1-1/e)} \cdot e^{V/eV_1}$$

$$= \frac{V}{\cancel{e} \cdot g_{max}} e^{1-1/e} \cdot \cancel{e}^{\frac{\cancel{V}}{\cancel{e} \cdot \cancel{V}/\cancel{e}}}$$

$$\boxed{R = \frac{V}{g_{max}} e^{1-1/e}}$$

$$\boxed{R = 1.881 \frac{V_1}{g_{max}}} \text{ ..... (6)}$$

Radius of outer sheath

Questn

A 60kV single core cable is graded by means of metallic intersheath. the safe electric stress of insulating material is 4kV/mm. calculate

1) diameter of intersheath and voltage at which it must be maintained in order to obtained minimum overall diameter and the corresponding conductor diameter

2) compare the conductor diameter obtained in question (1) with that of and ungraded cable working under same condition

Soln 1) with intersheath

voltage across inner layer = $V_1 = V/e = \frac{60}{2.718}$

$= 22.1kV$

:- economical radius of conductor

$$r = \frac{V}{e\,g_{max}} = \frac{60}{2.718 \times 4}$$

$$r = 5.5\,mm$$

:- economical diameter of conductor $= 2 \times 5.5$
$= 11\,mm.$

radius of inter sheath $r_1 = \frac{V}{g_{max}} = \frac{60}{4} = 15\,mm.$

:- economical diameter of intersheath $= 2 \times r_1 = D_1 = 30\,mm$

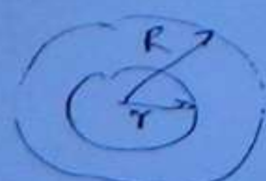
economical radius of outer sheath or cable.

$$R = 1.881\frac{V}{g_{max}} = 28.2\,mm.$$

So diameter $= 2 \times 28.2 = 56.43\,mm.$

now voltage across second layer $= (V - V_1)$
$\Rightarrow 60 - 22.1$
$V_2 = 37.5\,kV$

2) without intersheath



now $R/r = e$

$$\Rightarrow R = e \cdot r = 2.718 \times r.$$

now operating voltage = 60K., when sheath is not used the voltage totally operated at dielectric. Now voltage b/w conductor and sheath.

$$V = g_{max} \cdot r \ln(R/r)$$

$$V = g_{max} \cdot r \cdot 1$$

$$\frac{60}{4} = 15mm = r \text{ . and } d = 30mm \text{. (condu}$$

$$\text{so } R = 2.718 \times 15mm$$
$$= 40.77mm.$$

∴ economical radius of cable $R = 40.77mm$

$$D = 81.54mm.$$

CHARGING CURRENT IN CABLE

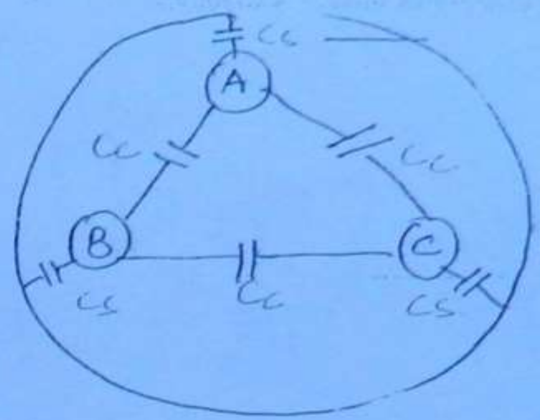
- the capacitance of a cable determines

1) charging current
2) Charging KVA
3) dielectric loss.

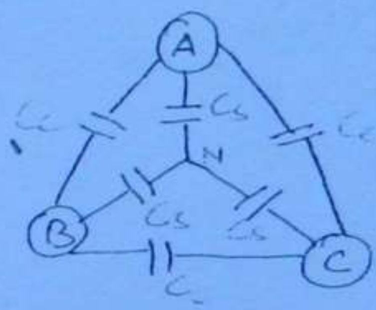
- charging current limits the use of cables on extra-high voltage ~~H~~ lines.
- In a/c ~~st~~ system the charging current depends on length of line and location of capacitance. The current carrying capacity of a transmission line increases when the locatn of capacitance moves away from the sending end.
- In d/c system the current carrying capacity of d/c cable is independent of the length.
- ∵ capacitor behaves like open circuit

CALCULATION OF CAPACITANCE IN 3-CORE CABLE

- conductors in cable are separated from each other by dielectric. Similarly there is dielectric b/w conductor and sheath when potential difference is applied b/w conductors in a cable. The effect of combination of 6-capacitances must be considered.
- Capacitance b/w the conductors is denoted by 'C_c' and capacitance b/w conductor and sheath is denoted by C_s

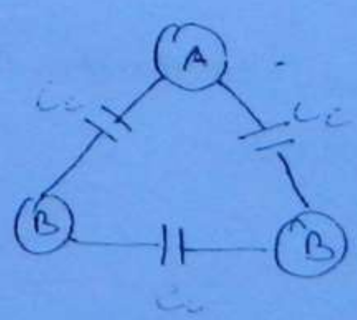


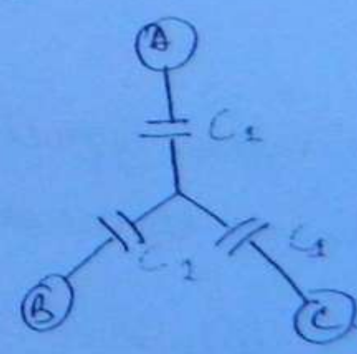
- Sheath operates at zero potential. therefore the entire sheath is represented by a ground/neutral point.



- Conductor capacitance is in delta and capacitance between conductor & sheath is in star.

- Converting capacitances connected in delta into equivalent star.





$\Delta \rightarrow \quad C_{AB} = C_c + \frac{C_c}{2} = 1.5\, C_c$

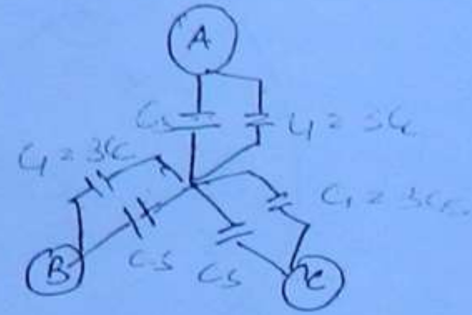
$Y \rightarrow \quad C_{AB} = \frac{C_1}{2}$

now

$$C_{AB} = \frac{C_1}{2}$$

$$1.5\,C_c = C_1/2$$

$$\boxed{C_1 = 3C_c}$$



So

$$C_0 = C_{N-A} = C_1 + C_s = 3C_c + C_s$$

$$C_0 = C_{N-B} = C_1 + C_s = 3C_c + C_s$$

$$C_0 = C_{N-C} = C_1 + C_s = 3C_c + C_s$$

$$\boxed{C_0 = 3C_c + C_s}$$

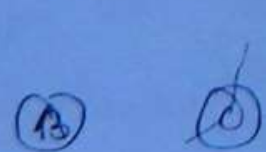
- charging current $= \dfrac{V_{ph}}{X_C}$

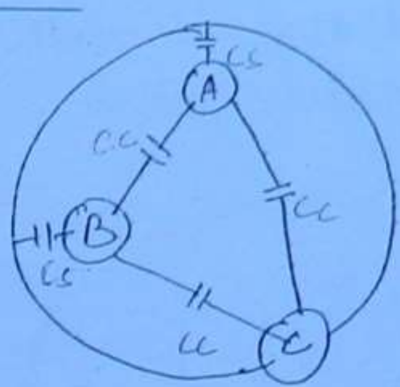
$$= \frac{V_{ph}}{\frac{1}{\omega C_0}} = \omega C_0 V_{ph}$$

$$\boxed{\text{charging current} = \omega C_0 V_{ph}}$$

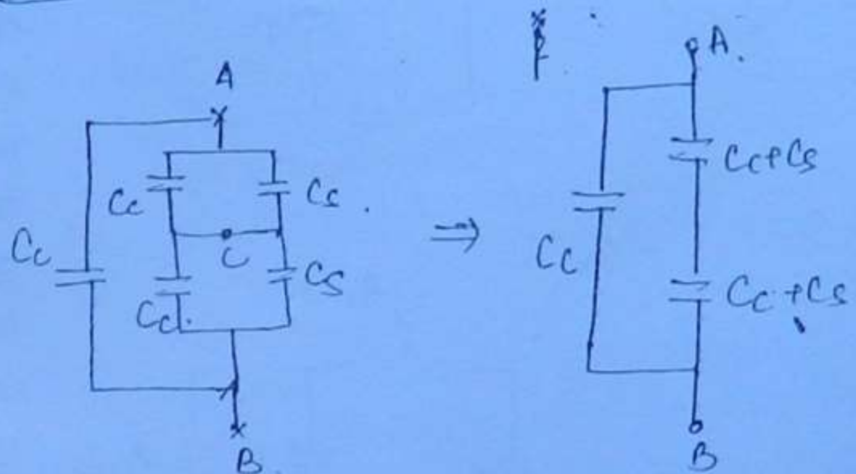
Questⁿ

Determine the equivalent capacitance b/w two conductor A & B when conductor C is connected to the sheath





Solution:



$C_{AB} = C_c + \frac{(C_c+C_s)}{2}$

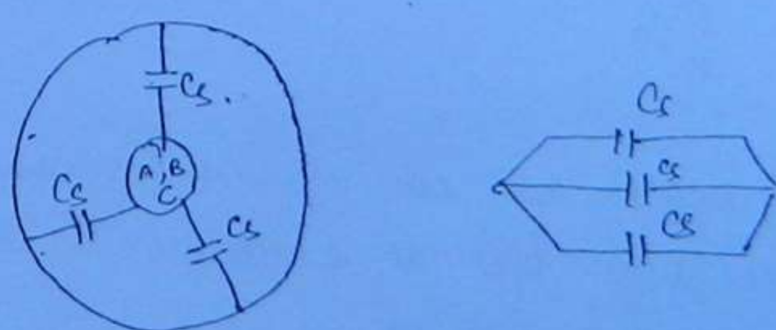
$= \frac{1}{2}[3C_c + C_s]$

$C_{AB} = \frac{1}{2} C_0$

Ques^n

Determine the capacitance b/w conductor and sheath when all the 3 conductors are connected together are bunched together.

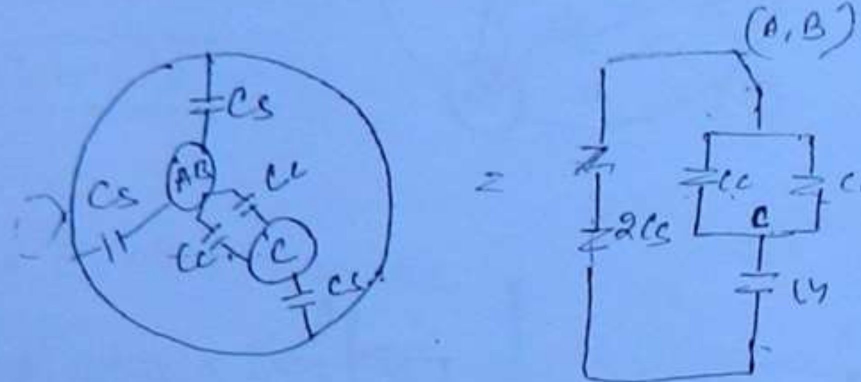
Sol^n



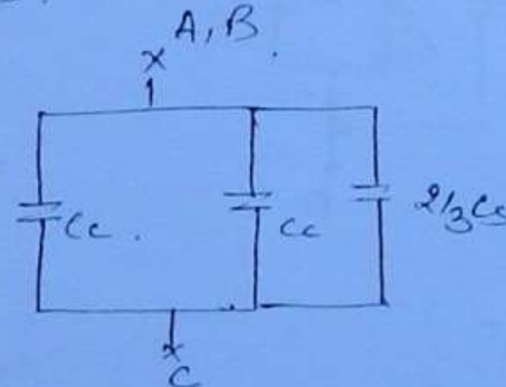
$\Rightarrow 3C_s$

Ques
Two conductors A and B are joined together determine the capacitance between the conductor A and C or conductor B and C.

Solutⁿ



$$\frac{2Cs \times Cs}{3Cs} = \frac{2}{3}Cs$$



Now = $2Cc + \frac{2}{3}Cs$

$C_{A-C} / C_{B-C} = 2Cc + \frac{2}{3}Cs$

$2\left[Cc + \frac{1}{3}Cs\right)$

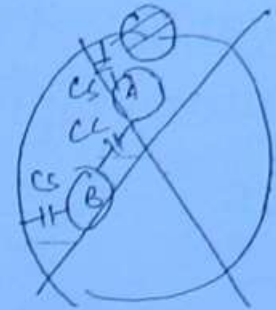
$6\left[Cc + Cs\right]$

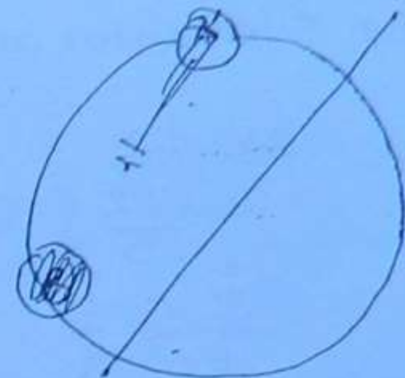
$\frac{2}{3}\left[3Cc + Cs\right]$

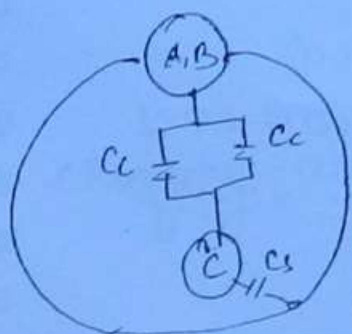
$C_{A-C} / C_{B-C} = \frac{2}{3}Co$

Ques
Two conductors A and B are connected to sheath determine the capacitance b/w the conductors A and B and third conductor C.

Solution:-







~~2Cc+~~

~~2Cc + Cs~~

~~2(Cc +~~

$C_{A-C} = 2C_c + C_s$

$= (C_c + 2C_c + C_c) - C$

$= (3C_c + C_s) - C_s$

$C_{A-C} = C_0 - C_c$

Ques:

The result of 1 KM, 3-φ cable give measured capacitance 0.7 μF between 1 conductor and other 2 conductors bunched together with earthed sheath and 1.2 μF measure b/w 3-bunched conductors and sheath. Calculate

1) capacitance b/w and pair of conductors, sheath being isolated

2) charging current when cable is connected to 11kV at 50Hz supply.

Soln

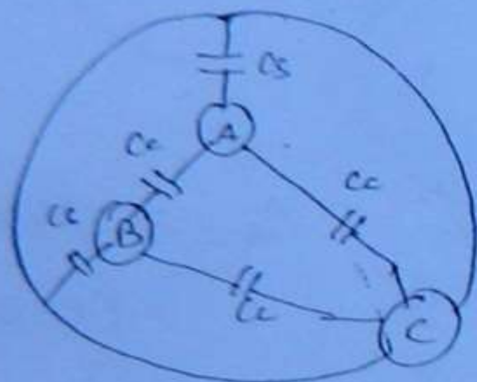
Capacitance b/w 1 conductor and other 2-conductors bunched together.

$$2C_c + C_s = 0.7\,\mu F$$

capacitance b/w 3-conductor and sheath.

$$3C_s = 1.2$$

$$C_s = \frac{1.2}{3} = 0.4\,\mu F$$

1) 

$\therefore C_c + 0.4 = 0.7$

$C_c = 0.15\,F$

2)
$$C_{AB} = C_0/2.$$

$$= \frac{1}{2}(3C_c + C_s)$$

$$= \frac{1}{2}[3 \times 0.15 + 0.4]$$

$$C_{AB} = 0.425\,\mu F.$$

3) charging current $= \dfrac{\times 11 \times 10^3 \cdot 2\times\pi\times 50 \times}{\sqrt{3}}$

$= 1.69\,A/\text{phase}.$

Pbm:

The capacitance measure b/w any two core of 3-ϕ cable is 0.3 μF/km. Determine the charging reactive power taken by 5km length of this cable when connected to an 11kV, 50Hz supply

When conductor 'C' is conn
the capacitance b/w condu

$C_{A-B} = C_0/2$

$\Rightarrow 0.3\,\mu f \times 5\,km = C_0$

$C_0 = 3\,\mu f$.

charging current $= \frac{11 \times 10^3}{\sqrt{3}}$

$I_C = 5.98\,A$

reactive power $= \cancel{I_C^2 X_C}$

$= \sqrt{3} V_L I_C$

$= \sqrt{3} \times 11 \times 10^3 \times 5.98$

$= 114\,KVAR$

Ques^n

A single core cable 5-km long has insulation resistance of 0.4 MΩ the diameter of core is 20mm. diameter over insulation is 50mm. Calculate the resistivity of insulating material. ρ

Insulation resistance of cable $R_i = \frac{\rho}{2\pi l} \ln(R/r)$

$l \to$ length of cable

$r \to$ radius of conductor or internal radius of dielectric

$= 4$

$50mm$

$R = 25mm.$

$R_i = 0.4 M\Omega$

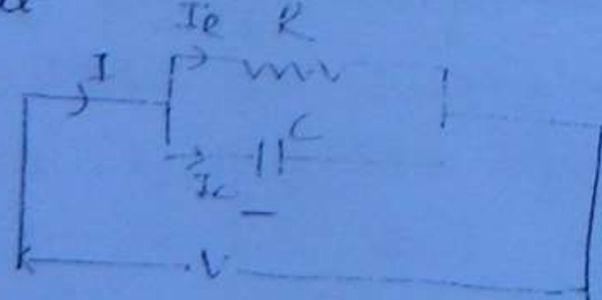
$$0.4 \times 10^6 = \frac{\rho}{2 \times 3.14 \times 5000} \ln\left(\frac{25}{10}\right)$$

$$R_i = 13.42 \times 10^3 M\Omega - m.$$

- The insulation resistance is inversely proportional to length of cable.

DIELECTRIC POWER LOSSES

- In a perfect cable resistance of dielectric is negligible
- All practical cables has dielectric resistance.
- The resistance are 'R' is connected in parallel to capacitance of cable.
- Equivalent circuit



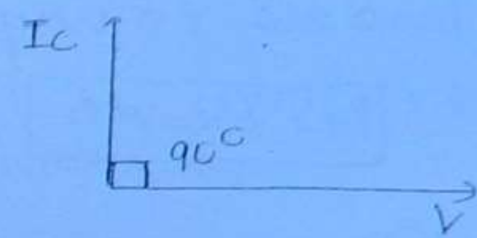
Vector diagram :-

1) Perfect cable

open circuit.

$R=0, \; I_R=0, \; I=I_C$

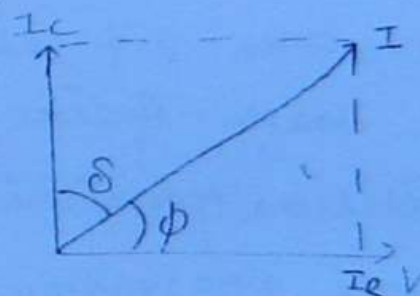
$\therefore I_C$ leads V by 90°



2) Practical cable

- $I = I_R + I_C$.
- I_R in phase with V
- I_C lead V by 90°

$\delta \rightarrow$ dielectric power loss angle.



- For a single phase line the dielectric power loss

*
$$\boxed{\begin{aligned} P_d &= V \cdot I_R. \quad \text{---} (1) \\ P_d &= V I \cos\phi \quad \text{---} (2) \end{aligned}}$$

- On applying $\tan\delta = \frac{I_R}{I_C}$

$$I_R = I_C \tan\delta \quad \text{--} (3)$$

$$I_C = V C \omega \quad \text{--} (4)$$

so

$$\boxed{I_R = \omega C V \tan\delta.} \quad \text{--} (5)$$

(5) → (3)

$P_d = V \cdot (\omega C_0 V) \tan\delta$

3-φ $\boxed{P_d = \omega C_0 V^2 \tan\delta}$ ... (6) ... dielectric loss

as $\tan\delta \approx \delta$ (δ very small)

$\boxed{P_d = \omega C_0 V^2 \delta}$ ... (7).

- For 3-φ line

$\boxed{P_d = 3\omega C_0 V^2 \cdot \delta}$ ... (8)

Questⁿ

A 11 kV, 50Hz 1-φ cable has diameter 20mm and internal sheath radius 15mm. If the dielectric has relative permittivity of 2.4 and dielectric loss angle 0.031 radian. Determine for 2.5 km length of cable.

1) capacitance
2) charging current
3) Generated reactive volt ampere
4) Dielectric loss
5) equivalent insulatioⁿ resistance

Sol

$$C = \frac{\epsilon_r}{18 \ln(R/r)} = \frac{2.4}{18 \ln\left(\frac{15}{1}\right)}$$

$= 0.322 \mu F$

Charging current = $V.\omega.C_0$

$= \frac{11\times10^3\times2\times3.14\times0.323\times2.5}{\sqrt{3}}$

$= 2.84$ Amp /phase

Reactive power = $V_L I_L$ = $11\times10^3\times2.84$

$= 11\times10^3$ KVAR

Dielectric loss. = $\omega C_0 V^2 \tan\delta$.

$= 2\times\pi\times50\times0.8225\times10^{-6}\times\tan 0.03$

$\Rightarrow$ 968.75 W.

5) $V I_R = P_d$.

$= V^2/R = P_d$.

$R = V^2/P_d$

$\Rightarrow \frac{(11000)^2}{968.75}$

$R_i = 0.125 M\Omega$

(continued)

DISTRIBUTION SYSTEMS

- A distribution s/m consists of 3-components.

1. feeder [T.L]
2. Distributor
3. Service Mains.

FEEDER:

feeder is a conductor of large current carrying capacity, carrying the current to the feeding points.

- A current carrying element, carrying uniform current through out the length of the conductor is known as feeder.
- Transmission lines are also known as feeder lines

DISTRIBUTOR:

- Distributor is conductor from which current is tapped to supply to the consumer.
- A current carrying element carrying current for distance less than feeder is known as distributor

• SERVICE Mains:

• The small cable located between distributor and consumer

• The size of feed, distributor or service main depends on current carrying capacity.

HV, EHV, UHV → criteria to select the feeder is current carrying capacity.

• The selection of size of conductor for EHV line is based on current carrying capacity.

• The design of distributor size is based on voltage drop or percentage voltage drop

$$V = RI$$

$$V = \frac{\rho l}{A} \cdot I$$

$$VA = \rho l \cdot I$$

$$I \propto A$$

$$I = J A$$

current density equal → feeder

current density unequal → dist.

$$\boxed{\text{current density} = I/A}$$

A feeder has ~~an~~ constant current density and distrib has variable current density

Ques

For same power, same material and equal length the operating voltage of EHV line is increased by n times. then the area of cross-section is

a) a

a) na

c) a/n

d) an^2.

Solution

$V_2 = nV_1$

at V_1 : $P_1 = V_1 I_1 \cos\phi$

at V_2 : $P_2 = V_2 I_2 \cos\phi$

$P_1 = P_2$

$V_1 I_1 \cos\phi = V_2 I_2 \cos\phi$

$\cancel{V_1} I_1 = n \cancel{V_1} I_2$

$\boxed{I_2 = I_1/n}$

$I \propto A$

$I_1 \propto a_1$

$I_2 \propto a_2$

$\frac{a_2}{a_1} = \frac{I_2}{I_1}$

$a_2 = \frac{a_1 I_2}{I_1} = a/n$.

2) weight of conductor:

$\rho = \frac{wt}{Vol}$

$wt \propto Vol$. (current density is same)

$wt \propto Vol$

$\propto (A \times l)$

$wt \propto (Al)$

$$\% \eta = \frac{P}{P + I(J\rho l)} \times 100$$

and $P = VI\cos\phi$

$$\Rightarrow I = \frac{P}{V\cos\phi}$$

so $$\% \eta = \frac{P}{P + \frac{P}{V}\cos\phi \cdot J\rho l} \times 100$$

$$\% \eta = \frac{1}{1 + \frac{J\rho l}{V\cos\phi}} \times 10$$

$$\% \eta = \left\{1 + \frac{J\rho l}{V\cos\phi}\right\}^{-1} \times 10$$

$$\% \eta = \left\{1 - \frac{J\rho l}{V\cos\phi}\right\} \times 100$$

now $P_2 = 1/n\, P$; $I_2^2 R_2 = \frac{1}{n}(I_1^2 R)$

$$I_2^2 \frac{1}{a_2} = \frac{1}{n}\left(I_1^2 \frac{1}{a_1}\right)$$

$$I_2(J_2) = \frac{1}{n}(I_1)(J_1)$$

$$\boxed{I_2 = I_1/n}$$

$V_1 = I_1 R_1$

$V_1 = I_1 \cdot \frac{1}{a_1}$

$V_1 = J_1$

$V_2 = I_2 R_2$

$V_2 = I_2 \frac{1}{a_2}$

$V_2 = J_2$

$V_1 = J_2$

$\boxed{V_2 = V_1}$

now for ρl

$$\rho = R \cdot \frac{a}{l}$$

$$\rho_1 \propto R_1$$
$$\propto 1/I_1$$

$$\rho_2 \propto R_2$$

$$\propto \frac{1}{I_2}$$

$$\boxed{\frac{\rho_2}{\rho_1} = \frac{I_1}{I_2} = n}$$

So

$$\%\eta = \left\{1 - \left(\frac{jl}{V\cos\phi}\right)\cdot\rho_1\right\} \times 100$$

$$\boxed{\rho_2 = n\rho_1}$$

$$\%\eta = \left\{1 - \left(\frac{jl}{V\cos\phi}\right)(n\rho_1)\right\} \times 100$$

- the percentage efficiency increases as per above relation

<u>Questn</u>

In a distributor line the operating voltage is increased by n-times. Determine the new resistance R_2

<u>Solution</u> :-

At V_1 voltage drop = $\frac{I_1 R_1}{V_1}$

at V_2 voltage drop = $\frac{I_2 R_2}{V_2}$

given $\boxed{V_2 = nV_1}$

Based on the power equation

- voltage drop must be equal.

$$\therefore \frac{I_1 R_1}{V_1} = \frac{I_2 R_2}{V_2}$$

$$\frac{I_1 R_1}{V_1} = \frac{(1/n\, I_1)(R_2)}{n V_1}.$$

$$\frac{\cancel{I_1} R_1}{\cancel{V_1}} = \frac{\cancel{I_1} R_2}{n^2 \cancel{V_1}}$$

$$\boxed{R_2 = n^2 R_1}$$

$P_1 = V_1 I_1 \cos\phi$

$P_2 = V_2 I_2 \cos\phi$

$V_1 I_1 \cos\phi = V_2 I_2 \cos\phi$

$V_1 \cancel{I_1} = n \cancel{V_1} I_2$

$$\boxed{I_2 = \frac{1}{n} I_1}$$

a) for above condition the cross-sectional area

$$R \propto \frac{1}{a}$$

$$R_1 \propto \frac{1}{a_1} \text{ and } R_2 \propto \frac{1}{a_2}$$

$$\frac{R_1}{R_2} = \frac{a_2}{a_1}.$$

$$a_1 = a_2 \frac{R_2}{R_1} = a_2 \times \frac{n^2 \cancel{R_1}}{\cancel{R_1}}$$

$$\boxed{a_2 = \frac{a_1}{n^2}} \text{ ---- distributer}$$

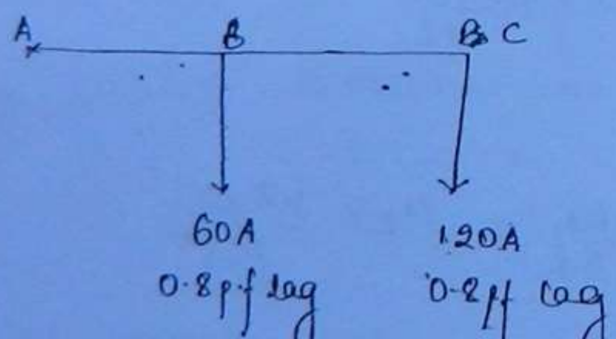
$$\boxed{a_2 = a_1/n} \text{ ---- feeder}$$

- for the same power, same material, length, when the operating voltage increased by 'n' times

— area of the cross sect^n of feeder $\boxed{a_2 = \frac{a_1}{n}}$ and of distributor is $\boxed{a_2 = \frac{a_1}{n^2}}$

Dated
27 Oct 2010

A two conductor feeder extending over a distance carries current of 120 Amp at point C a 60 Amp at point B. The impedences of the section AB and BC are $Z_{AB} = (0.04 + j0.08)\,\Omega$ and $Z_{BC} = (0.08 + j0.12)\,\Omega$. Currents at point B and point C operates at power factor of 0.8 lagging. The voltage at point C is 400 V. Calculate currents at point B and C



Sol^n current tapped at B

$$I_B = 60\angle -\cos^{-1}0.8$$

$$= 60\angle -36.8\ A$$

Current at point C

$$I_C = 120\angle -\cos^{-1}(0.8$$

$$120\angle 36.8\ A$$

• current flowing in the section AB.

$$I_{AB} = I_B + I_C$$

$$= 60\angle{-36.8} + 120^{\circ}\angle{-36.8}$$

$$= 179\angle{-36.8^{\circ}}\,A.$$

• current flowing in section BC.

$$I_C = 120^{\circ}\angle{-36.8^{\circ}}\,A.$$

Voltage drop in the section AB

$$V_{AB} = I_{AB} \cdot Z_{AB}$$

$$= 179\angle{-36.8} \cdot (0.04 + j0.08)$$

$$V_{AB} = 16\angle{26.6^{\circ}}\,V$$

Voltage drop in the section BC.

$$V_{BC} = I_{BC} \cdot Z_{BC}$$

$$= 120\angle{-36.8^{\circ}}(0.08 + j0.12)$$

$$V_{BC} = 17.5\angle{19.54^{\circ}}\,V$$

Voltage at point B = $V_C + V_{BC}$

$$= 400 + 17.5\angle{19.54}$$

$$= \cancel{417.5\angle{19.54}}\ 416.\angle{0.79^{\circ}}\,V$$

$$V_A = V_{AB} + V_B$$

$$416.4\angle{0.79} + 16\angle{26.6^{\circ}}$$

$V_A = 450.8\angle 1.72^\circ$ V

Quest^n

A single phase A/c distributor 500m long having impedence $(0.02+j0.04)$ is fed with 250V at the extreme end. Currents are tapped at 3-points on the distributor

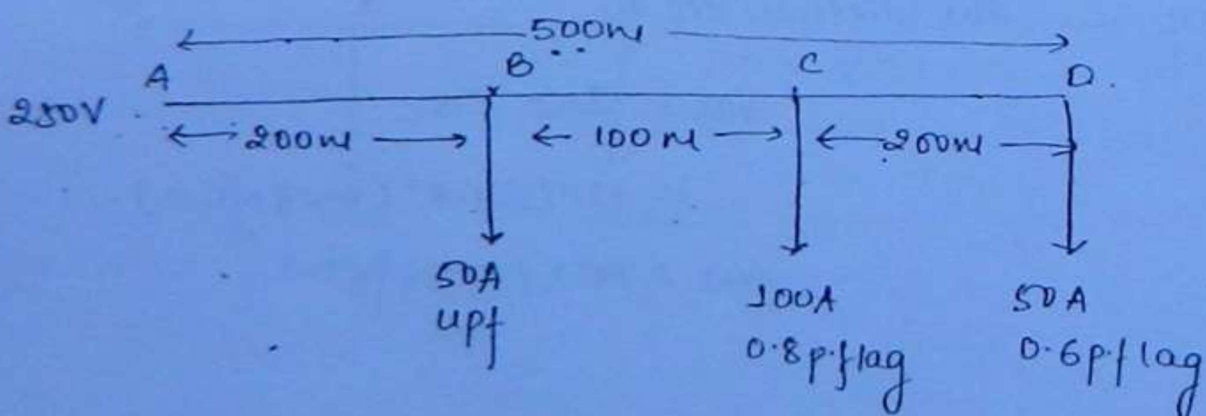
→ 50Amp UPF and 200m from extreme end ⊙

→ 100 Amp 0.8 pf lag 300m from extreme end.

→ 50 Amp 0.6 pf lag 500m from extreme end.

Determine the voltage drop in each section and potential at the point where current 50Amp at 0.6 p.f lag is tapped.

Sol^n



• Current tapped at point B.

$$I_B = 50\angle 0^\circ \text{ Amp}$$

Current tapped at point C

$$I_C = 100\angle -\cos^{-1}0.8 = 100\angle -36.8^\circ \text{ Amp}$$

$I_D = 50\angle -\cos^{-1} 0.6$

$= 50\angle -53.2^\circ$ Amp.

Section AB

Impedence of section AB

$Z_{AB} = \frac{200}{500}(0.02 + j0.04)$

$= (0.008 + j0.016)\,\Omega$

$I_{AB} = I_B + I_C + I_D$

$= 100\angle -36.8^\circ + 50\angle -53.2^\circ + 50\angle 0.$

$= 188.6\angle -31.9$ Amp

$V_{AB} = I_{AB} \cdot Z_{AB}$

$= 188.6\angle -31.9 \times (0.008 + j0.016)$

$V_{AB} = 3.37\angle 0.B2$ Volt.

Section BC

$Z_{BC} = \frac{100}{500}(0.02 + j0.04)$

$Z_{BC} \Rightarrow (0.004 + j0.008)\,\Omega$

$I_{BC} = I_C + I_D$

$= 50\angle -\cos 0.6 + 100\angle -36.8.$

$I_{BC} = 148.5\angle -42^\circ A$

$V_{BC} = I_{BC} \cdot Z_{BC}$

$= 1.32\angle 20.8^\circ V$

Section CD

$$Z_{CD} = \frac{200}{500}(0.02 + j0.04)$$

$$= (0.008 + j0.016)$$

$$I_{CD} = I_D$$

$$= 50\angle -53.2^\circ A$$

$$V_{CD} = I_{CD} \cdot Z_{CD}$$

$$\Rightarrow 50\angle -53.2^\circ \times (0.008 + j0.016)$$

$$V_{CD} = 0.89\angle 10.2 V$$

now

$$V_D = V - (V_{AB} + V_{BC} + V_{CD})$$

$$= 250 - [5.57\angle 0.31 + 1.32\angle 20.8 + 0.89\angle 10.2]$$

$$V_D = 245.08\angle -0.5^\circ V$$

Limitation of Radial system :-

- when a section of system is subjected to fault power is not supplied to the remaining sections. there by interruption of power supply takes place for the consumers to over cum this disadvantage and increase reliability of supply RING MAIN SYM is adopted

Question:

A two wire dc distributor ABCDEA is in the form of a ring main fed point A at 220V and is loaded as follows.

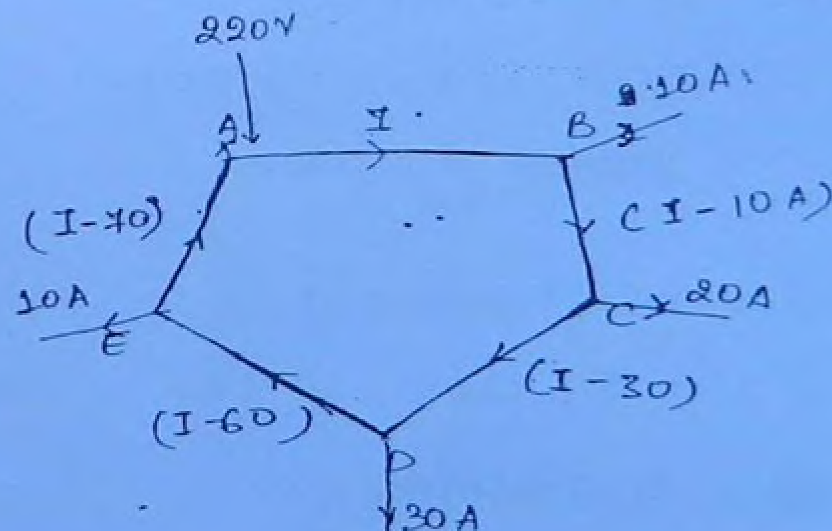
10Amp at point B, 20Amp at point C, 30Amp at point D and 10Amp at point E. The resistances of various sections are.

$$R_{AB} = 0.1\Omega;\ R_{BC} = 0.5\Omega;\ R_{CD} = 0.01\Omega$$

$R_{DE} = 0.025\Omega$. $R_{EA} = 0.075\Omega$. Determine

1) Current flowing b/w point A and B.
2) The point of minimum potential
3) Current in each section of distributor

Soln



Applying KVL to ring mainsystem

$$= I(0.1) + (I-10)\times 0.5 + (I-30)0.01 + (I-60)0.025 + (I-70)0.075\Omega.$$

$$= I(0.1 + 0.5 + 0.01 + 0.025 + 0.075) + 5 - 3 - 15 - 5$$

$I = 29.04$ Am.

$I_{AB} = I = 29.04$ Amp

- potential at point B

$$V_B = V_A - I(0.01)$$

$$= 220 - (29.04)(0.01)$$

$$V_B = 217.09 \text{ V}$$

p. now

$$\boxed{\begin{aligned} V_C &= \cancel{V_B - (I-10)(0.05)} \\ &= \cancel{208.48} \\ &\cancel{22} \end{aligned}}$$

$$V_C = V_B - (I-10)(0.05)$$

$$217.09 - (29.04-10)(0.05)$$

$$= \cancel{206.67}\ 216.158 \text{ V}$$

$$V_D = V_C - (I-30)(0.01)$$

$$= 216.128 \text{ V}$$

$$V_E = V_C - (I-60)(0.025)$$

$$V_E = 216.902 \text{ V}$$

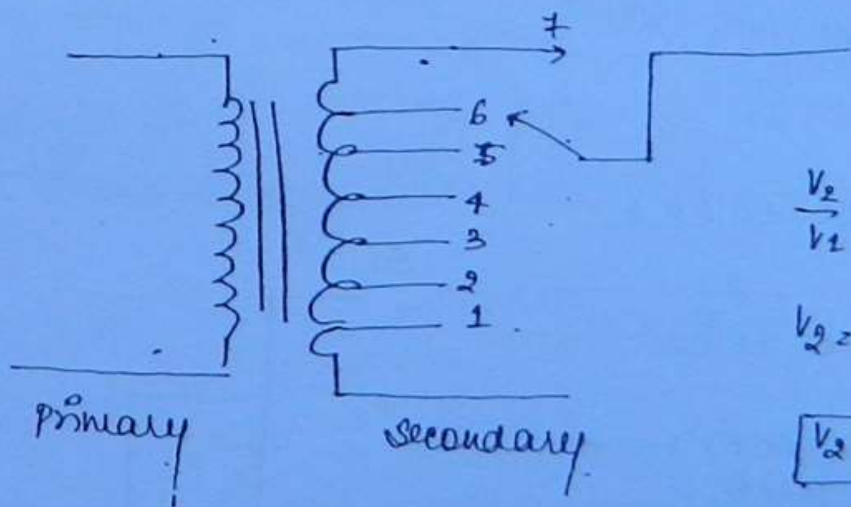
V

Voltag Control Methods

- For the ~~sam~~ safe operation of power s/m network the operati voltage of power s/m components must be with in the operating limits.
- Voltage control in power system equipment can be obtained by three methods.

1) OFF-load tap changing xmer.
2) On load tap changing xmer
3) Autoxmer tap changing.

1) OFF-LOAD TAP CHANGING X^{mer}



$$\frac{V_2}{V_1} = \frac{N_2}{N_1}$$

$$V_2 = (N_2)\left(\frac{V_1}{N_1}\right)$$

$$\boxed{V_2 \propto N_2}$$

- $S \rightarrow 1$ position | $S \rightarrow 7$ positⁿ
  $V \rightarrow$ min | $V \rightarrow$ max

the voltage is minimum when the switch is

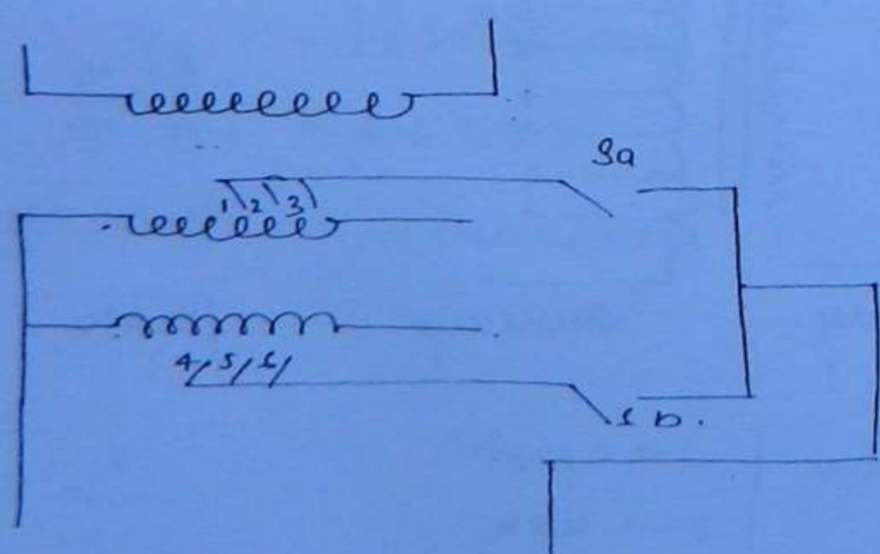
is located at position 1.

- Voltage is max^m. when the switch is located at the position 7.
- By varying the position of the switch the required voltage can be obtained
- Voltage control is acheived by changing turns in secondary.

Limitation:-

- The thickness of the switch must be less so that the switch donot come into contact with two positions at the same time which otherwise results in short-circuit of windings
-

2) ON-LOAD TAP CHANGING X^mer:-



- Using this method required voltage is obtained without disconnecting load from S/Y

Steps:

1) 2 secondary winding

2) Sa → closed. Sb → closed.

→ 2 ⟶ 5

3) V↑ 2→3 5→6.

4) Sa → open , Sb → closed.

↓

2→3 carries twice previous current

Sa → closed. Sb → open

5) Sa → closed. Sb → open.

↓

carries twice previous current

6) Sa → closed Sb → closed.

- ~~to decrease~~ In this method voltage controll is achived by means of the load current flowing through secondary winding of the S/M.
- The changes in the voltage depends on the changes in the load demand and load current

SUBSTATION

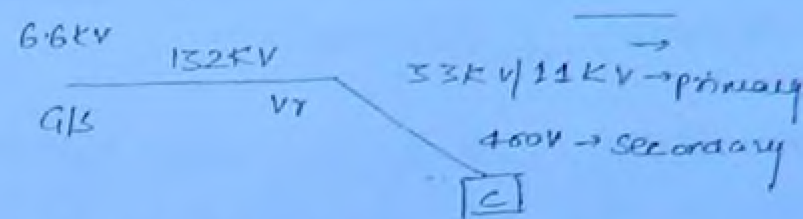
- Substation are located from the generating statn to the consumer premisis

Types of Substation:

1) Step-up substation:- The step-up substation are located at generating statn.

- Step up substatn, steps up the generated voltage.
- Power is transmitted at stepped up voltage through

T.L.



2) Primary substation:-

- Primary substation are located at load centers along primary T.L.
- the primary Transmission voltage is stepped down. to a no. of secondary voltages.

3) Secondary substations:-

- A secondary substations the voltage level is further stepped down to sub transmission voltage and primary distribution voltage.

4) Distribution substations:

- Distribution sub-station supply power to the consumer ~~to~~ through distributor and service lines.

5) Industrial Substations:

- Industrial substations regulate voltage levels of component in an industry

6). Mining Substation:

- Mining sub-station are the stand by sub-statn which operates when one of the existing substatn is subjected to abnormal conditions.

7) Mobile substatn:

- Mobile ~~st~~ substatn are utilized ~~till~~ the construction of or an industry is completed.

- In the latest applications the mobile substations are used as the mining substatn.
- The mobile sub-statn is initial sub-statn i.e useful for completion of industry or generating statn.

HVDC - TRANSMISSION

- North
- Eastern
- Central West
- South
- North Eastern

→ Grids in INDIA

= A/C transmission takes place only when operating at same frequency.
= when a/c frequency same, known as synchronous Tx
= In India HVDC transmissions are mainly used

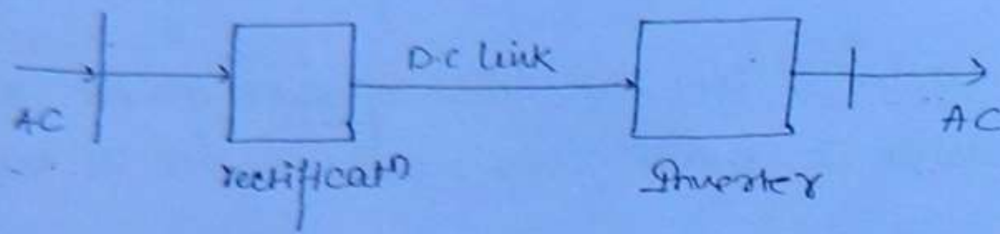
- All the generating statn, load centers and power s/m components in a grid operate at same frequency therefore with in a grid a/c transmission takes place because the entire grid operates at same frequency
- Two different grids may not operate at the same

same frequency.

- If A/c power transmission b/w the grids operating at different frequencies is ~~to~~ not possible.
- Since D/C transmission is independent of frequency power transfer b/w grids operating at different frequencies must be d/c in nature.
- HVDC transmission is b/w the two grids operating at different frequencies. HVDC
- HVDC transmission line is located b/w one grid and another grid
- A/C transmission is known as synchronous transmission because A/C transmission takes place when frequency is same.
- HVDC transmission is known as asynchronous transmission, coz d/c transmission takes place for different frequencies.

- HVDC Application :-

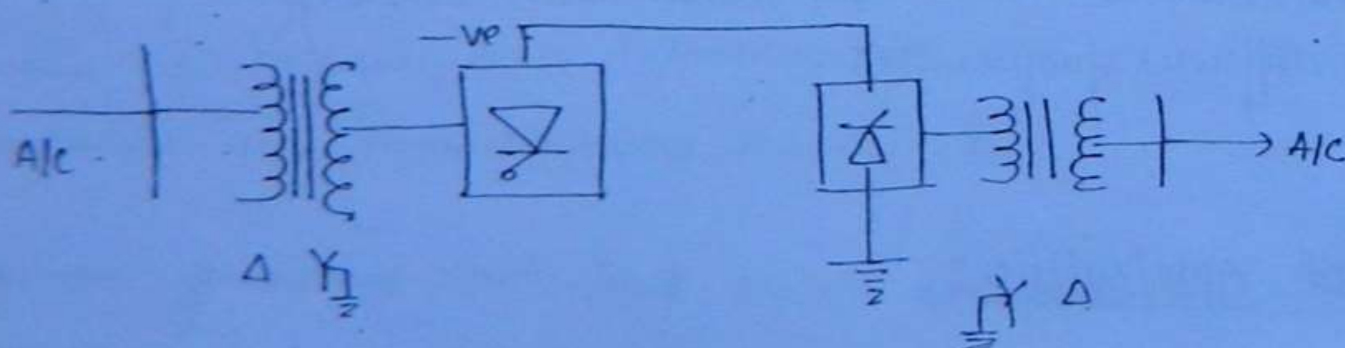
- HVDC transmission deals with transmission of power over long distances.
- There fore ~~a~~ HVDC transmission is distance contraints



- A rectifier is located b/w generating statn and transmission line to convert generation which is in a/c to d/c transmission. Inverter is located b/w transmission line and load center to convert d/c transmission to the ac distribution.

TYPES OF DC LINKS:-

1) Monopolar DC link:-

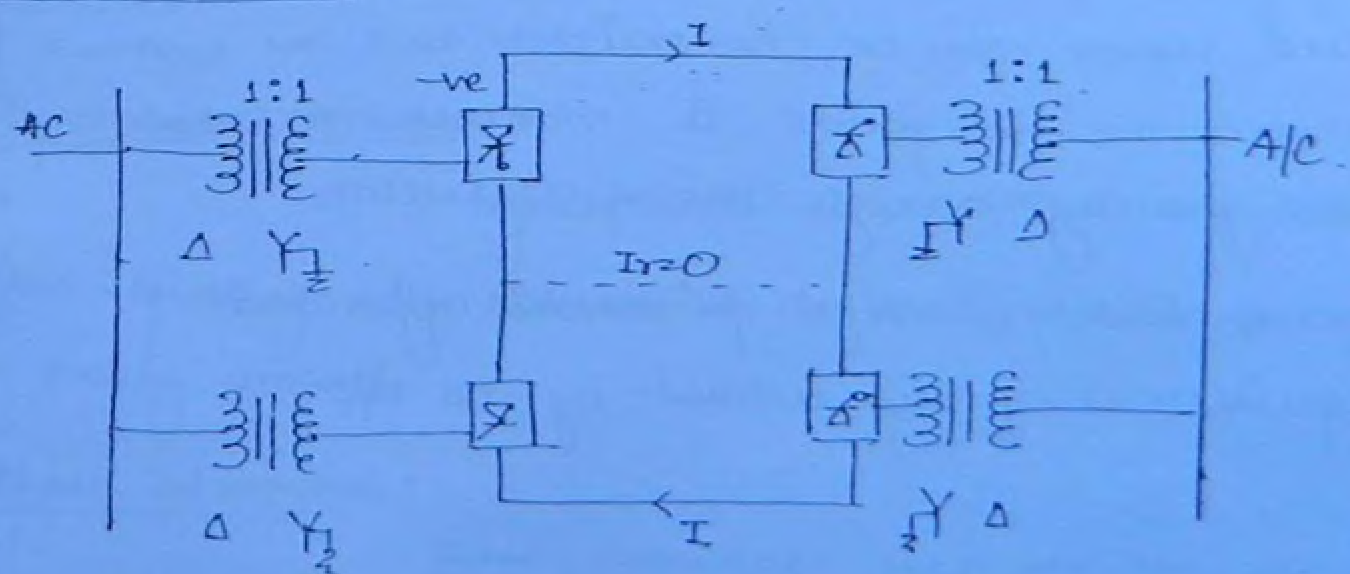


- A monopolar dc link consists of one conductor ~~with~~ w.r.t ground.
- Conductor operates at -ve polarity in order to

decrease corona loss.

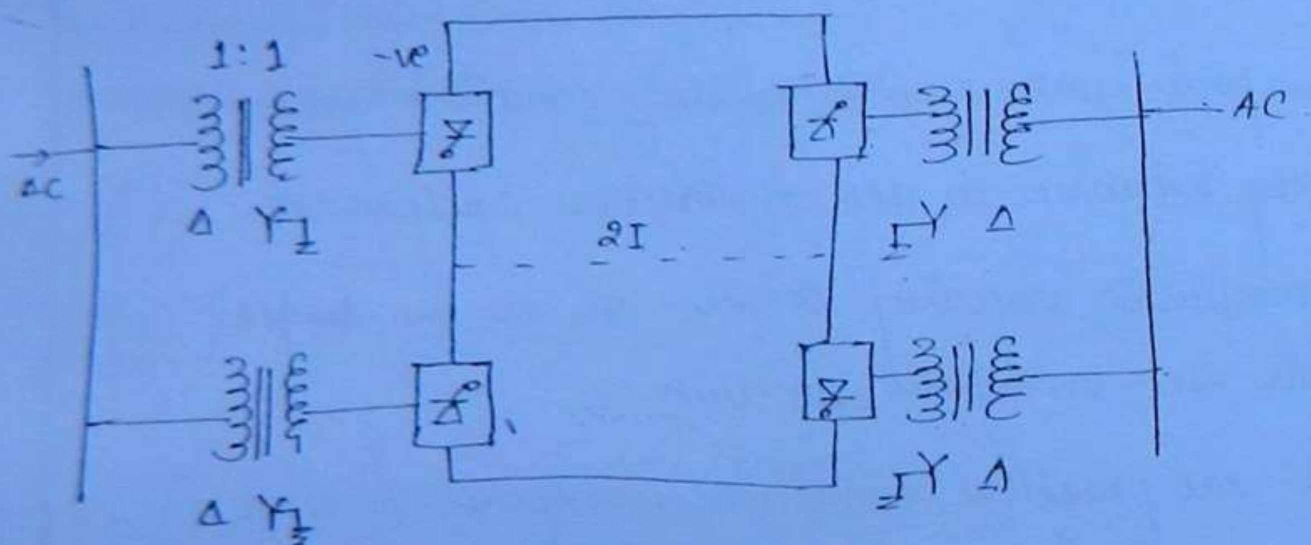
- Skin effect donot exist for a dc link.
- Since stringing of solid conductor is difficult, *stranded conductors are used.
- No of strands depends on operating voltage.
- The power transformer on either side of dc link operates at 1:1 transformation ratio.
- The power transformer under normal operating condition prevents power frequency harmonic to act on terminal equipments.
- The power transmission capacity is less due to the single conductor in the monopolar dc link.
- Therefore in the practical conditions monopolar d/c link is not used.

2) Bipolar d/c link :-



- In bipolar dc link the current carrying capacity is increased by the two conductors in the d/c link
- All practical HVDC D/C links operates with bipolar d/c link

3) Homopolar d/c link:-



- By changing the position of thyristor of second conductors. the required power can be transmitted and the current flowing between the two points is increased to 2 time the current flowing through either of conductors
- Homopolar d/c link is useful for certain applications like requirement of high current by d/c n/c.

Advantages of HVDC Transmission:-

- Power transmitted per conductor is increased.
- The power transfered in a circuit increases.

Disadvantage:-

- To convert a/c to d/c we require rectifier unit and to convert d/c to a/c we require Invertor unit

POWER FACTOR IMPROVEMENT

1) Static capacitor:

- Static capacitor are connected in parallel with the equipment operating at lagging power factor
- Static capacitor improve powerfactor in industries and factories.

2) Synchronous Condensor:-

Synchronous condensor is a synchronous motor, operating with over excitatⁿ on load condition taking the leading current

3) Phase advancers:

Phase advancer improves the power factor of induction m/r. the low power factor in induction motor is due to the stator winding which draws exciting current which lags behind the supply voltage by 90°

Ques^{n}

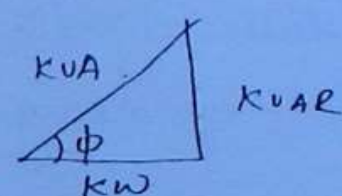
A synchronous g/r is supplying load of 300 KW at p.f 0.6 lag. If the power factor is increased to unity, the no of kilowatts the synchronous g/r can supply for the same KVA loading is

a) 300 KW
b) 200 KW
c) 500 KW
d) 700 KW

Sol^{n}

$KW = 300 \qquad \cos\phi = 0.6$

when pf $\rightarrow$ 0.6 lag



$\cos\phi = \frac{KW}{KVA}$

$\frac{KW}{\cos\phi}$

$= \frac{300}{0.6} = 500 KVA.$

when pf — 1

$KW = KVA \times \cos\phi$

$= 500 KW$

When the p.f is increased from 0.6 to 1 the synchronous g/r has to supply 200 KW in excess.

Quest^n :

the following reading are obtained in a month of 30 days. at a consumer location

KVAR meter - 83830

Kwh meter - 291940

Demand meter - 1400 KW.

the average monthly load factor and power factor at the consumer premises is.

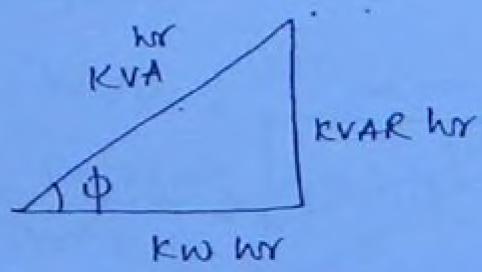
Solut^n

$$\text{Average load factor} = \frac{\text{Energy generated in a month}}{(30 \times 24) \times \text{Max}^m \text{ demand (KW)}}$$

$$\Rightarrow \frac{291940}{30 \times 24 \times 1400} \times 100$$

$$\Rightarrow 0.289 \times 100$$

$$28.9\%.$$



$$\cos\phi = \cos\left[\tan^{-1}\left(\frac{83830}{291940}\right)\right]$$

$$\cos\phi = 0.961.$$

Quest^n

A 3-ϕ, 50Hz, 30Km. T.L supplies a load of 5MW at a power factor 0.707 lag to the receiving end where the voltage is maintaind constant at 1KV. the line resistance and inductance are 0.02Ω and 0.84 mH/phase/Km a capacitor is connected across the load to rise the p.f 0.8 lag. calculate

1) capacitance / phase

2) Voltage regulation

3)

Soln length of the line $l = 30km$.

$$Load = 5MW \text{ at } 0.707 \text{ lag}.$$

$$V_R = 11KV$$

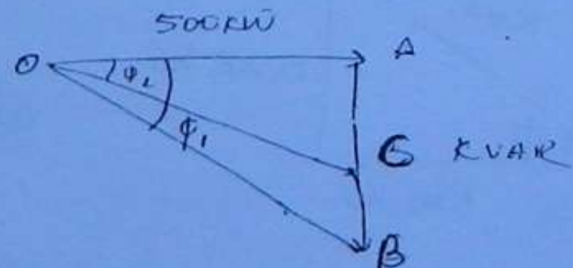
resistance of 30km length $= 0.02 \times 30$

$$\Rightarrow 0.6\Omega / phase.$$

Reactance of 3km $= 2 \times 3.14 \times 50 \times 30 \times 0.84 \times 10^{-3}$

$$= 7.9\Omega / phase$$

Impedance of line $Z = (0.6 + j7.9)\Omega / phase$.



$\cos\phi_2 = 0.8$.

B

capacitive reactive power

$BC = AB - AC$

AB:

$$\tan\phi_1 = \frac{AB}{OA}$$

$$AB = OA \tan\phi_1$$

$AB = OA \cdot \tan\phi_1$

$= 5000(\tan\{\cos^{-1}(0.707)\})$

$5000(\tan(45°))$

$= 5000 KVAR = AB.$

<u>AC</u>:

$\tan\phi_2 = \frac{AC}{OA}$

$AC = OA \tan\phi_2$

$= 5000 \tan\{\cos^{-1}(0.8)\}$

$= 3749.5 KVAR$

so $BC = AB - AC$

$= 1250 KVAR$

capacitive reactive power $V_R \cdot I_C = 1250$

$\sqrt{3} V_r I_C = 1250$

$\sqrt{3} V_r \cdot \frac{V_r}{\sqrt{3} X_C} = 1250$

$V_r^2 / X_C = 1250$

$\frac{1250 \times 10^3}{V_r^2 \times \omega} = 1250$

$\sqrt{3} V_r \cdot \frac{V_r}{X_C} = 1250$

$\sqrt{3} \frac{V_r^2}{X_C} = 1250$

$C = \frac{1250}{\omega V_r^2} \quad \frac{1250}{\sqrt{3} \times 2 \times \pi \times 50 \times (11 \times 000)^2}$

$C = 0.18 \times 10^{-6} F$

$\frac{1250 \times 1000}{(1100)^2 \times 2 \times \pi \times 50} = 3.289 \times 10^{-3} F.$

$V_s = V_r + IR\cos\phi_r + IX\sin\phi_r$

$\Rightarrow$ I

$500 \times 10^{-6} = \sqrt{3} \times 11 \times 10^{-3} \times I_L \times 0.8.$

$I_L = 32.80 A.$

$V_s = 1\times10^3 + 32.80 \times 0.6 \times 100\ 0..$

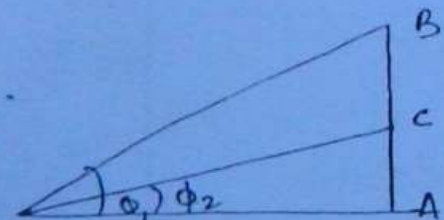
$$V_s = \frac{11000}{\sqrt{3}} + (37119.0)(0.6)\times0.8 + (37119.0)(7.9)\times0.6.$$

$= 200.1 KV$

$$\frac{V_s - V_r}{V_R} \times 100 = \frac{200.1 - 1000}{1000} \times 100.$$

Quesⁿ An industry draws 100 KW at 0.7 pf lagging from a 3φ, 11KV supply. It is desired to increase the pf to .95 lag using series capacitor. The rating of Req. capacitor

a) 90 KVAR
b) 69 ,,
c) 50 ,,
d) 79 ,,



Sol

$BC = AB - AC$

$AB =$

$$\tan\phi = \frac{AB}{OA}$$

$AB = OA \tan\phi_1$

$BC = AB - AC = OA(\tan\phi_1 - \tan\phi_2)$

$= 100 \times 10^3 [\tan$

$=$ 69 KVAR

$w_1 \propto a_1 l$. $\quad$ ∵ length is same.

$w_2 \propto a_2 l$.

$$\frac{w_2}{w_1} = \frac{a_2}{a_1} = \frac{1}{n} \cdot w_1$$

$$\boxed{w_2 = \frac{1}{n} w_1.}$$

Gate

The operating voltage of a s/m is increased by 50%. The cost of the s/m increases by

earlier = V_1

new = $1.5 = V_2$

$$V_2 = 1.5\, V_1$$

$$w_2 = \frac{1}{1.5} w_1$$

$$\boxed{cost_2 = \frac{1}{n} cost_1}$$

$$\frac{cost_2}{cost_1} = \frac{1}{n} = \frac{1}{1.5} = {}^{10}/_{15} = {}^{2}/_{3}$$

$\Rightarrow$ 66.67%

→ $cost_2$ is increased by 66.67% of $cost_1$

3) BHEL-01

A current carrying elect c̄ equal current density has its current carrying capacity decreased by n times the new power loss in feeder is

Sol.

$$I_2 = \frac{1}{n} I_1$$

$$P_1 = I_1^2 R_1$$

at $I_2 \Rightarrow P_2 = I_2^2 R_2$

$$\Rightarrow \frac{1}{n^2} \cdot n R_1$$

$$\boxed{P_2 = \frac{1}{n} P_1}.$$

$$I_1 \propto \frac{1}{R_1}$$

$$I_2 \propto \frac{1}{R_2}$$

$$\Rightarrow \frac{I_1}{I_2} = \frac{R_2}{R_1}.$$

$$R_2 = n R_1.$$

$\Rightarrow$ the power losses in T.L are decreased by n times $\left[P_2 = \frac{1}{n} P_1\right]$ the efficiency of the s/m increases by

Soln

percentage $\eta = \dfrac{P}{P + P_{loss}} = \dfrac{P}{P + I^2 R} \times 100$.

$$\Rightarrow \frac{P}{P + I^2 \frac{\rho l}{a}} \times 100 \qquad R = \rho l / a.$$

and current density $J = I/a \Rightarrow a = I/J$

$$= \frac{P}{P + \frac{I^2 \rho l}{I/J}} \times 100$$

(Kaman)

[redacted]

-: LOAD FLOW STUDIES

- → Network Modelling
- → Mathematical Modelling
- → Solution stage.

- Study means obtaining parametric values of s/s parameter.
- S/s parameter describe the condition of s/m.
- System parameters are of two type.
  - → independent
  - → dependent.
- Studies are carried under two stage of s/m
  - → steady state
  - → dynamic / transient

- In steady state of system, system parameters are described as time invariant funcⁿ. and dynamic state of system they are represented as time variant function.

- In any study we have to pass through three stage.
  - → Network Modelling
  - → Mathematical Modelling
  - → Solution stage.

- Network Modelling: Here various component of power system is represented by its electrical equivalent circuit component model. There by an overall obtained. [redacted]

• Mathematical Modelling: Here with the knowledge of n/w analysis the network model is converted into mathematical model. A mathematical model comprises of set of ~~auxiliary~~ ~~algebraic~~ algebric or set of differential eqn depending upon type of study we carry.

• Solution stage: In this stage by using appropriate numerical techniques the mathematical equatn are solved. and system parameters are obtained. With the knowledge of system parameter we are able to analyse the s/m. this complete study.

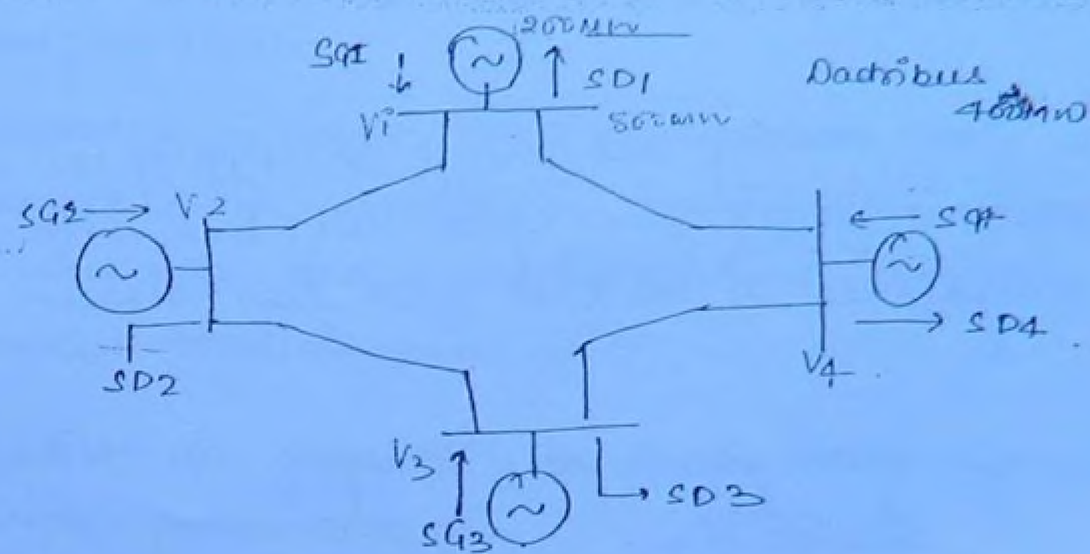
• When a load flow study is performed it is conducted in two stages.

- Stage 1
  - Injected active Power (P)
  - Injected reactive power (Q)
  - Magnitude of Bus voltage (V)
  - Load torque Angle (δ)
- Stage 2
  - Line flow
  - losses

STAGE 1

$$\boxed{S_{Gi} = P_{Gi} + jQ_{Gi} = \text{Complex power generated at } i^{th} \text{ bus}}$$

$$S_{Di} = P_{Di} + jQ_{Di} = \text{Complex power demand at } i^{th} \text{ bus}$$



- $S_i = S_{Gi} - S_{Di}$ = Complex power injected to i^{th} bus.

$S_i = P_{Gi} + jQ_{Gi} - P_{Di} - jQ_{Di} = P_i + jQ_i$.

P_i → active, Q_i → Reactive

• If $S_{Gi} > S_{Di} \rightarrow S_i > 0 \rightarrow$ Bus acts like exporting bus
• If $S_{Gi} < S_{Di} \rightarrow S_i < 0 \rightarrow$ Bus acts like importing bus

- Magnitude of bus voltage is measured by voltmeter.

- Load torque angle $\boxed{\delta_i = \angle V_i - \angle V_{ref}}$

<u>Ex</u>. $\delta_1 = \angle V_1 - \angle V_{ref} \rightarrow 0$ always zero

$\delta_2 = \angle V_2 - \angle V_1$

$\delta_3 = \angle V_3 - \angle V_1$

$\delta_4 = \angle V_4 - \angle V_1$

- Based on value of injected power a bus may act like an exporting bus $[S_i > 0]$ or importing bus $[S_i < 0]$. The power will flow from exporting bus to importing buses

- Active power flow leading bus voltage to lagging bus voltage. And reactive power flows from the bus with high voltage magnitude to the bus with low voltage magnitude.
- With same voltage, active power still transfers due to ∅ leading.

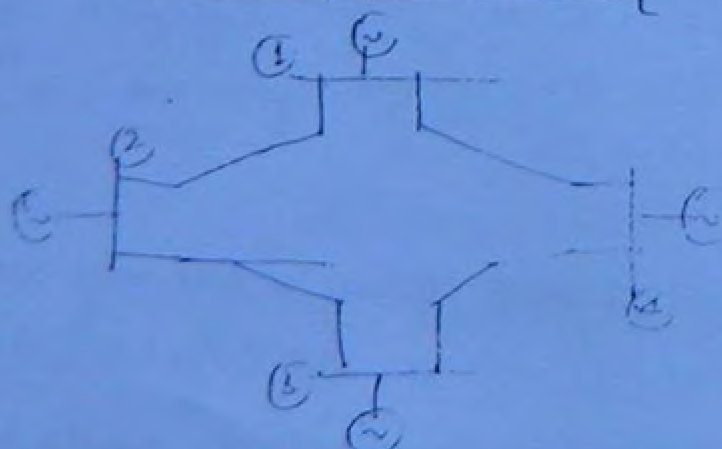
~~STAGE 2~~

Application:

- It data is used for planning of power system.
- can be a estimated to voltage profile.
- Economic scheduling.
- Steady state data.

- Load flow analysis is mainly used for planning power s/m.

1. NETWORK MODELING

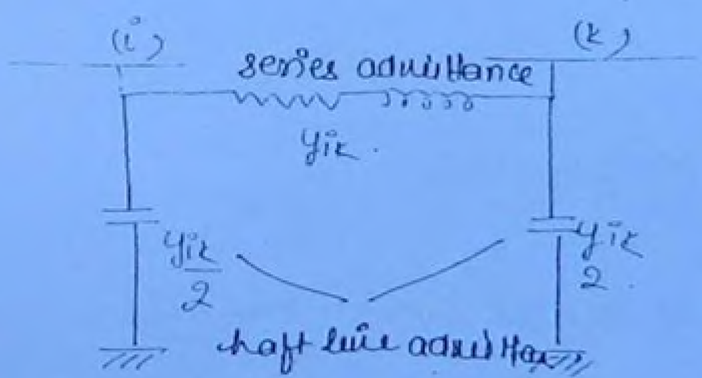


• In load flow studies

1). Generator are represented as complex power source., this means it is represented by complex no. where real no. indicates active power g/rn and imaginary no. represent reactive power g/rn

2) Similar to generator load are represented as complex power demand.

3) Transmission line are represented as π n/w. with series admittance & half line charging admittance.



• Data given

R_{ik}

X_{ik}

$\frac{y_{ik}'}{2}$

$$y_{ik} = \frac{R_{ik}}{R_{ik}^2 + jX_{ik}^2} - j\frac{X_{ik}}{R_{ik}^2 + X_{ik}^2}$$

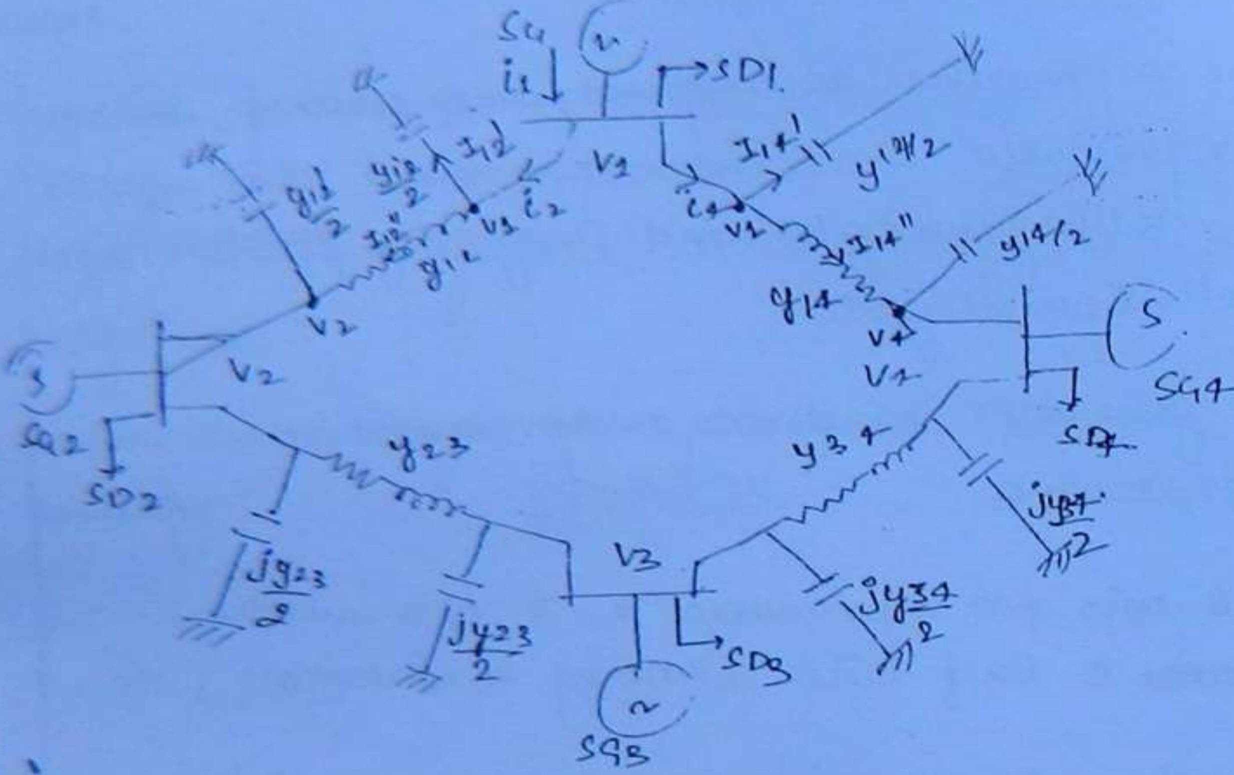
* T network is better than π n/w as, no. of junction of T n/w is less than π and T gives more good performance. Still in load flow we use π n/w coz of mathematical simplification.

$$Z = R \pm jX$$

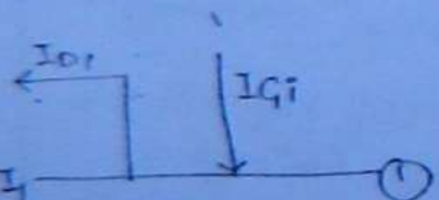
(+ → inductive, − → capacitive.)

$$Y = G \pm jB$$

(+ → C, − → L)



2) MATHEMATICAL MODELLING



Injected current into 1st bus = I_1

$$I_1 = I_{12} + I_{14}$$

$$= (I_{12}' + I_{12}'') + (I_{14}' + I_{14}'')$$

$$I = (V_i - V_k)\,y$$

$$I_1 = \frac{V_1 y_{12}'}{2} + (V_1 - V_2)y_{12} + \frac{V_1 y_{14}'}{2} + (V_1 - V_4)\,y_{14}$$

$$= V_1\left(\frac{y_{12}'}{2} + y_{12} + \frac{y_{14}'}{2} + y_{14}\right) + (-y_{12})V_2 + (0)V_3$$

$$+ (-y_{14})V_4$$

$$I_1 = Y_{11}V_1 + Y_{12}V_2 + Y_{13}V_3 + Y_{14}V_4$$

and Y_{11} is total admittance connected to 1st bus.

$$\boxed{Y_{11} = \frac{y_{12}'}{2} + \frac{y_{14}'}{2} + y_{12} + y_{14}}$$ we see the directly connected admittances.

- Y_{12} = Negative value of series admittance connected b/w bus 1 & 2

$$Y_{12} = -y_{12}$$

- Similarly $Y_{13} = -y_{13} = 0$

$$Y_{14} = -y_{14}.$$

<u>Now</u>

$$I_2 = Y_{21}V_1 + Y_{22}V_2 + Y_{23}V_3 + Y_{24}V_4.$$

$$Y_{21} = -y_{12}$$

$$Y_{22} = \frac{y_{12}'}{2} + \frac{y_{23}'}{2} + \frac{y_{24}'}{2} + y_{12} + y_{23} + y_{24}$$

$$Y_{23} = -y_{23}; \quad Y_{24} = -y_{24}.$$

* Off diagonal terms gives information about the no of T.L.

similarly eq^n of I_3 and I_4.

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} & Y_{14} \\ Y_{21} & Y_{22} & Y_{23} & Y_{24} \\ Y_{31} & Y_{32} & Y_{33} & Y_{34} \\ Y_{41} & Y_{42} & Y_{43} & Y_{44} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix}$$

$$\Rightarrow \quad [I_{bus}]_{n\times1} = [Y_{bus}]_{n\times n}\,[V_{Bus}]_{n\times1} \quad \ldots\ldots (1)$$

:-equation for injected current into ith bus of n-bus power s/m

$$I_i = Y_{i1}V_1 + Y_{i2}V_2 \;\ldots\; Y_{in}V_n$$

$$\boxed{I_i = \sum_{k=1}^{n} Y_{ik}V_k} \quad \text{for } 1,2,\ldots n. \;\ldots (2)$$

Y_{BUS}

Ybus can be developed by direct inspection method.

Load flow analysis can done using Z-bus

Y-bus is preferred. cox it is sparsity Matrix

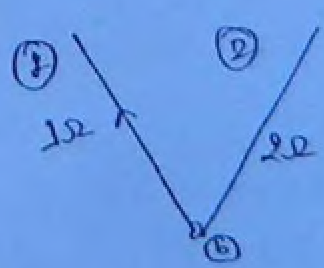
Sparsity Matrix:- when elements of matrix. are often zero is known as sparsity matrix. a null matrix has 100% sparsity.

As Ybus is sparsity matrix the more no. of elements are zero thus the memory required for storage decreases greatly

$$Y_{bus} \begin{cases} \rightarrow \text{sparsity Matrix.} \\ \rightarrow \text{symmetric Matrix } [Y_{bus} = Y_{bus}^{T}] \\ \rightarrow \text{square matrix [Inverse} \end{cases}$$

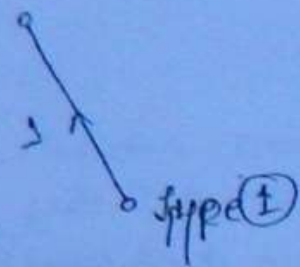
- In power system every bus is connected to 2-3 bus, in view of this Y bus is dominated by zero, and hence said to sparsity matrix.
- As Ybus is sparsity Matrix its inverse Zbus is Full Matrix
- A matrix with less no of zero provide more information of the network therefore Z-bus is used in short circuit studies.
- Y-bus can be obtained by two methods.
  1) Direct inspection Method.
  2) Singular Transformation Method.
- When the mutual couplain is present b/w the two line direct inspectn method cannot be used to go for singular Transformation method using A matrix.

<u>Question:</u> form Z and Ybus!

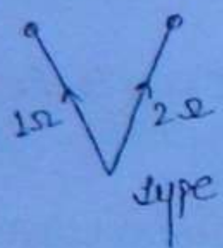


Solutⁿ: Z_{bus}

Step 1:



$$\begin{array}{c|c} & (1) \\ \hline (1) & 1\Omega \end{array}$$



	(1)	(2)
(1)	1Ω	0
(2)	0	2Ω

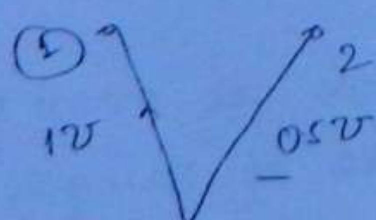
Method 1: Ybus through Z_{bus}^{-1}

$$Y_{bus} = \begin{bmatrix} 1 & 0 \\ 0 & 2 \end{bmatrix}^{-1}$$

$$= \frac{1}{2}\begin{bmatrix} 2 & 0 \\ 0 & 1 \end{bmatrix}$$

$$Y_{bus} = \begin{bmatrix} 1 & 0 \\ 0 & 0.5 \end{bmatrix}$$

Method 2: Direct inspection Method.



$Y_{11} = 1℧$

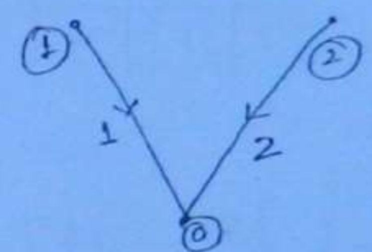
$Y_{12} = 0$

$Y_{21} = 0$

$Y_{22} = 0.5℧$

$$Y_{bus} = \begin{bmatrix} 1 & 0 \\ 0 & 0.5 \end{bmatrix}$$

Method 5 :- Single Transformation Method.



	(1)	(2)
1	+1	0
2	0	+1

$$A^T = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

primitive Interface MATRIX

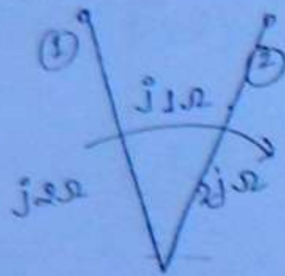
$$Z = \begin{array}{c|c|c} & 1 & 0 \\ \hline 1 & 1\Omega & 0 \\ \hline 2 & 0 & 2 \end{array}$$

$$y = Z^{-1} = \begin{bmatrix} 1 & 0 \\ 0 & 0.5 \end{bmatrix}$$

$$Y_{Bus} = [A^T][y][A]$$

$$= \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & 0.5 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & 0 \\ 0 & 0.5 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 0.5 \end{bmatrix}$$



primitive impedance matrix

$Z =$

	1	2
1	j2	j1
2	j1	j2

primitive admittance matrix

$-4+1$

$$y = Z^{-1} = \frac{1}{-3}\begin{bmatrix} j2 & -j1 \\ -j1 & j2 \end{bmatrix}$$

$$y = \begin{bmatrix} -0.66j & -j1/-3 \\ -1/3 j & -j0.667 \end{bmatrix}$$

$$y = \begin{bmatrix} -j0.667 & +j0.33 \\ +j0.33 & -j0.667 \end{bmatrix}$$

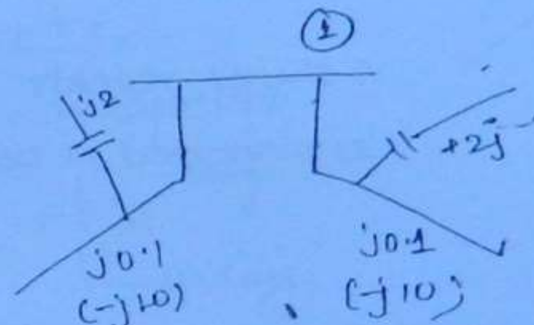
$[A] =$  $= \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$ ... incidence matrix.

$$[A]' = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

$$Y = [A^T][y][A] = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}\begin{bmatrix} -j0.667 & +j0.33 \\ +j0.33 & +j0.667 \end{bmatrix}$$

$$Y_{bus} = \begin{bmatrix} -0.667j & +j0.33 \\ +j0.33 & -j0.667 \end{bmatrix}$$

<u>Questn</u>. In a pure imaginary Ybus matrix which element of Ybus are +ve imaginary and -ve imaginary



$$Y_{11} = +j2 + j2 - j10, -j10$$
$$= -j16$$

$$Y_{12} = -(-j10) = +j10$$

$$Y_{14} = -(-j10) = +j10$$

Ans + off diagonal → 0 +ve

Diagonal = -ve.

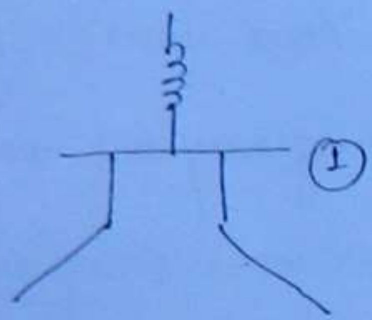
**

The condition for convergence of load flow problem is all the diagonal element of Ybus must dominate the off diagonal element.

In aft above example mag Y_{11} is 16

and mag of Y_{12} is $\overline{10}$. As mag Y_{11} > mag Y_{12} problem converges.

(2)



A shunt reactor of $-j10$ is connected to bus (1)

$Y_{11} = -j16 - j10$

$= -j26$

$Y_{12} = +j10$

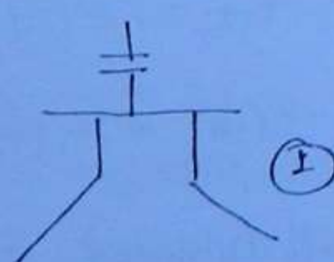
$Y_{14} = +j10$

$Y_{11} = -j16 + j10$

$= -j6$

$Y_{12} = +j10$

$Y_{14} = +j10$



A load flow problem may converge or diverge can be initially estimated by absorbing Y bus. The condition for convergence all of the diagonal element of Ybus must dominate off-diagonal elements otherwise diverges.

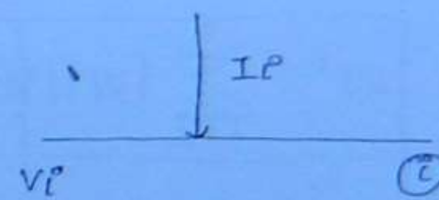
shunt reactors in power s/m improves the convergence condition where as shunt capacitors in power s/m improves divergence of load flow problem.

Dated
29th Oct 2010

- $Z = R \pm jX$ (+ → inductor, − → capacitor)

- $S = P \pm jQ$ (+ → lag, − → leading)

$$I_i = \sum_{k=1}^{n} Y_{ik} V_k \quad \text{--- (1)}$$



V → is taken as reference vector.

Pf is lagging $V = |V| \angle 0^\circ$

$I = |I| \angle -\theta$

$S = VI^* = |V||I| \angle \theta$

$= |V||I|\cos\theta + j|V||I|\sin\theta$

$= P + jQ$

$S_i = P_i + jQ_i$

$= V_i I_i^*$

$$S_i = V_i \left[\sum_{k=1}^{n} Y_{ik} V_k \right]^*$$

- so we calculate $S_i^* = V_i^* I_i^* = P_i - jQ_i$

$$\boxed{\begin{array}{l} P_i = \text{Real}\{S_i^*\} \\ Q_i = -\text{Imag}\{S_i^*\} \end{array}}$$

Let

$V_i = |V_i| \angle \delta_i$

$V_i^* = |V_i| \angle -\delta_i$

$Y_{ik} = G_{ik} - jB_{ik}$

$$= \sqrt{G_{ik}^2 + B_{ik}^2} \; \angle \tan^{-1}\left(\frac{-B_{ik}}{G_{ik}}\right)$$

$$= |Y_{ik}| \angle -\gamma_{ik}.$$

$$\boxed{V_k = |V_k| \angle \delta_k.}$$

and

$$S_i^* = P_i + jQ_i$$

$$= |V_i| \angle -\delta_i \sum_{k=1}^{n} |Y_{ik}| \angle -\gamma_{ik} \, . \, |V_k| \angle \delta_k$$

$$\boxed{S_i^* = \sum_{k=1}^{n} |V_i||V_k||Y_{ik}| \angle -(\delta_i - \delta_k + \gamma_{ik}).}$$

and

$$\boxed{P_i = \text{Re}\{S_i^*\} = \sum_{k=1}^{n} |V_i||V_k| |Y_{ik}| \cos(\delta_i - \delta_k + \gamma_{ik})} \quad \cdots (A)$$

$$Q_i = -\text{Imaginary}\{S_i^*\}$$

$$\boxed{Q_i = \sum_{k=1}^{n} |V_i||V_k||Y_{ik}| \sin(\delta_i - \delta_k - \gamma_{ik})} \quad \cdots (B)$$

Eqn (A) and (B) are known as static load flow equatn.

- The load flow equations are non linear simultanous algebric equatn.

- BUS VOLTAGE EQUATION :-

$$S_i^* = V_i^* I_i = P_i - jQ_i$$

$$I_i = \frac{P_i - jQ_i}{V_i^*}$$

$$\sum_{k=1}^{n} Y_{ik} V_k = \frac{P_i - jQ_i}{V_i^*}$$

$$Y_{ii} V_i + \sum_{k=1}^{n} Y_{ik} V_k = \frac{P_i - jQ_i}{V_i^*}$$

$$\boxed{V_i = \frac{1}{Y_{ii}} \left[\left[\frac{P_i - jQ_i}{V_i^*}\right] - \sum_{\substack{k=1 \\ k \neq i}}^{n} Y_{ik} V_k \right]}$$

for $i = 1, 2, \dots n$.

3. SOLUTION OF STAGE :-

1) GAUSS & SEIDEL METHOD

Let take

$$y_1 = f_1(x_1, x_2) = x_1^2 - \log x_1 x_2 + x_2^2 = 2$$

$$y_2 = f_2(x_1, x_2) = -2x_1^2 + \log x_1 x_2 + x_2^2 = 5$$

$$x_1 = \sqrt{2 + \log x_1 x_2 - x_2^2} \quad \dots \text{(i)}$$

$$x_2 = \sqrt{5 + 2x_1^2 - \log x_1 x_2}$$

$$= f_4(x_1, x_2)$$

→ start with Gauss of Guess:

$$x_1^0 = x_2^0 = 4$$

• first Iteration

$$x_1^{(1)} = f_3(x_1^0, x_2^0)$$

$$= \sqrt{2 + \log x_1^0 x_2^0 - (x_2^0)^2}.$$

$$x_2^{(1)} = f_4(x_1^{(1)}; x_2^0).$$

$$= \sqrt{5 + 2(x_1)^2 - \log x_1^{(1)} x_2^{(1)}}$$

→ check for convergence:-

$$\cdot |x_1^{(1)} - x_1^{(0)}| \le \text{Error}.$$

$$\cdot |x_2^{(1)} - x_2^{(0)}| \le \text{Error}$$

NOTE:-

• Gauss method is not appropriate coz takes a very long process.

• Classification of Buses:-

→ Load flow study has to be performed under online CPU execution time is very important in this aspect. In order to reduce the total no. of iterat"

Out of four bus quantities of each bus, two bus quantities are specified.

- Depending upon which two bus quantities out of four bus quantities are specified, buses are classified into different type.

Classification of Buses

85%

PQ / Load Bus

- specially P_i, Q_i [unspecified]

[mainly bus are connected to load, a very few are connected to G/r]

- unspecified: $|V_i|, \delta_i$

Slack bus

[Max^m G/r capacity bus]

unspec: P_i, Q_i

spec: V_i, δ_i

- Are called as reference bus swing bus

15%

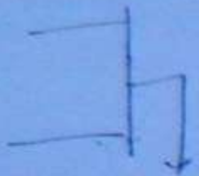
- **PV / Generator / voltage control bus**

[At these buses generator are connected]

- specified: $P_i, |V_i|$
- unspecified: Q_i, δ_i

- Every PV bus can be generator or voltage controlled buses but it cannot be that every generator or voltage controlled buses is PV bus.

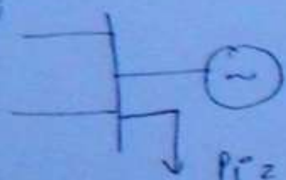
- Slack bus is called as the reference bus.

① 

$P_i = -P_{Di}$

$Q_i = -Q_{Di}$

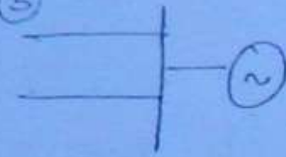
- Cannot be taken as PQ bus

② 

$P_i = P_{Gi} - P_{Di}$

$Q_i = Q_{Gi} - Q_{Di}$

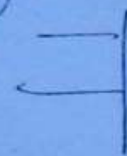
- Can be taken as PQ bus

③ 

$P_i = P_{Gi}$

$Q_i = Q_{Gi}$

- Can be taken as PQ bus.

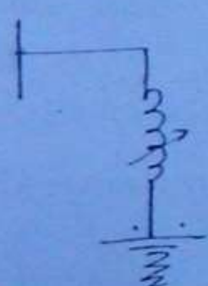
④ 

$P_i = 0$

$Q_i = 0$

- Cannot be PQ bus.

- PURE VOLTAGE CONTROLLED BUS:-



$P_i = 0$ (active power is ~~known~~ 0)

$V_i \to$ constant

$Q = V^2/X$

$\therefore \delta \to$ is unknown.

- Similar is the case with capacitor connected 

In order to conduct load flow study under online condition CPU execution type should be less.

By reducing the total no of unknowns we can reduce the iteration, convergence need to be

PQ Buses :-

- If the values of P and Q are known the bus can be selected as PQ bus. By default all load buses are PQ buses.

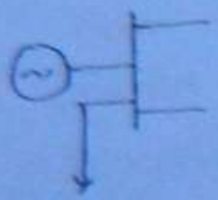
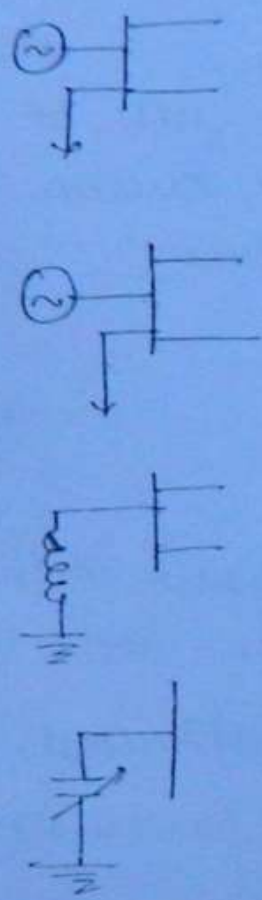
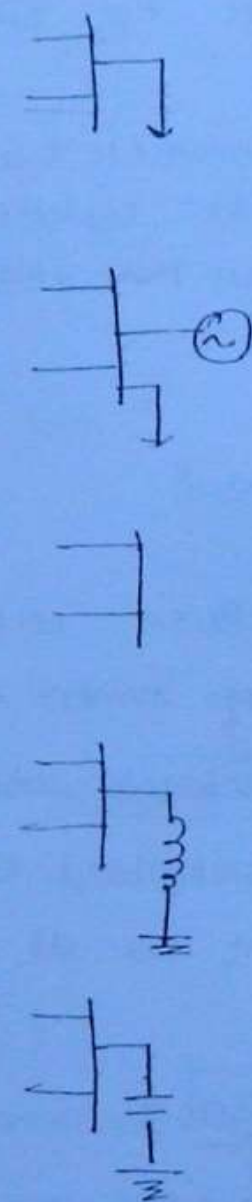
- Buses connected with generators can be selected as PQ bus since the values of P.Q are known. Voltage controlled buses can be selected as PQ bus.

PV Buses:

- A PV Buse must be equipped with either generator or voltage control equipment. At these buses $\boxed{P_i = 0}$ $\boxed{V \text{ is constant}}$ and $\boxed{Q \text{ can be estimated}}$. Therefore a pure voltage controlled bus the only parameter which is unknown to us is 'δ'

SLACK Bus:

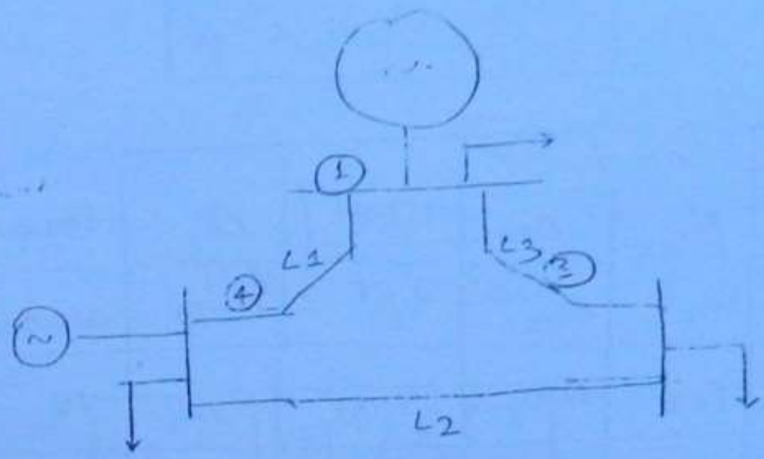
- A Generator bus with maximum generating capacity is chosen as ~~slag~~ slack bus. As the generator is connected to the bus voltage can be specified and this bus voltage is ~~taken~~ taken as reference vector. Load angle for this bus is zero. Without slack bus load flow problem never converges

• Slack Bus	• PV Bus	• PQ bus.
		

ALGORITHM

Case 1: PV buses are absent

Stage 1: To find bus quantities



- Line data.

Line no	From bus (i) to Bus (k)	R_{ik}	X_{ik}	$\frac{y'_{ik}}{2}$
L_1	1 - 2	R_{12}	X_{12}	$y'_{12}/2$
L_2	2 - 3	R_{23}	X_{23}	$y'_{23}/2$
L_3	3 - 1	R_{31}	X_{31}	$y'_{31}/2$

series Impedance $Z_{ik} = R_{ik} + jX_{ik}$

Series admittance $= y_{ik} = \frac{R_{ik}}{R_{ik}^2 + X_{ik}^2} - j\frac{X_{ik}}{R_{ik}^2 + Y_{ik}^2}$

- from Ybus by using Direct inspection Method.

$$Y_{Bus} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & Y_{23} \\ Y_{31} & Y_{32} & Y_{33} \end{bmatrix}_{3\times 3}$$

$$Y_{11} = \frac{y'_{12}}{2} + y'_{13}/_2 + y_{12} + y_{31}$$

$$Y_{12} = -y_{12}$$

• Bus Data:

Bus no. (i)	Generator		Load		V_i	δ_i	Remark
	P_{Gi}	Q_{Gi}	P_{Di}	Q_{Di}			
1	?	?	P_{D1}	Q_{D1}	V_1	$\delta = 0$	slack.
2	P_{G2}	Q_{G2}	P_{D2}	Q_{D2}	$V_2 = ?$	$\delta_2 = ?$	PQ
3	P_{G3}	Q_{G3}	P_{D3}	Q_{D3}	$V_3 = ?$	$\delta_3 = ?$	PQ.

$P_{G1} = P_1 + P_{D1}$

$Q_{G1} = Q_1 + Q_{D1}$.

Bus summary:

given: $V_1, \delta_1, P_2, Q_2, P_3, Q_3$.

not Given: $P, Q, V_2, \delta_2, V_3, \delta_3$

$$P_i = \sum_{k=1}^{n} V_i V_k Y_{ik} \cos(\delta_i - \delta_k + \gamma_{ik})$$

$$V_{Qi} = \frac{1}{Y_{11}}\left[\frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{k=1 \\ k \neq 1}}^{n} Y_{ik} V_k\right]$$

$$Q_i = \sum_{k=1}^{n} V_i V_k Y_{ik} \sin(\delta_i - \delta_k + \gamma_{ik})$$

• FLAT START:-

$$V_2^0 = V_3^0 = 1\,p.u.$$

$$\delta_2^0 = \delta_3^0 = 0 \text{ radians}$$

$$V_2^{(1)} = \frac{1}{Y_{22}}\left[\frac{P_2 - jQ_2}{|V_2|^0 \angle -\delta_2^0} - Y_{21}V_1 - Y_{23}V_3\right]$$

$$\boxed{V_2^{(1)} = |V_2|^{(1)} \angle \delta_2^{(1)}.}$$

$$V_3' = \frac{1}{Y_{33}}\left[\frac{P_3 - jQ_3}{V_3^{0} \angle -\delta_3^{0}} - Y_{31}V_1 - Y_{32}V_2^{(1)}\right]$$

$$\boxed{V_3' = |V_3|^{(1)} \angle \delta_3^{(1)}}$$

Check for convergence

$$\cancel{|V_i^{(1)} - V_i^{(0)}| \le \epsilon}$$

$$|V_i^{r} - V_i^{(r-1)}| \le \epsilon$$

$$|\delta_i^{r} - \delta_i^{(r-1)}| \le \epsilon$$ ∴ where r is current iteration r

If convergence is occured, then calculated slack bus power and losses then go to stage-2. If not repeat the process.

USE OF ACCELERATION

Example

the 20th iterated value

$$V_2^{20} = \frac{1}{Y_{22}}\left[\frac{P_2 - jQ_2}{|V_2|^{19} \angle -\delta_2^{19}} - Y_{21}V_1 - Y_{23}V_3^{19}\right]$$

$= |V_2|^{20} \angle \delta_2^{(20)}$.

before using V_2 in the next cal.

accelerate V_2 first and then used it-

$$\boxed{V_2^{20}\ \text{accelerated} = V_2^{19} + \alpha\left(V_2^{20} - V_2^{19}\right)}$$

acceleratⁿ factor

$\boxed{\alpha = 1.6}$

reduction of 20-30%

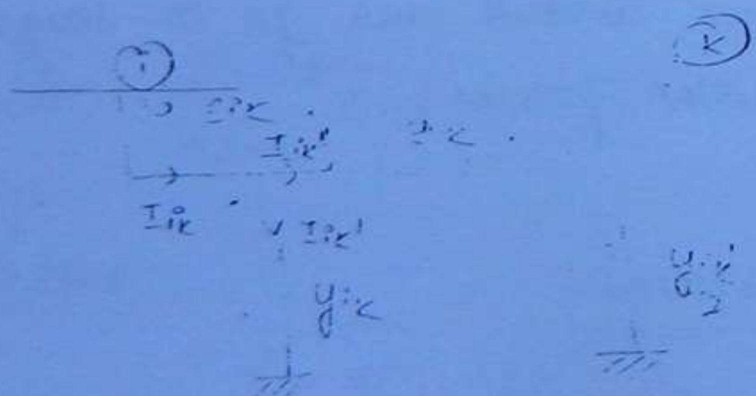
$$\boxed{\delta_2^{20} = \delta_2^{19} + \alpha\left(\delta_2^{20} - \delta_2^{19}\right)}$$

STAGE-2: to find line flow / losses.

$\left.\begin{matrix} P_i \\ Q_i \end{matrix}\right] S_i$

V_i

δ_i



$\left.\begin{matrix} P_k \\ Q_k \end{matrix}\right] S_k$

V_k

δ_k

$S_{ik} = P_{ik} + jQ_{ik}$ = complex power transfered from bus (i) to bus (k)

$$I_{ik} = I_{ik}' + I_{ik}'' = V_i \frac{y_{ik}'}{2} + (V_i - V_k)\, y_{ik}$$

$$S_{ik} = V_i I_{ik}^* = V_i\left(V_i^* \frac{y_{ik}^*}{2} + (V_i^* - V_k^*)\, y_{ik}^* \right)$$

Similarly

$$S_{ki} = V_k I_{ki}^* = V_k\left[V_k^* \frac{y_k^*}{2} + (V_k^* - V_i^*)\, y_{ik}^* \right]$$

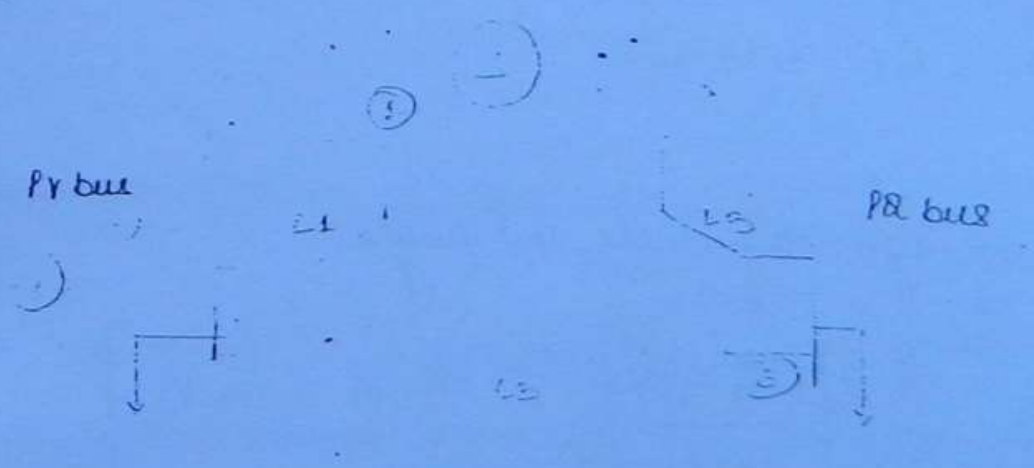
$S_{ki} = 1.1 + j0.9$ → sending (k to i) (importing)

$S_{ik} = -0.3 - j0.2$ → receiving (from i to k) (exporting)

Dated
9 Nov 2010

Case 2: PV buses are present.

Stage 1: to find bus quantities



- using line data from Y bus

- Bus data :

Given: $V_1, \delta_1 = 0$

$P_2, V_2, Q_{2\,min}, Q_{2\,max}, P_3, Q_3$

Find:

$V_1, \delta_1, P_2, \delta_2$

V_3, δ_3

Initial start:

$V_3^{(0)} = 1 \angle 0$

$\delta_2^{(0)} = \delta_3^{(0)} = 0$ radian

= Step 1: calculate $Q_2^{(0)}$

$$Q_2^{(0)} = |V_2||V_1||Y_{21}| \sin(\delta_2^{0} - \delta_1 + \gamma_{21})$$
$$+ |V_2||V_3|^{0} |Y_{23}| \sin(\delta_2^{0} - \delta_3^{0} + \gamma_{23}).$$

= Step 2: check for reactive power limits

$$Q_{2min} \leq Q_2^{(0)} \leq Q_{2max}$$

= Step 3: update voltage magnitude and angle.

$$V_2^{(1)} = \frac{1}{Y_{22}} \left[\frac{P_2 - jQ_2^{0}}{|V_2| \angle -\delta_2^{0}} - Y_{21} V_1 - Y_{23} V_3^{0} \right]$$

$$= |V_2|^{(1)} \angle \delta_2^{(1)}$$

omit $|V_2|^{(1)}$, retain $\delta_2^{(1)}$

$$V_2^{(1)} = |V_2| \angle \delta_2^{(1)}$$

$$V_3^{(1)} = \frac{1}{Y_{33}}\left[\frac{P_3 - jQ_3}{|V_3|^0 \angle -\delta_3^0} - Y_{31}V_1 - Y_{32}V_2^{(1)}\right]$$

$$= |V_3|^{(1)} \angle \delta_3^{(1)}$$

step4 : check for convergence.

$$|\delta_1^{r} - \delta_1^{(r-1)}| \le \epsilon$$

$$|V_3^{r} - V_3^{(r-1)}| \le \epsilon.$$

- If convergence occurs than calculate slag bus power, P_1, Q_1 and find value of Q_2 then goto stage 2 calculation
- If convergence do not occur repeat step 2 to 4 using current iteration values until convergence occurs.

Reactive-Power Limit Voilation At PV Buses

- let we have completed r^{th} no. of Iteration, convergence couldnot be obtained even at the end of r^{th} iteration Before going to $(r+1)^{th}$ iteration for updating voltages and load angle, $Q_2^{(r)}$ is calculated using r^{th} iteration values of (V) and (δ) - Now $Q_2^{(r)}$ has voilated the limits. It can voilate limit in two ways.

$$Q_2^{(r)} \begin{cases} \to\ < Q_{2\,min} \\ \to\ > Q_{2\,max} \end{cases}$$

- Under these circumstances the voltage at the second bus may be more than or less than specified value.
- Treating second bus as PV bus is **WRONG**; it should be treated as PQ bus only.
- The same active power V_2 can be selected as specified value. The reactive power Q_2 may be said $Q_{2(min)}$ or $Q_{2(max)}$ depending upon the case may be.

NEWTON - RAPHSON METHOD

(a) Single value function:

$$y = f(x) = x^2 - \log x + 1$$

$$f(x) = 0$$

Let $x = x^0$ is the root

$$y^{(0)} = f(x^0) \neq 0$$

$x^{(1)} = x^0 + \Delta x^0$

$y^{(1)} = f(x^{(1)}) = f(x^0 + \Delta x^0) = 0$

expand the eqn by taylor series approximates

$$y^{(1)} = y^{(0)} + \Delta y^{(0)} = f(x^0) + \left(\frac{\partial y}{\partial x}\right)^0 \Delta x^0 + \left(\frac{\partial^2 y}{\partial x^2}\right)^0 \Delta^2 x^{(0)} + \cdots$$

$$f(x^0) + \left(\frac{\partial y}{\partial x}\right)^0 \Delta x^0 = 0$$

$$\Rightarrow \boxed{\Delta x^{(0)} = -\frac{f(x)^0}{\left(\frac{\partial y}{\partial x}\right)^0}}$$

175
x
375

$\longrightarrow \quad x^{(1)} = x^{(0)} + \Delta x^0$

check for convergence.

$$|x^{(1)} - x^{(0)}| \leq \in$$

$$x^{(2)} = x^{(1)} + \Delta x^{(1)}$$

$$\boxed{\Delta x^{(1)} = -\frac{f x^{(1)}}{\left(\frac{\partial f}{\partial x}\right)^1}}$$

—

b) Multi value function :-

$$y_1 = f_1(x_1, x_2) = x_1^2 - \log x_1 x_2 + x_2^2$$

$$y_2 = f_2(x_1, x_2) = -2x_1^2 + \log x_1 x_2^2 - x_2^2$$

$$f_1(x_1, x_2) = 0$$

$$f_2(x_1, x_2) = 0$$

$x_1^{(0)}, x_2^0 \longrightarrow$ Intial guess

$$y_1^{(0)} = f_1(x_1^0, x_2^0) \neq 0$$

$$y_2^{(0)} = f_2(x_1^0, x_2^0) \neq 0$$

New roots

$$x_1^{(1)} = x_1^{(0)} + \Delta x_1^{(0)}$$

$$x_2^{(1)} = x_2^{(0)} + \Delta x_2^{(0)}$$

$$y_1^{(1)} = y_1^{(0)} + \Delta y_1^{(0)} = f_1(x_1^{(1)}, x_2^{(1)}) = f_1(x_1^0 + \Delta x_1^0, x_2^0 + \Delta x_2) = 0$$

$$f_1(x_1^0, x_2^0) + \left(\frac{\partial f_1}{\partial x_1}\right)^0 \cdot \Delta x_1^0 + \left(\frac{\partial f_1}{\partial x_2}\right)^0 \Delta x_2^{(0)} = 0 \quad \text{---- (1)}$$

$$f_2(x_1^0, x_2^0) + \left(\frac{\partial f_2}{\partial x_1}\right)^0 \Delta x_1^0 + \left(\frac{\partial f_2}{\partial x_2}\right) \Delta x_2^0 = 0 \quad \text{---- (2)}$$

Put eqn's (1) and (2) in Matrix form.

$$\underbrace{\begin{bmatrix} \frac{\partial f_1}{\partial x_1} & \frac{\partial f_1}{\partial x_2} \\ \frac{\partial f_2}{\partial x_1} & \frac{\partial f_2}{\partial x_2} \end{bmatrix}^0}_{\text{Jacobian Matrix}} \underbrace{\begin{bmatrix} \Delta x_1 \\ \Delta x_2 \end{bmatrix}^0}_{\text{Increment Matrix}} = - \underbrace{\begin{bmatrix} f_1(x_1, x_2) \\ f_2(x_1, x_2) \end{bmatrix}}_{\text{Constant Matrix}}$$

$$\boxed{[J]^0 [\Delta X]^0 = -[f]^0}$$ --- condensed form

so,

$$\boxed{[\Delta x]^0 = -[J^0]^{-1}[f]^0}$$

After getting the increments update the values of (x_1 and x_2) using the increment value then check for convergence. If convergence is occured take the solut^n of simultaneous algebric equat^n otherwise repeat the process.

new roots :

$$x_1^{(2)} = x_1^{(1)} + \Delta x_1^{(1)}$$

$$x_2^{(2)} = x_2^{(1)} + \Delta x_2^{(1)}$$

$$\boxed{[\Delta x]^{(2)} = -[J^n]^{-1}[f^{(1)}]}$$

NR METHOD :

$P_i = f_1(\delta, |V|)$ $i = 1, 2 \ldots n$

$Q_i = f_2(\delta, |V|)$ $i = 1, 2 \ldots n$

$$\Delta P_i = \cancel{\left(\frac{\partial P_i}{\partial \delta_1}\right)\Delta \delta_1} + \left(\frac{\partial P_i}{\partial \delta_2}\right)\Delta \delta_2 + \cdots + \left(\frac{\partial P_i}{\partial (\delta_n)}\right)\Delta \delta_n$$

$$+ \cancel{\left(\frac{\partial P_i}{\partial |V_1|}\right)\Delta |V_1|} + \left(\frac{\partial P_i}{\partial |V_2|}\right)\Delta |V_2| + \cdots + \left(\frac{\partial P_i}{\partial |V_n|}\right)\Delta |V_n|$$

$$\Delta Q_i = \cancel{\left(\frac{\partial Q_i}{\partial \delta_1}\right)\Delta \delta_1} + \left(\frac{\partial Q_i}{\partial \delta_2}\right)\Delta \delta_2 + \cdots + \left(\frac{\partial Q_i}{\partial \delta_n}\right)\Delta \delta_n$$

$$+ \cancel{\left(\frac{\partial Q_i}{\partial |V_1|}\right)\Delta |V_1|} + \left(\frac{\partial Q_i}{\partial |V_2|}\right)\Delta |V_2| + \cdots + \left(\frac{\partial Q}{\partial |V_n|}\right)\Delta |V_n|$$

For slack buses δ_1 and V_1 are constant so the values like $\Delta\delta_1$ and ΔV_1 do not exist.

$$\underbrace{\begin{bmatrix} \Delta P_2 \\ \Delta P_3 \\ \hline \Delta Q_2 \\ \Delta Q_3 \end{bmatrix}}_{\text{Power mismatch matrix } [(2n-2)\times 1]} = \underbrace{\left[\begin{array}{cc|cc} \frac{\partial P_2}{\partial \delta_2} & \frac{\partial P_2}{\partial \delta_3} & \frac{\partial P_2}{\partial |V_2|} & \frac{\partial P_2}{\partial |V_3|} \\ \hline \frac{\partial Q_2}{\partial \delta_2} & \frac{\partial Q_2}{\partial \delta_3} & \frac{\partial Q_2}{\partial |V_2|} & \frac{\partial Q_2}{\partial |V_3|} \\ \frac{\partial Q_3}{\partial \delta_2} & \frac{\partial Q_3}{\partial \delta_3} & \frac{\partial Q_2}{\partial |V_2|} & \frac{\partial Q_3}{\partial |V_3|} \end{array}\right]}_{\text{Jacobian Matrix } [(2n-2)\times(2n-2)]} \underbrace{\begin{bmatrix} \Delta \delta_2 \\ \Delta \delta_3 \\ \hline \Delta |V_2| \\ \Delta |V_3| \end{bmatrix}}_{\text{Increment al Matrix } [(2n-2)\times 1]}$$

$$\boxed{\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \left[\begin{array}{c|c} H & N \\ \hline J & L \end{array}\right] \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix}}$$

H, N, J, L $\longrightarrow$ submatrices of [J]

$$H = \frac{\partial P}{\partial \delta} \; ; \; N = \frac{\partial P}{\partial |V|} \; ; \; J = \frac{\partial Q}{\partial \delta} \; ; \; L = \frac{\partial Q}{\partial |V|}.$$

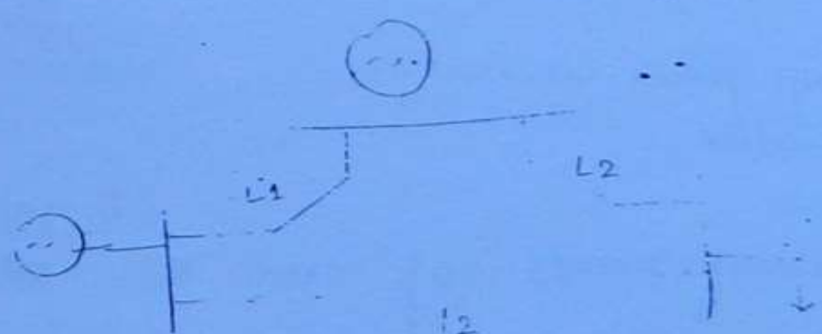
ex -

$$H_{22} = \frac{\partial P_2}{\partial \delta_2} \; ; \; H_{23} = \frac{\partial P_2}{\partial \delta_3} \; ; \; L_{32} = \frac{\partial Q_2}{\partial |V_2|}.$$

NR METHOD :-

case 1 : PV buses are ~~present~~ absent.

stage 1 : To find the bus quantity.



$\rightarrow$ using line data form Ybus.

Bus data :-

Given : $V_1, \delta_1, P_2, Q_2, P_3, Q_3$

To find : $P_1, Q_1, V_2, \delta_2, V_3, \delta_3$

* Flat start :-

$$V_2^{(0)} = V_3^{(0)} = 1\,p.u$$

$$\delta_2^{(0)} = \delta_3^{(0)} = 0\,radian$$

* Step 1:

- calculate P and Q values for PQ buses.

$$P_2^{(0)} = |V_2|^0 |V_1| |Y_{21}| \cos(\delta_2^0 - \delta_1 + \delta Y_{21})$$
$$+ |V_2|^0 |V_2|^0 |Y_{22}| \cos Y_{22}$$
$$+ |V_2|^0 |V_3|^0 |Y_{23}| \cos(\delta_2^0 - \delta_3^0 + Y_{23})$$

similarly calculate P_3^0, Q_2^0, and Q_3^0

* Step 2:

- calculate power mismatches

$$\Delta P_2^0 = P_2^0 - P_2 \quad \| \text{ fill up power mismatch matrix.}$$

$$\Delta P_3^0 = P_3^0 - P_3$$

$$\Delta Q_2^0 = Q_2^0 - Q_2$$

$$\Delta Q_3^0 = Q_3^0 - Q_3$$

Step 3: Fill up $[J]^0$ elements

$$\left(\frac{\partial P_2}{\partial \delta_2}\right)^0 = H_{22}^0 = -|V_2|^0 |V_1| |Y_{21}| \sin(\delta_2^0 - \delta_1 + Y_{21})$$
$$-|V_2|^0 |V_3|^0 |Y_{23}| \sin(\delta_2^0 - \delta_3^0 + Y_{23})$$

$$\left(\frac{\partial P_2}{\partial |V_3|}\right)^0 = V_{23}^0 = |V_2|^0 |Y_{23}| \cos(\delta_2^0 - \delta_3^0 + \gamma_{23})$$

Similarly all other elements can be found.

- After filling up the Jacobian elements and power mismatch elements the increments for delta and magnit. |V| can be obtained as

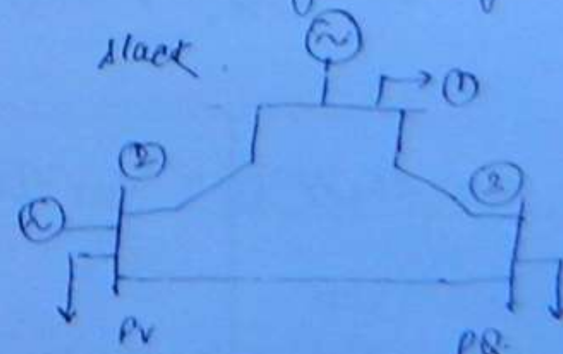
$$\begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix}^0 = \left[J^0\right]^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}$$

Step 5:

- Using the increments obta update and magnitude of V values.

Step 6:

The check for convergence, if convergence occur then calculate slack bus power P_1, Q_1 and go to stage 2 calculatn, if not repeat the process



Case 2: PV buses are present

Stage 1: to find bus quantities

$$\begin{bmatrix} \Delta P_2 \\ \Delta P_3 \\ \hline \Delta Q_3 \end{bmatrix} = \left[\begin{array}{cc|c} \frac{\partial P_2}{\partial \delta_2} & \frac{\partial P_2}{\partial \delta_3} & \frac{\partial P_2}{\partial |V_3|} \\ \frac{\partial P_3}{\partial P_2} & \frac{\partial P_3}{\partial \delta_3} & \frac{\partial P_3}{\partial |V_3|} \\ \frac{\partial Q_3}{\partial \delta_2} & \frac{\partial Q_2}{\partial \delta_3} & \frac{\partial Q_3}{\partial |V_3|} \end{array}\right] \begin{bmatrix} \Delta \delta_2 \\ \Delta \delta_3 \\ \Delta |V_3| \end{bmatrix}$$

Non-existing elements:

$J_{22}, J_{23}, L_{23}, L_{22}, N_{22}, N_{32}, L_{32}$

-- using line form Ybus

Bus data:

Given: $V_1, \delta_1, P_2, V_2, Q_{2min}, Q_{2max}, P_3, Q_3$

to find: $P_1, Q_1, Q_2, \delta_2, V_3, \delta_3$

Flat start:

$V_3^0 = 1 p.0$

$\delta_2^0 = \delta_3^0 = 0$ rad.

Step 1: check Q_2^0 for limits

Step 2: ~~that~~ calculate b P and Q values for PQ buse and P values of PV buses

Step 3 Calculate power mismatches ΔP_2^0, ΔP_3^0 and ΔQ_3^0 and fill up the matrix.

Step 4 Evaluate Jacobian element and fill the matrix.

Step 5 Calculate increment for δ and $|V|$ as follow.

$$\begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix} \begin{matrix} = \cancel{[J^0]^{-1}} \\ = \cancel{[J^0]^{-1}} \end{matrix} \; [J^0]^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}^0$$

Step 6: using the increments update δ and $|V|$ value

Step 7: Check for convergence, if occurs calculate slack bus power P_1, Q_1 and final value of Q_2 if not repeat the process.

Date
10 | Nov | 20

= COMPARISION B/W NR AND GSM :-

Parameter of Comparision	GS METHOD	NR METHOD
1 time for each iteration	LESS	MORE —
2. Complexity of iteratn.	Easy	Very Difficult.

3. Type of convergence	Linear	Quadratic
4. Convergence rate	slow	fast.
5. Total no. of iteration	Increase with size of P.S	Independent of size of P.S
6. Gaurantee of Convergence ~~Acceleration~~	Not Gauranteed.	Gauranteed.
7. Acceleration	External	Internal.
8. Selection of slag bus on convergence	more dependent	less dependent
9. Suitability	for small size P.S	for large size P.S.
10. So Accuracy	Less	Highest

DECOUPLED LOAD FLOW METHOD

NR method

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} H & N \\ J & L \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix}$$

$$H = \frac{\partial P}{\partial \delta} \begin{matrix} 100 \\ 50 \\ 10 \end{matrix} \qquad N = \frac{\partial P}{\partial |V|} \begin{matrix} 0.1 \\ 0.1 \\ 0.001 \end{matrix}$$

$$J = \frac{\partial Q}{\partial \delta} \begin{matrix} 0.1 \\ -0.1 \\ 0.001 \end{matrix} \qquad L = \frac{\partial Q}{\partial |V|} \begin{matrix} 100 \\ 50 \\ 200 \end{matrix}$$

Decoupled LF Method

$$\boxed{\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \left[\begin{array}{c|c} H & 0 \\ \hline 0 & L \end{array}\right] \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix}}$$

$$\Delta P = H \cdot \Delta \delta$$

$$\Delta Q = L \cdot \Delta |V|$$

<u>Further assumption made</u> :- (<u>fast decoupled load flow method</u>)

1) Neglect resistance of Generator, T/F, Transmission lines etc.

$$Y_{Bus} = j\,[B] \;\; \text{Integer Matrix}$$

2) $\delta_i - \delta_k \simeq 0$ rad. [as the value of difference in radian is very small value.]

$$\boxed{\begin{aligned} H_{ii} &= L_{ii} \\ H_{ik} &= -L_{ik} \end{aligned}}$$

Advantages of Decoupled Load flows Method over NR Method:-

1) Instead of finding 100% of Jacobian element in NR method, in DCLF method we find 50% of J. element

2) Sparsity of Jacobian matrix is improved.

3) No. of Calculations are reduced.

4)

Advantages of FDCLF over DCLF Method:-

1) In contrast to 50% of Jacobian element in FDLF method we calculate only 25% of the J. elements.

2) By neglecting the resistance Ybus is stored as integer matrix.

3) Less memory space is required for storing J matrix.

NOTES:

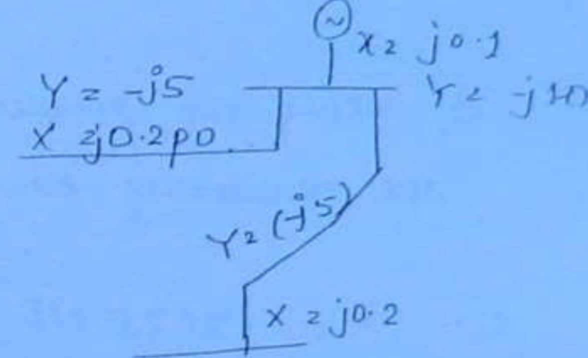
- For small size p/s or offline p/s GS method is used.
- For large size power s/m and for online applicatn NR, FDLF is used.

• for evaluating sensitivity co-efficients NR methods is used.

WORK BOOK

1)

Total admittance connected to bus 2



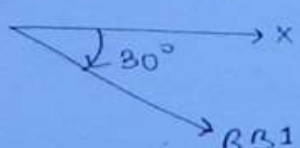
$Y_{22} = -j10 - j5 - j5$

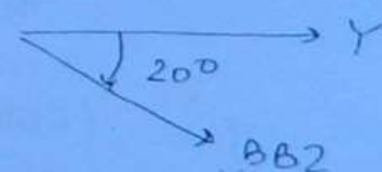
$Y_{22} = -j20$

2) d

3) Active power transfer from BB1 to BB2 is zero if busbar voltage are in phase

Reactive power transfer from BB1 to BB2 is zero if busbar voltage magnitude V are same

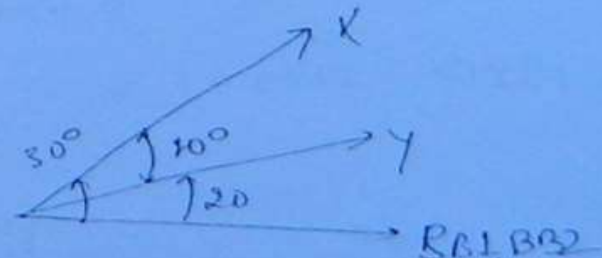




BB1 voltage lag voltage by 30°

BB2 voltage lag Y by 20°.

after either connection



A) Ans

4) $n = 300$; 20 buses → G/r buses

25 buses → reactive power

15 buses → Shunt capacities

240 buses → PQ buses

Size of Jacobian.

Solution: By taking one Generator bus as the slack bus the remaining no buses connected with $Q/r = 19$.

Let $x = 19+25+15 = 59$ PV buses.

Jacobian $(2\times300-2$

$600-2-59)$

$\Rightarrow 539\times539$ X

(i) Let 19 generator bus and 25 bus of reactive power support are taken as PV buses

$\therefore x = 19+25 = 44$

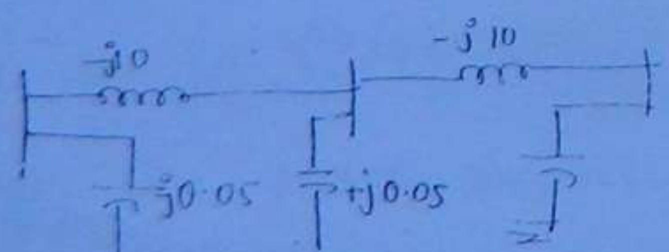
$J = (600-2-44)$

$\Rightarrow 554\times554$ d)

12) $2\times12-2-3 = 19\times19$

5) c

6)



$-j10 + j10 + j0.05$

$= 19.95j$

7) $Z = \begin{bmatrix} 0.9 & 0.2 \\ 0.2 & 0.6 \end{bmatrix}$

$0.54 - 0.04$

$Y = \frac{1}{0.50} \begin{bmatrix} 0.6 & -0.2 \\ -0.2 & 0.9 \end{bmatrix}$

$\Rightarrow Y_{22} = 1.8$.

8) $Z_{bus,(new)} = Z_{bus}(old) - \frac{1}{Z_{22}+Z_3} [2']$

$$\begin{bmatrix} j0.3408 & j0.2586 \end{bmatrix} - \frac{1}{j0.3408 + j0.2} \begin{bmatrix} j0.2860 \\ j0.3408 \\ j0.2586 \\ j0.2414 \end{bmatrix} [j0.2660 \; j.3408 \; j0.2581 \; j0.24$$

$Z_{22}(new) = j0.3408 - \frac{1}{j0.5408} \times j0.3408 \times j0.3408$

$= 0.1266$

$Z_{33}(new) = j0.2586 - \frac{1}{j0.5408} \times j0.348 \times j0.2586$

$= j0.0956$

9) b

13) c

14) Total no of zero element $= 9000$

Total no of non-zero element $= 1000$

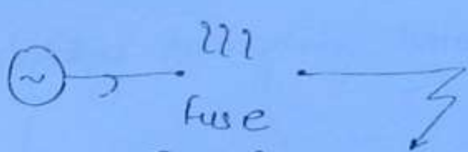
Total no of non zero elements in the upper / lower triangle

$$= \frac{1000 - 100}{2} = 450.$$

No of transmission line = 450.

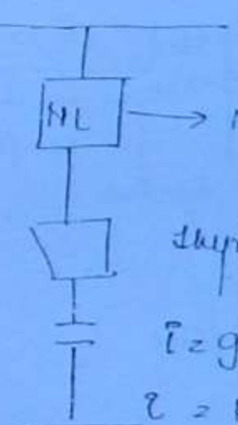
SWITCH GEAR PROTECTION.

- Circuit Breaker
- Relays
- Lighting Arresters (over voltage)
- Fuse. (over current)



$I_{sc}\ R_{fuse}$

Fuse



→ NL resistor block

thyrite / Metal oxide (ZnO)

$i = gv$ . . . linear

$i = kv^{\alpha}$ . . . Non linear

* lighting arresters

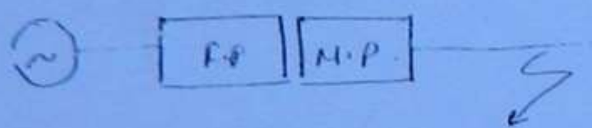
* Every circuit breaker acts as the series switch

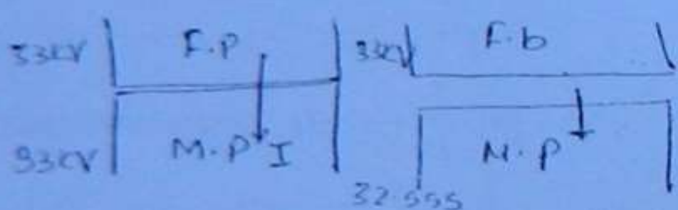
CIRCUIT BREAKERS

- the only difference arc and current is, if the flow of charges take place in conducting Material like Al, Cu, we call it as current, if same flow of charges take place in medium we call it an 'arc'

- During the time of arching I^2 losses are very high and high heat is produced. This in-term produces light.

ARC INITIATION :-





$$\frac{\Delta V}{\Delta d} \text{ K.V./cm}$$

- dielectric stress increases tremendously as distance is in micron

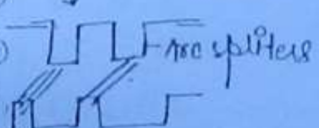
- In circuit breaker arc is initiated because of field emission process, at the instant when two poles are separating a high dielectric stress will occur because of negligible less distance b/w two contacts. This dielectric stress is much near higher than the dielectric strength of any dielectric medium. therefore ionisation begins / arc strikes. This process is known as field emission process

- In circuit breakers arc is maintained because of thermionic emission process.

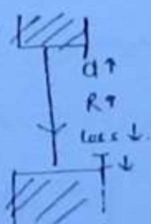
ARC INTERRUPTION :-

(methods)

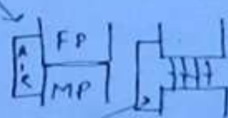
High resistance (D/C Bus)

- Arc splitting


  * metal evaporates near arc

- Arc lengthening


  * size of C.B need to be big

- Forced blast


  * High pressures compressor are needed.

Low resistance. Natural current zero (A/C Bus)

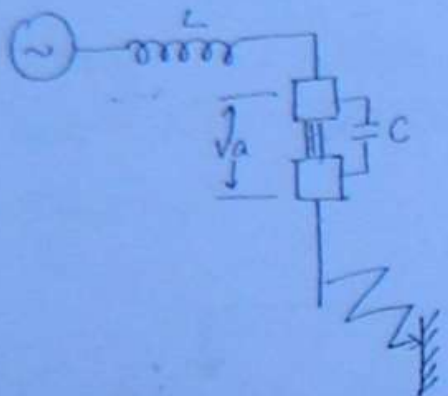
* low pressure is used.
* Here arc itself goes to zero

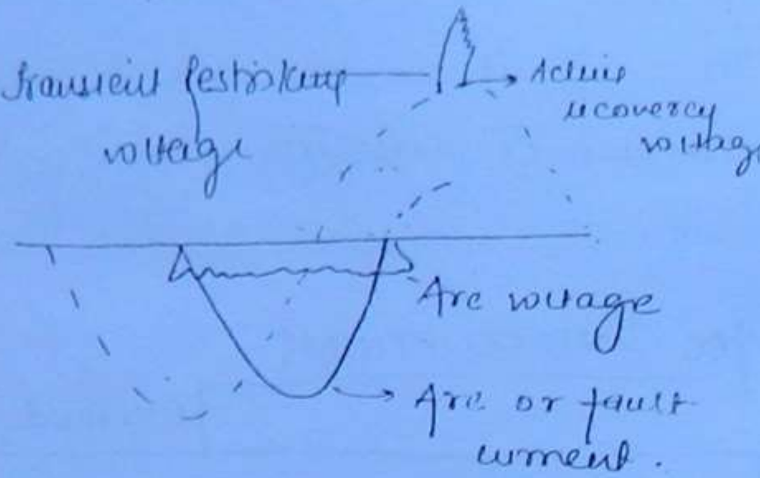
- In a/c CB arc interruptⁿ takes places once after the arc passes natural current zero.

Dated
12 Nov 2015

ARC RESTRICKING

Consider a power s/m with negligible resistance.



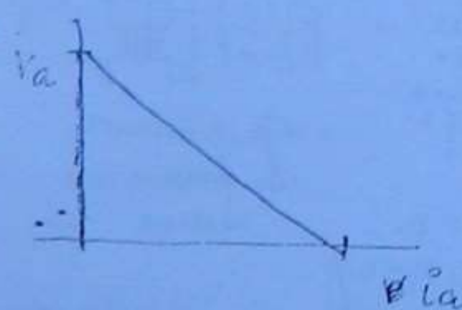


L → inductance of s/m upto fault resistance.

$V_a = i_a R_a$

(i) Arc has unity power factor*

2) characteristic of arc



Arc has negative resistance characteristic

. During the time of arching the voltage across the breaker poles is the arc voltage which is generally a small value due to short circuit condition.

. At the instant when the arc passes its natural current zero arc is interrupted. At this point of time some heat is present in gap.

- the system response is oscillatory coz a capacitance is appearing a across the breaker poles due to open circuit condition.

- the arc may restrike or not will depend on behavior of restriking voltage. the behaviour of restriking voltage depends upon L and C. the values of L and C are such that restriking voltage is raising rapidly this means in this short time the heat in gap cannot be removed and contact can not be cooled. therefore all the conditions in the gap helping restriking voltage to make arc restrike again; in other way the values of L and C are such the restriking voltage is raising slowly this means ample of time is available to remove the heat and to cool the contacts therefore no condition are helping the restriking voltage to make arc restrike again. Hence final arc interruption takes place.

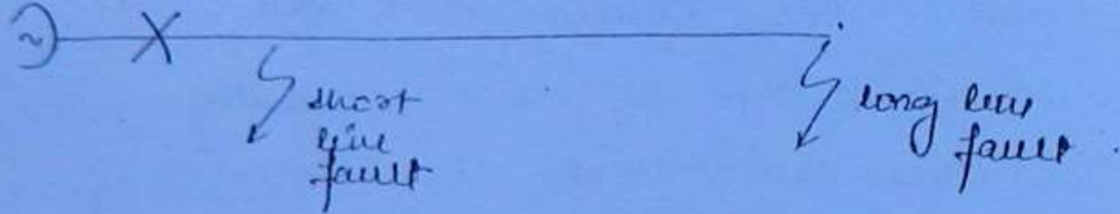
Transient Restriking voltage (Vr):-

The transient voltage that appears across breaker pole at instant of arc interruption is known as transient restriking voltage.

$$\boxed{V_r = V_{max}\left[1 - \cos\frac{t}{\sqrt{LC}}\right]}$$

V_{max} → supply peak voltage.
t → time instance
L, C → line inductance and capacitance.

Example



Short line fault: L and C $\downarrow$ $\frac{t}{\sqrt{LC}}\uparrow$ $\cos\frac{t}{\sqrt{LC}}\downarrow$ $1-\frac{\cos t}{\sqrt{LC}}\uparrow$ $V_r\uparrow$

Long line fault: L and C $\uparrow$ $\frac{t}{\sqrt{LC}}\downarrow$ $\cos\frac{t}{\sqrt{CL}}\uparrow$ $1-\frac{\cos t}{\sqrt{LC}}\downarrow$ $V_r\downarrow$

In view of restriking voltage a short line fault is more severe compare to long line fault

Rate of Rise of Restriking voltage :- [RRRV]

For restriking free operation of CB RRRV should be less

$$RRRV = \frac{dV_r}{dt}$$

$$\boxed{RRRV = \frac{V_m}{\sqrt{LC}}\sin\left(t/\sqrt{LC}\right)}\quad KV/\mu sec$$

$$\boxed{\text{Maximum RRRV} = \frac{V_m}{\sqrt{2c}}\ \text{kV}/\mu\text{sec}}$$

- Natural frequency of oscillation $f = \frac{1}{2\pi\sqrt{LC}}$

- Average RRRV = (Max value of restriking voltage) / time taken to reach the value

$$\boxed{\text{Average RRRV} = \frac{2V_{max}}{\pi\sqrt{LC}}\ \text{kV}/\mu\text{sec}}$$

objective:

If the rate at which heat is dissipated is less compared to RRRV then arc will restrikes otherwise arc is interrupted

Active Recovery Voltage:

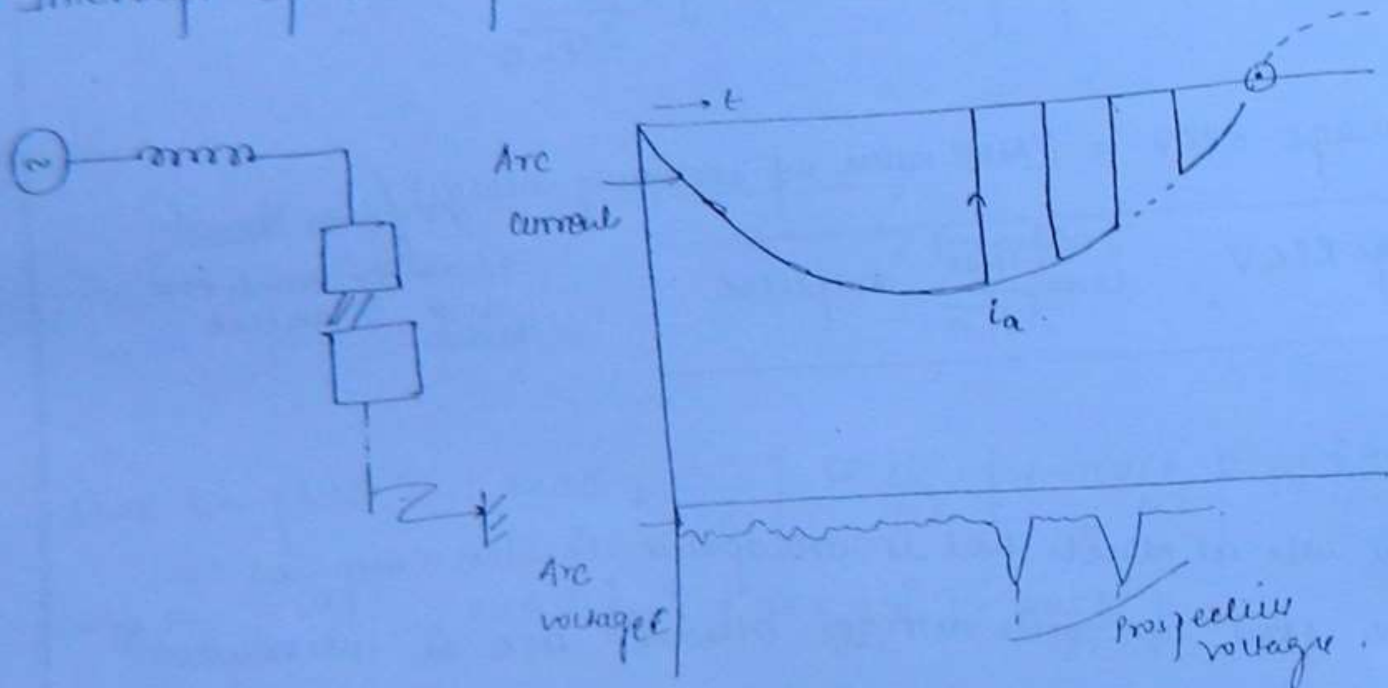
The instantaneous voltage that appear across breaker force after final arc interruption is known as active recovery voltage.

Recovery voltage:

The rms voltage that appear across breaker for after final arc interruption is known as recovery voltage.

Current Chopping Phenomenon

- "Interrupt" of arc before natural current zero"



i_a = Instantaneous current i.e interrupted

energy stored by inductance $E = \frac{1}{2} L i_a^2$

- Energy balance equation

$$\frac{1}{2} C V^2 = \frac{1}{2} L i_a^2$$

$$\boxed{V = i_a \sqrt{\frac{L}{C}}}$$ - prospective voltage.

- As the strength of arcing deionising force is so high and severity of fault current is so so less arc will be interrupted well before it passes the natural current zero.

the energy stored in the inductance will start converting into electro-static energy by the capacitor. When the capacitor is charging the voltage across breaker poles as well as dielectric stress starts increasing. At particular value of dielectric stress arc will restrike again. As the de ionising force is still on the arc will interrupt again. This process repeats until arc passes natural zero.

Disadvantage:

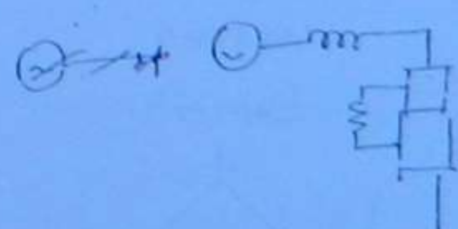
transient off voltage known as switching overvoltage s/w will appear.

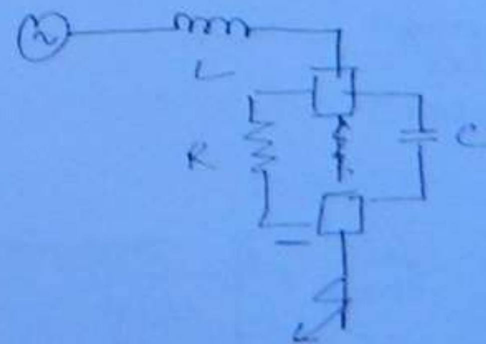
* The insulation requirement for EHV lines is designed based on switching over voltages.

RESISTANCE SWITCHING OF CIRCUIT BREAKER

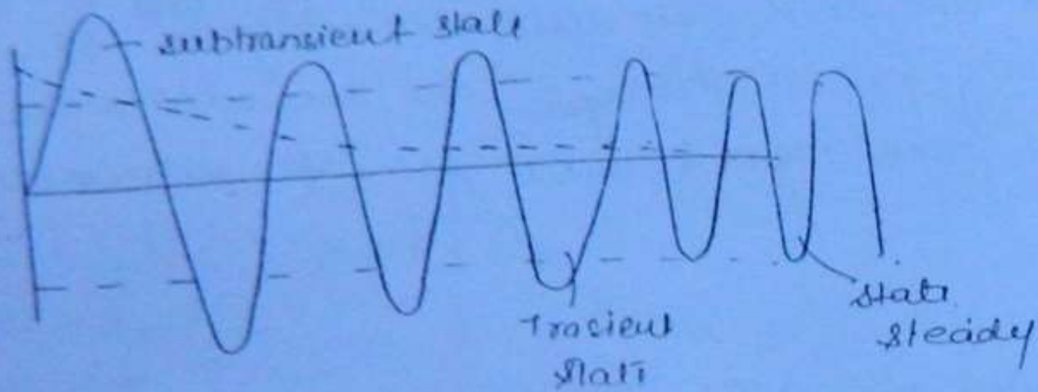
- Resistance switching is employed in ckt breaker to avoid C C phenomena.

$$\boxed{R = 0.5\sqrt{\frac{L}{C}}}$$





CIRCUIT BREAKER RATING



- Subtransient current → Breaking current

\# A CB can make the circuit during subtransient state or brake the circuit during transient or steady state.

CB Rating

- Breaking capacity
  - KV
    - symmetrical
    - Asymmetrical
  - MVA
- Making capacity
  - KA
  - MVA
- Short time rating (Rated breaking capacity for specified duration)

$I_{break} = \frac{y}{\sqrt{2}}$

$I_{break} = \sqrt{x^2 + \left(\frac{y}{\sqrt{2}}\right)^2}$

$$\boxed{\text{Making capacity} = 2.55 \times \text{Breaking capacity}}$$

Numerical:

A 33KV 3300MVA, 1500A, 3sec, 50Hz 1-ϕ oil CB has

1) Rate normal current = 1500 A
2) Rate breaking capacity 3300MVA
3) Rated breaking capacity in KA = $3300/33 = 100$ kA
4.) Rated making capacity in KA = 2.55×100 KA $= 255$ KA
5) Short time rating = 3300MVA for 3sec. or 6600MVA for 1.5 sec.

Classification based on dielectric:-

Circuit Breaker

- Oil less
  - Air blast CB [ABCBs]
  - Sulphur Hexafloride [SF$_6$CBs]
  - Vacuum [VCBs]
- Oil type
  - Minimum Oil (MOCB)
  - Bulk Oil CB [BOCB]

- current chopping phenomenon is more severe in case of above ABCBs

- Resistance switching is mainly employed in ABCBs.
- Resistance switching reduces the severity RRRV.
- Air pressure in AB CB's is maintained around $30 kg/cm^2$
- ABCB's are more suitable for high speed and repeated operatn.
- ABCB's are more suitable for EHV and UHV applicatn [400kV range].
- Both arc energy and arcing time are least in case of ABCB's
- SF_6 gas is 3 to 5 time better than air due to its electronegativity properties. Electronegativity means affinity of electrons
-

$$SF_6 + e^- \longrightarrow SF_5^- + F$$

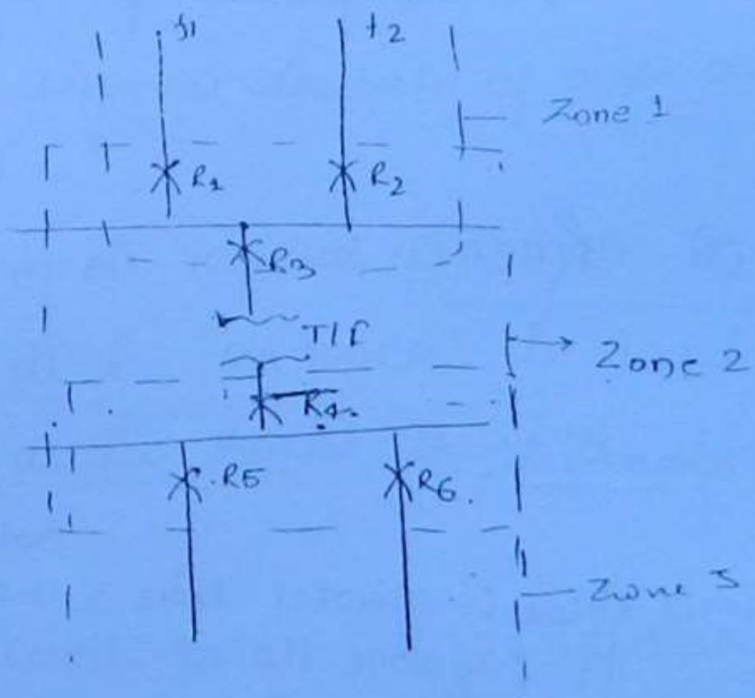
-
- Because of its low molecular weight ~~SF6~~ SF_6 gas has excellent thermal conducting properties
- SF_6 CB's are very popular and they are available from 11 kV to 220 kV.
- SF_6 gas is maintained at $14 Kg/cm^2$ below this pressure it is in powder form form. Hence heaters may be used.
- For interrupting low inductive or low capacitive current without resistance switching the CB employed is SF_6 CB's
- Transformer oil in OCB's has two application

FUNCTIONAL CHARACTERISTICS :-

1) Sensitivity:

Relay is able to produce sufficient operating torque to close the trip ckt even for small change in operating quantity

2. Selectivity (Zone of protection)



- the simultaneous operation of Relay 1, 2, 3, fault occur at BB:

(3) Speed :-

↳ clear the fault in time < 5 cycles time

$5 \times 0.02 sec = 0.1 sec.$

[redacted]

(4) Simplicity :-

↳ Design of the relay must be simple

(5) Cost :-

20% of the cost of the equipment can be spend on protect^n.

(6) Reliability :-

:- when fault occurs Relay should operate

Type of Relay

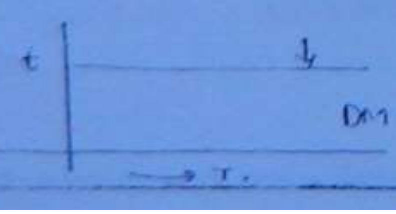
1) Based on type of operation :-

a) Instantaneous Relay :- operates time ≤ 0.1 sec

used for generator protection

made up of Balanced beam and induction cup.

b) Definite Minimum Time : time is constant



1) It acts as dielectric medium [dielectric strength of T/r 50KV,
,, ,, ,, air 30KV/inch

2) At 658° K temp oil decomposes and produces various gases, out of these gases ≈ 70% of gas is Hydrogen which act like coolant.

- In oil CB the strength of ~~dio~~ deionising force shall adjust in accordance to severity of fault current. therefore current chopping phenomenon is least in this case.
- The chance for arc interruption in subsequent natural current zero improves in case of OCB's but reduces in other types
- The volume of oil required for MOCB's is only 10% of BOCB's as oil in MOCB's is used for arc interruption only where as in BOCB's it ~~I~~ is used for insulating live parts also.
- OCBs are used for all voltage applications from 11 KV to ~~130~~ 132KV.
- The vacuum pressure in VCB's is maintained around 10^{-8} to 10^{-6} Torr

1 Torr = 1mmHg

- The principal of arc interruptⁿ in VCBs is condensification of arc products like copper vapours etc.

maintanance is least in case of VCB's

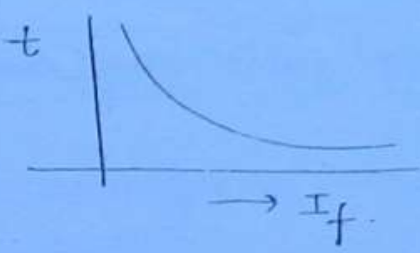
VCB's are suitable for remote and rural electrification

for interrupting high current and low voltage (11KV range) VCB's are used.

AUTO-RECLOSING FEATURES

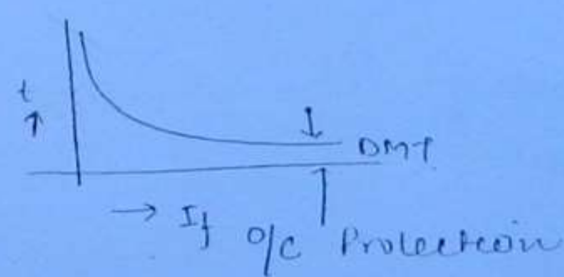
used for over current protectn of Induction Motor.

c) Inverse Relays :-

#. 

#. generally not used.

d) IDMT relay :- [combination of Inverse and DMT relay]



Commercially used.

Over current relay.

2) Based on the construction / operating principal :-

a) Electromagnetic attraction type :-

Balanced beam [differential protection]

Attracted armature

Moving plunger

b) Electromagnetic Induction Type:-

Shaded pole
Wattmeter [o/c protection]
Induction cup: fastest relay [distance relay].

c) Gas protected Type:-

Buchholz relay [used for protecting oil immersed xmer from internal / incipient faults]

d) Thermal Relays:-

Overload protection.

e) Static /Microprocessor base relays.

Not widely used as need much precaution.

OVER CURRENT PROTECTION

Definition:-

) PICK-UP VALUE:- It is the minimum value of operating quantity at which relay is 'WEDGE' of operation of

(2) RESET VALUE :- It is a maximum value of operating quantity at which relay is at the wedge of non-operation.

$$\boxed{\text{wedge condition} \Rightarrow \text{operation force} = \text{Restraining force}}$$

- Reset and Pick values are different because of hysteresis error
- For well-designed relays ratio of Reset to pick up value is unity. Howere for induction type relay it is 0.9

(3) TIME MULTIPLIER SETTING :-

$$\text{TMS required} = \frac{\text{time of operation required}}{t_{TMS=1}} \left[\frac{t_{required}}{t_{TMS=1}}\right]$$

Example:

1) A relay operates in 5 sec when TSM = 1, to operate relay in 2 sec TMS should be adjusted to.

$$\text{Tms required} = \frac{2}{5} = 0.4 \text{ sec}$$

2) A relays operates in 4 sec when TSM = 1. to operate relay in 1.98 sec, TMS should be adjusted to

$$\text{Tms} = \frac{1.98}{4} = 0.495 \approx 0.5 \text{ sec}$$

= time taken by relay = 0.5 × 4 = 2 sec

relay takes more time to react: delay of 0.02 sec

so take value as = 0.4 sec.

NOTE:-

TMS should always be rounded to nearest lower values always

$$\boxed{\frac{TMS_2}{TMS_1} = \frac{t_2}{t_1}}$$

) A relay operates in 3 sec when TMS = 0.7 when A TMS is adjusted to 0.2, the relay operate in ___ sec

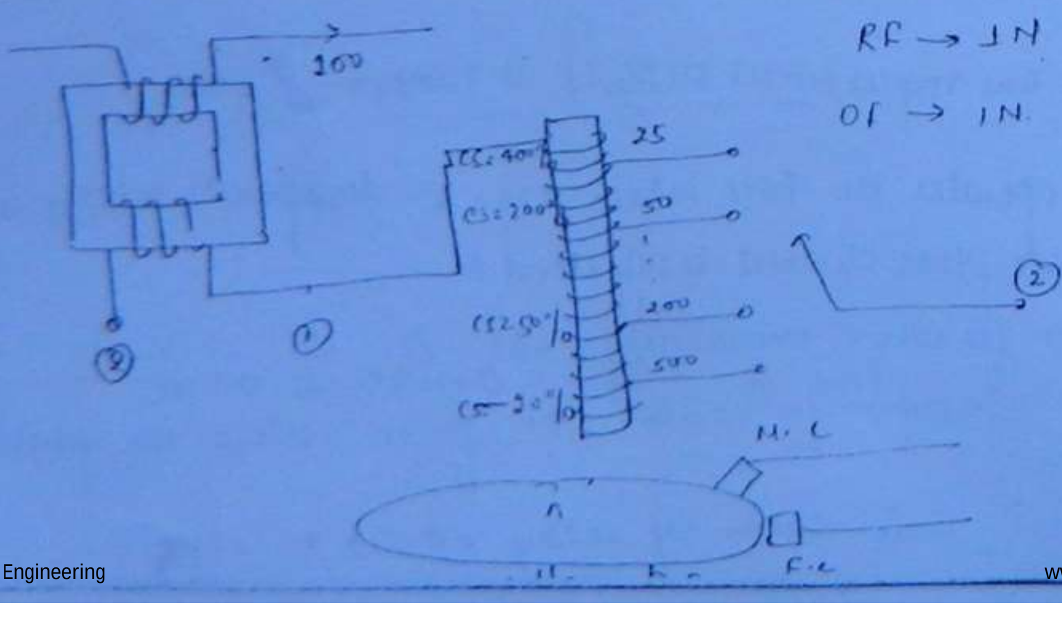
Solutn.

$$\frac{0.2}{0.7} = \frac{t_2}{3}$$

$$0.6/0.7 = t_2$$

$$t_2 = 0.857 sec$$

3) PLUG SETTING MULTIPLIER:(PSM).



RF → 1N

OF → 1N.

- Relay normal current
  = CT sec rated current = 5A

- Relay operating current = 20A
  = 4×5

$$\boxed{\text{Relay operating current} = \text{current setting} \times \text{CT secondary rated current}}$$

$$\boxed{\text{Relays operating current} = \text{Current setting} \times \text{CT secondary rated current} \times \text{CT ratio}}$$

↳ related to CT primaries.

$$\boxed{PSM = \frac{\text{Fault current}}{\text{Current setting} \times \text{CT secondary rated current} \times \text{CT ratio}}}$$

Example:

1) Current setting = 40%, fault current 2000A, CT = $\frac{100}{5}$, the PSM

$$PSM = \frac{2000}{\frac{40}{100} \times \frac{100}{5} \times 5} = 50$$

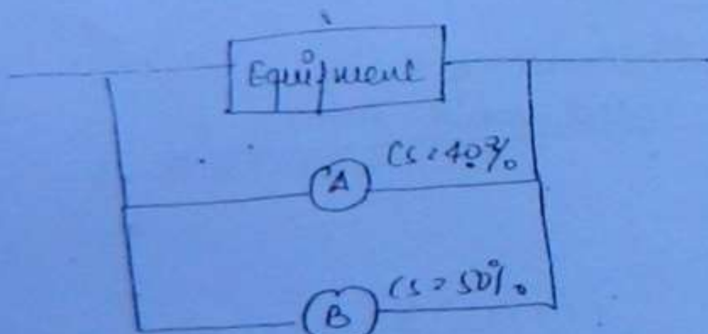
- PSM increases with fault current

- Higher the fault current lower is time of operation.

$$\boxed{\begin{array}{l} \cdot\ PSM\uparrow\ I_f\uparrow \\ \cdot\ I_f\uparrow\ PSM\uparrow\ t\downarrow \\ \cdot\ PSM\uparrow\ t\downarrow \end{array}}$$

- Higher the PSM higher the speed of disc.

- If $PSM < 1 \rightarrow$ will not operate
  $PSM = 1 \rightarrow$ wedge of operation
  $PSM > 1 \rightarrow$ Relay operates.



as # $PSM_A > PSM_B$

relay A acts like Primary relay.

As $\boxed{PSM \propto \frac{1}{CS}}$

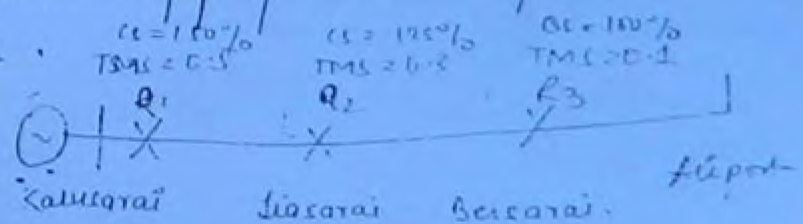
NOTE :-

- The TMS for primary relay is less than backup relay.

- Current setting for Primary and Back up relay is generally same.
- Except the protecting equipment there should not be anything common b/w primary and back-up relays.

Over Current Radial Feeder Protection

- The feature required in O/C radial feeder protection is if fault occurs at the far end from the supply we should clear the fault there itself, this leaves minimum no. of customers are given interruption and majority of customers are continued to be given void supply. This improves reliability of radial feeder.



- Methods used:

a) Time graded Method:

According to this method for the relay farthest from the source minimum TMS is set. As we are approaching towards the source the TMS is gradually increased.

- Disadvantage:

The disadvantage of this method is if the fault occurs near the source the magnitude of fault current is very high. This high magnitude fault current is ever cleared in more time

b) current graded method:-

According to this method for the relay farthest from the source minimum current setting is set, as we are approaching towards the source the over current setting is gradually increased.

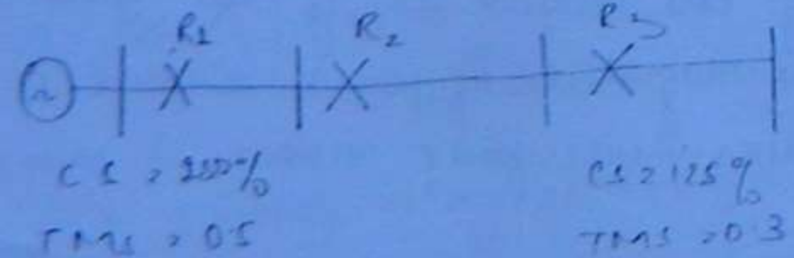
- the disadvantag is as we have only four over current setting viz 125, 150, 175 and 200%. we can make the radial four section. However by adopting time current graded method we can make the radial feeder into more no. of section of improve the reliability further.

c) time-current graded method:-

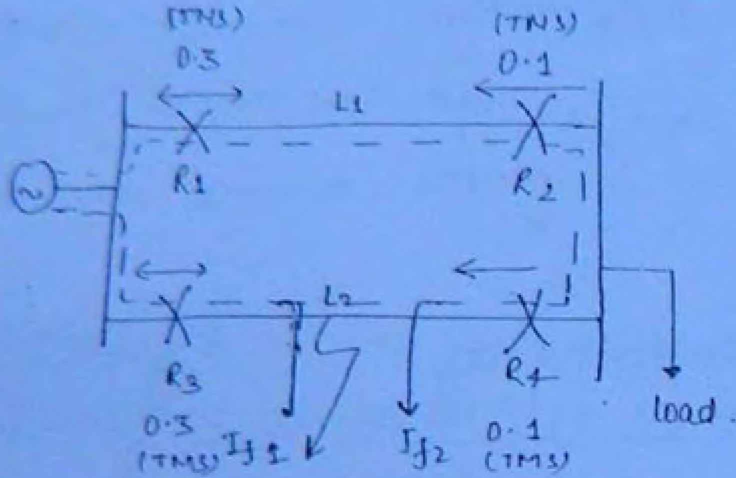
According to this method for the relay farthest from the source minimum PMS and CS are set as we are approaching towards the source these setting are gradually increased.

Example:-

the CS and TMS for relay zone



Protection Of Parallel Lines



If1 : R3

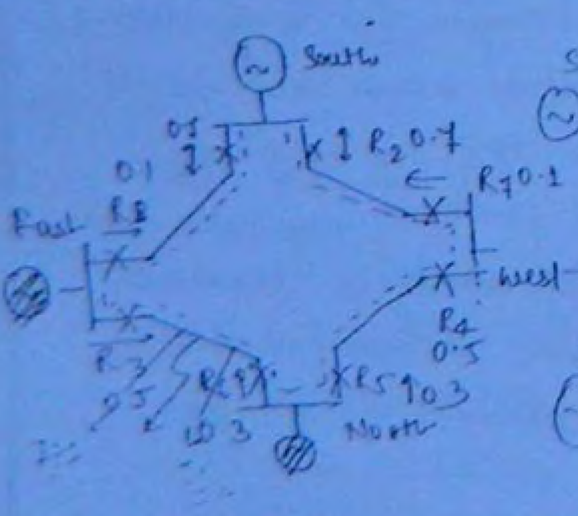
If2 : R1, R2, R4 → 0.1 → directional relay

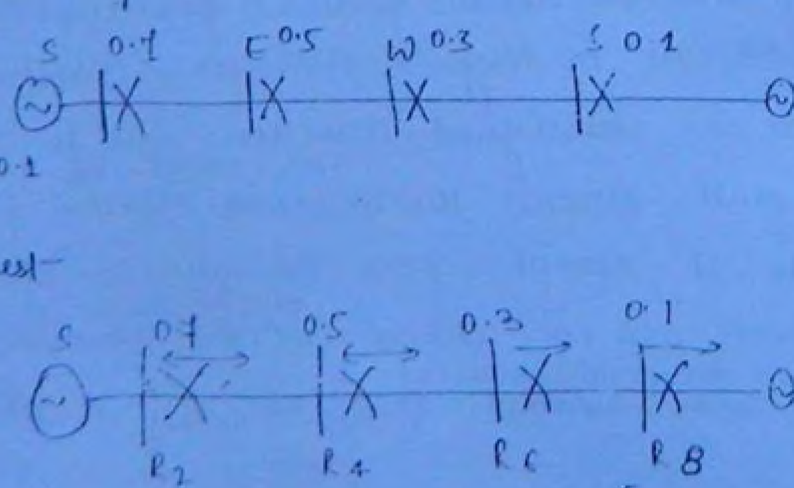
R1 → 0.3

(R4 operate first.

O/C Protection Of Ring Main Feeder.

= While providing over current protection for ring main feeder it is treated as two radial feeders.





I_{f1}: R_1 R_8 $R_3 \longrightarrow R_3$ [operate]

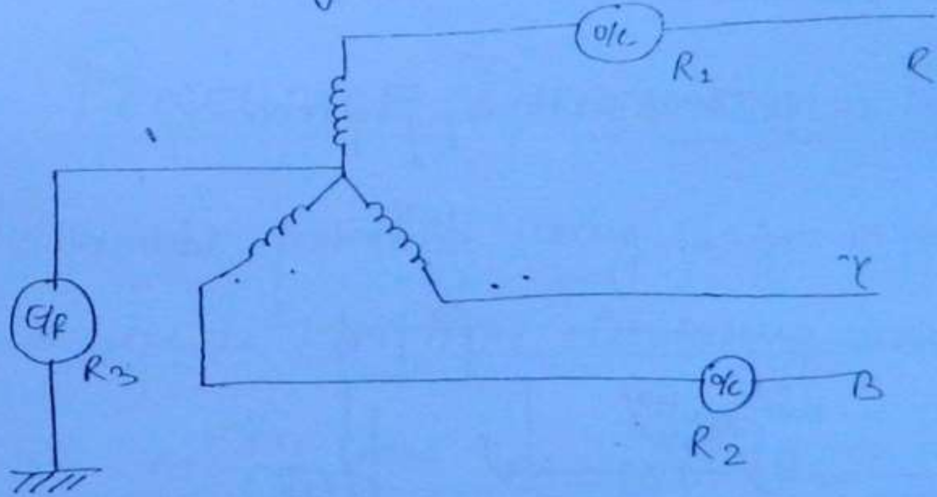
$R_1 \downarrow 0.7$ $R_3 \downarrow 0.5$ (directional)

I_{f2}: R_2 R_7 R_4 R_5 $R_6 \rightarrow R_6$ (operates

$R_2 \downarrow 0.7$

OVERCURRENT PROTECTION OF G/r

For complete over current protectn of generator two we need.
two overcurrent relay and one earth fault relay.



$R_1, R_2 \rightarrow$ phase f/t relay

$R_3 \rightarrow$ Earth fault Relay

- The R_3 is known as earth fault relay since it can detect only earth ~~falt~~ fault, in ~~adit~~ addition to earth fault this relay also ~~+~~ detects unbalanced condition therefore setting for this relay will of minimum like 20% - 40% etc

3ϕ faults $\longrightarrow$ R_1 and R_2 operates

LLG
R - Y $\rightarrow R_1, R_3$
Y - B $\longrightarrow R_2, R_3$
R - B $\longrightarrow R_1, R_2, R_3$

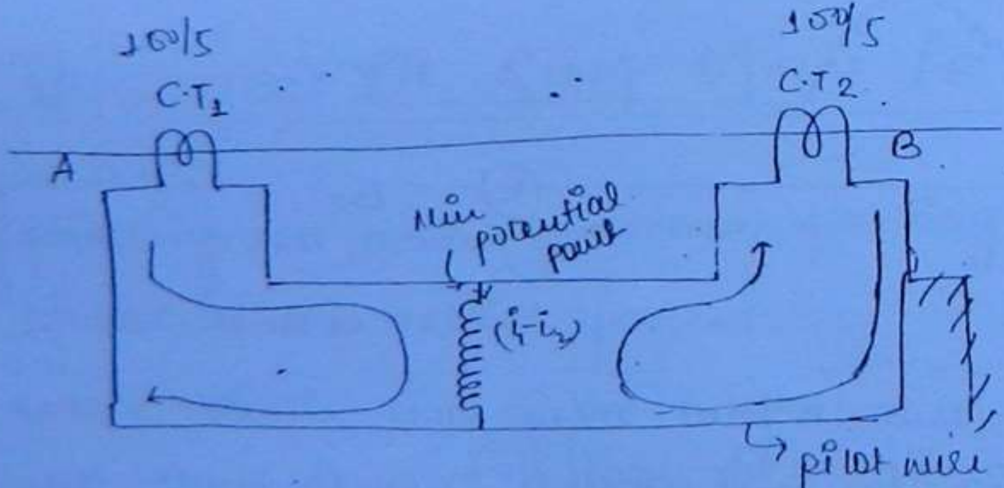
LL
- → R-Y → R_1
- → Y-B → R_2
- → R-B → R_1, R_2

[redacted]
- → R → $R_1 R_3$
- → Y → R_3
- → B → R_2, R_3

unbalanced condition → R_3

DIFFERENTIAL PROTECTION

→ Main application is to have zone of protection



→ A differential relay operates well when the difference of two same electrical quantities [i_1-i_2 or V_1-V_2 but not P_1-P_2] exceed the set of assigned value.

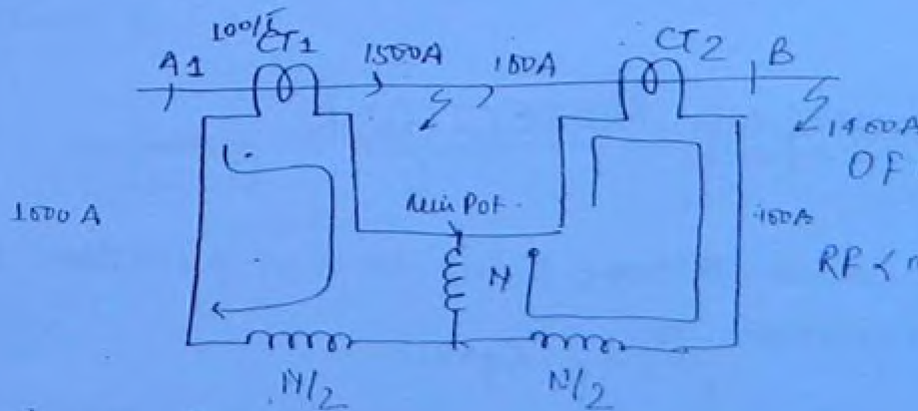
→ this relay operate only for internal fault and provide zone of protection. it cannot operate for external or through fault condition.

→ A differential protection comparing voltage is know as, Translay Protect?.

→ A differential relay may "mal operate" either due to unequal saturation level of two CTs or due to CT error. to avoid this mall operation. ordinary differentia relay is modified to percentage differential relay

PERCENTAGE DIFFERENTIAL RELAY

→ A differential protection using %age differential relay is known as Merz Price circulating current Method.



$OF \propto MMF \propto (i_1 - i_2) N$

$RF \propto MMF \propto i_1 \frac{N}{2} + i_2 \frac{N}{2}$

$\propto \left[\frac{i_1 + i_2}{2}\right] N$

$i_1 = 50;\ i_2 = 45$

$OF \propto (i_1 - i_2) N$

$RF \propto \frac{(i_1 + i_2)}{2} N$

$\propto 47.5 N$

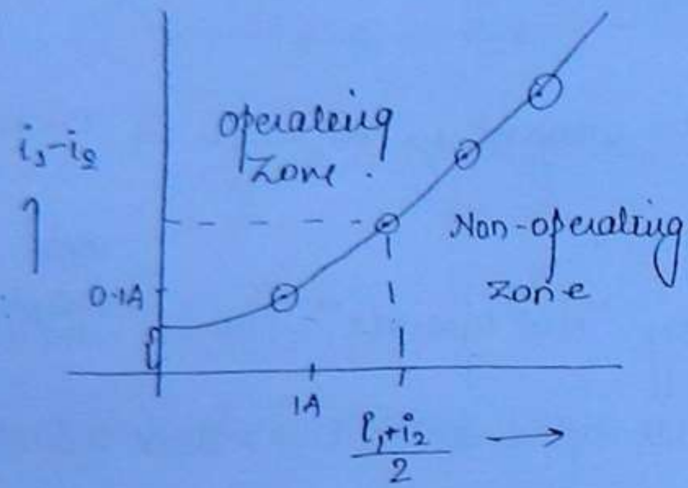
$i_1 = 50,\ i_2 = 5$

$OF \propto (50 - 5) N$

$\propto (45)$

$RF \propto (50 + 5)/2 = 27.5 N$

Characteristic:-

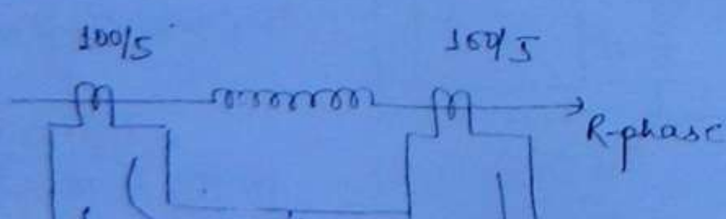


- the characteristic of differential relay starts above origin due to inertial problems.

$$\boxed{\% \text{ slope} = \frac{i_1 - i_2}{\left(\frac{i_1+i_2}{2}\right)} \times 100}$$

10% slope, means operating force is 10% of restraining force the Relay is on wedge of operation.

STATOR WINDING PROTECTION



Ques 1 : $CT_1, CT_2 \rightarrow 100/5$

$\%$ slope $= 10\%$

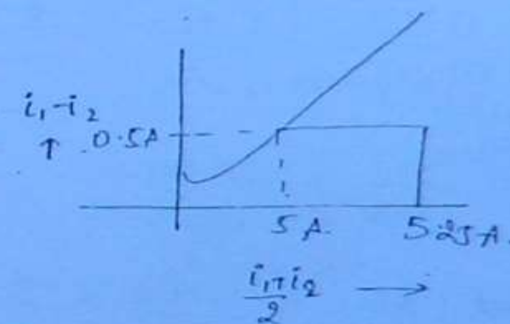
$I_f = 10A$

1) for the fault of 10A, with % slop 10, will relay opera CB or not.

1) $I_1 = 110A \Rightarrow i_1 = 110 \times \frac{5}{100} = 5.5A$

$I_2 = 100A$. $\quad i_2 = 100 \times \frac{5}{100} = 5A$.

$O.C = i_1 - i_2 = 0.5A$.



from % slope

$$\frac{i_1 - i_2}{i_1 + i_2/2} = 0.1$$

$$\frac{i_1 + i_2}{2} = \frac{0.5}{0.1} = 5$$

For an operating current of 0.5A, the restraining current at which current at which the relay is at the wedge operation is 5A.

Now ~~on finding~~ R = Original R.C $= \frac{i_1 + i_2}{2} = \frac{5.5 + 5}{2} = 5.25A$

as restraining force at 5.25A > at 5A, the relay will not operate

Ques 2

$CT_1, CT_2 = 100/5$

$\%$ slope $= 5\%$

$I_f = 10A$.

Soln

$I_1 = 110A$

$i_1 = \frac{110 \times 5}{100} = 5.5A$

$I_2 \; i_2 = \frac{100 \times 5}{100} = 5A$

$O.C = i_1 - i_2 = 0.5A$

$$\frac{i_1 - i_2}{(i_1 + i_2)/2} = 0.05$$

$$\Rightarrow \frac{0.5}{0.05} = \frac{i_1 + i_2}{2}$$

$$= \frac{.1}{.01} = 10 \text{ Amp.}$$

original RC $= \frac{i_1 + i_2}{2} = 5.25$

5.25A < as 10A so relay will operate

NOTE :-

the relay sensitivity is increasing with decreasing % slope

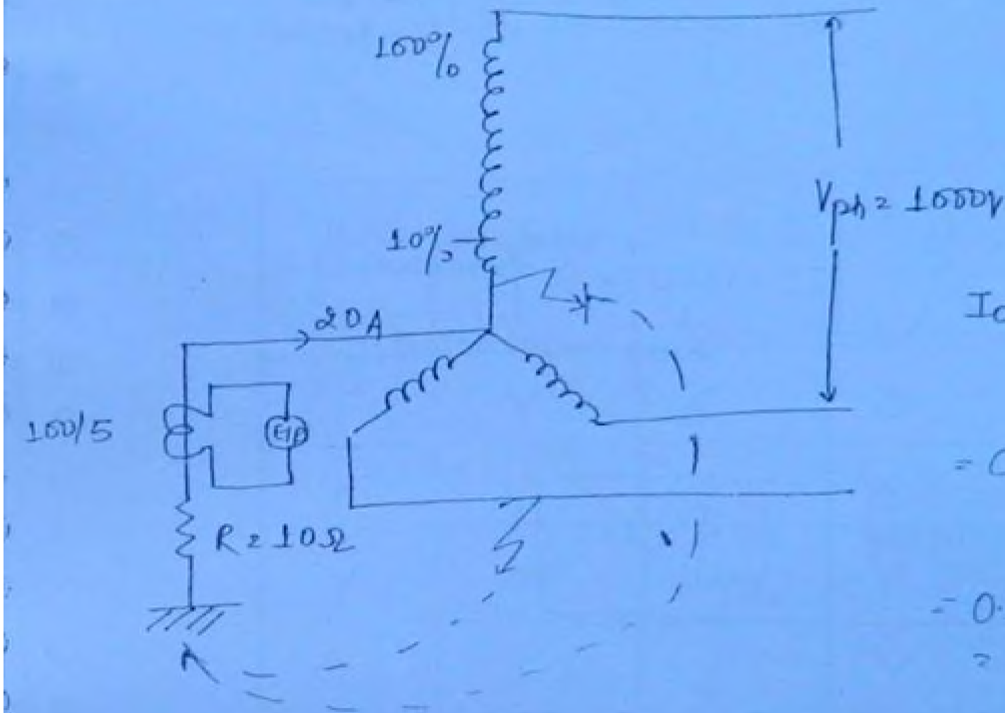
<u>PERCENTAGE WINDING PROTECTED / UNPROTECTED</u>

→ Out of 100% generator total 100% are star connected

→ 100
- → 85% LG
- → 5 LLG
- → 8 LL
- → 2.3ϕ

85% LG + 5 LLG] – 90%

→ At zero % winding 0% voltage induce and with 100% winding 100% voltage is induced.



I_o = Min picking current of relay

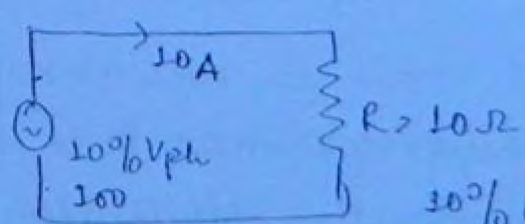
= C setting × CTS rated current × CT rat

= 0.2 × 5 × 20

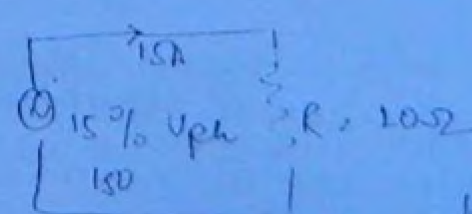
= 20A

→ To minimise most frequently occuring fault (earth), the neutral of g/r is grounded with resistance 'R'

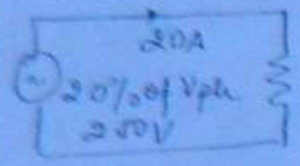
→ Generally for detecting unbalance current the current setting of earth fault relay is set to minimum say 20%



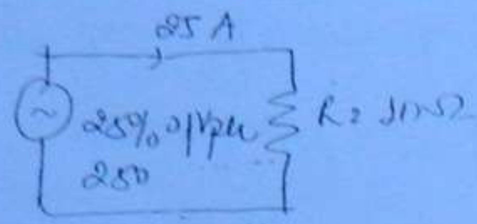
10% winding unprotected



15% winding unprotected



20% wdg unprotected



25% wdg protected

$$\boxed{I_0 = \frac{x V_{ph}}{R}}$$

where x is fraction of wdg unprotected.

$$\boxed{\% \text{ wdg } \cancel{\text{of}} \text{ unprotected} = \frac{I_0 R}{V_{ph}} \times 100}$$

DIFFERENTIAL PROTECTION OF TRANSFORMER

→ Before providing differential protectn to power transfer, there are two ~~to~~ issues to resolve.

1) How to design CT ratio in such a way that under normal operating condition the current flowing through operating coil is zero.

2) How to avoid mal operation of differential relay due to 30° phase shift b/w line currents of ~~Sta~~ star-delta and delta-star power transformer

→ To avoid the mal operation of differential relay due to 30° ratio between line currents of star-delta, delta-star power xmer, the secondaries of the CT's must be connected as per following table.

Power Transformer		CT's secondary	
LV	HV	LV	HV
Y	Y	Δ	Δ
Δ	Y	Y	Δ
Y	Δ	Δ	Y
Δ	Δ	Y	Y

Numerical:

A 8MVA, 33/11 kV, star Y-Δ power xmer is protected by merz-price circulating current method. Design the CT's ratio for a nominal CT-secondary current of 5Amp

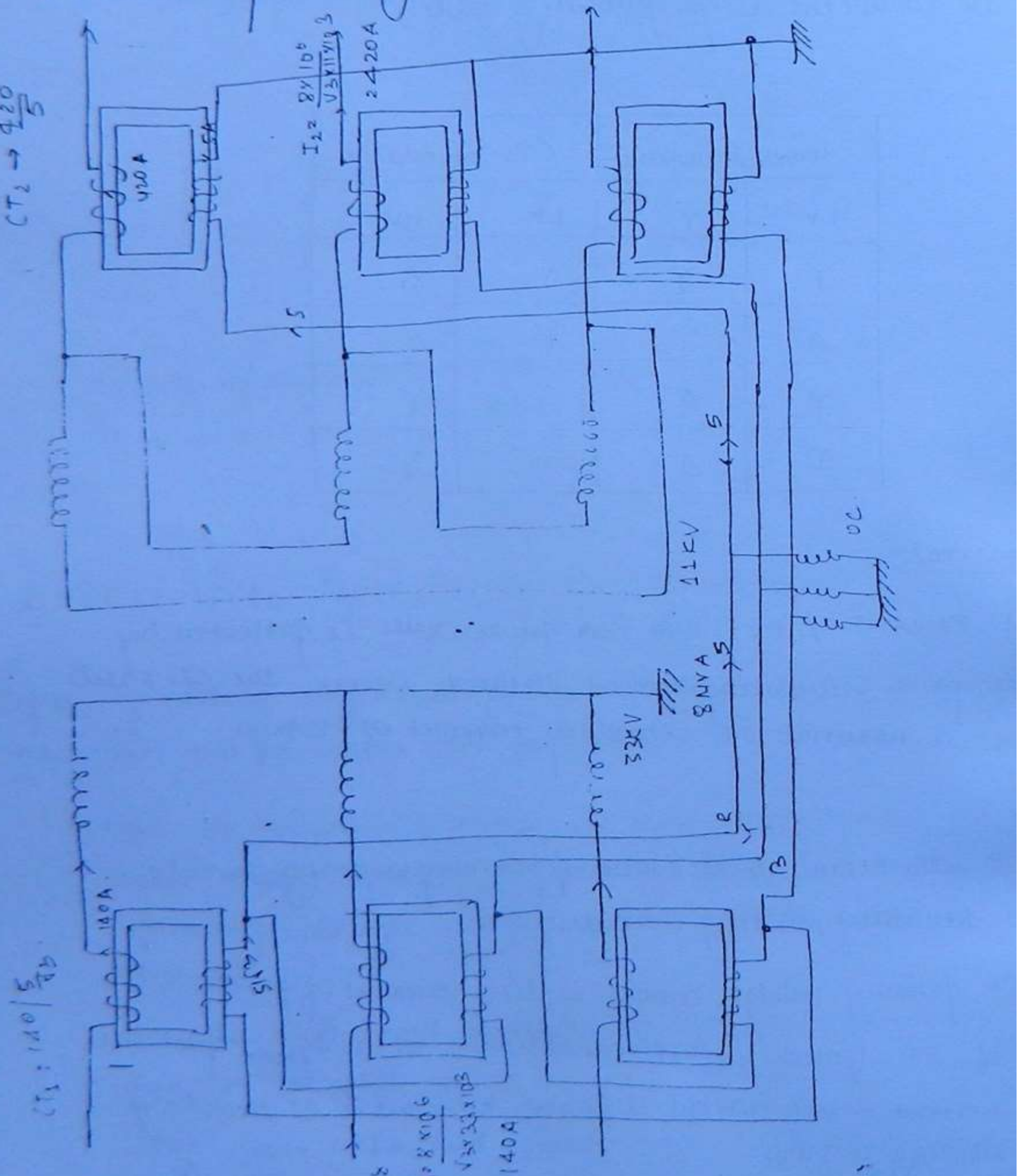
Sol:

1) CT ratio means it is a ratio of primary winding current to secondary winding current

2) CT primary winding current = line current of power xmer

3) If CT secondaries are connected in Y then pilot wire current = line current = phase current = CT secondary winding current.

4) If CT secondaries are connected in delta then pilot wire current is equal line current = $\sqrt{3}$ phase current = $\sqrt{3}$ secondary winding current



DISTANCE PROTECTION

→ can not be used for xmer protectⁿ.

→ can be used for generator and Transmission line protectⁿ

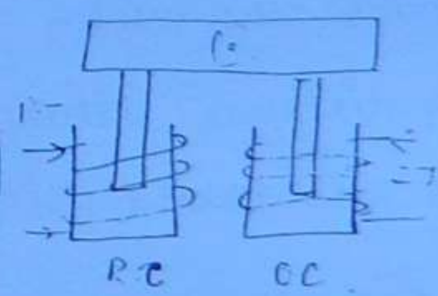
→ Main application is protectⁿ of T.L

→ used as primary protection for long lines.

→ In this type of relay operating force is produced due to CT secondary and restraining force is produced due to PT secondary.

→ Know as Double actuating quantity relay.

→ If induction type relay are used



$$\boxed{\begin{array}{l}\text{operating force} \propto I^2 \Rightarrow OF = K_1 I^2 \\ \text{Restraining force} \propto RF = K_2 V^2\end{array}}$$

→ Relay will operate when

$$RF < OF$$

$$K_2 V^2 < K_1 V^2$$

$$\frac{V^2}{I^2} < \frac{K_1}{K_2}$$

$$\boxed{\frac{V}{I} < \sqrt{\frac{K_1}{K_2}}}$$

→ The relay is operating when ratio of voltage to current seen by the relay is less than some set or designed value., K_1, K_2 are designed constant.

This relay is known as Ratio relay as well as impedence relay. [∵ V/I = Impedence]

→ As impedence and distance are proportional quantities is relay is also known as distance relay.

→ **REACH :-** It is the distance at which a distance relay is at the wedge of operation.

→ A distance relay operate for all the faults occuring below the reach.

→ A distance relay has a problem of under reach or over reach due to dc offset current.

Dated
14 Nov 2010

DEFINITE DISTANCE, DEFINITE TIME DISTANCE PROTECTION

(3-zone of Protection)

1st disc – $Z < 8\Omega$

→ Instantaneously

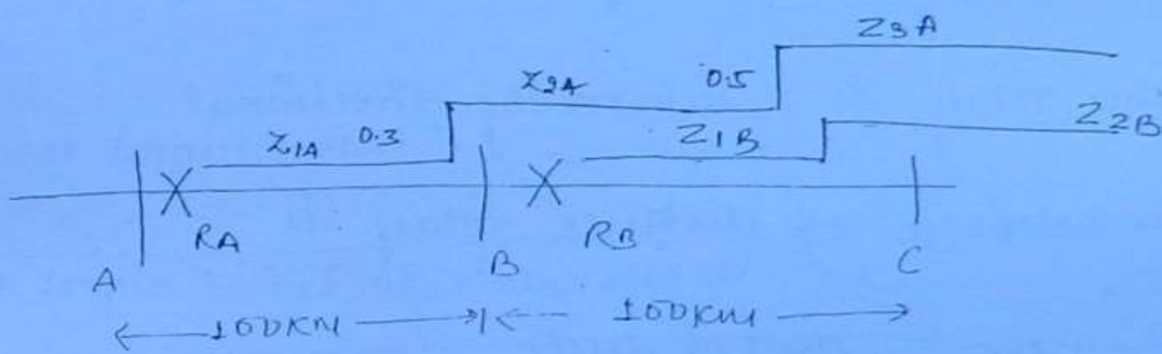
2nd disc – $Z < 15\Omega$ $t > 0.3$ sec

• exclusively Z ~~buses~~ values at which exclusive 2nd disc alone operate at 8-15Ω.

• 3rd disc — $Z < 20\Omega$ $t = 0.05$ sec

exclusive Z values at which 3rd disc alone operates 15-20Ω.

Example:



Relay - A has 3 zones

Z_{1A} : 80% distance of section

Z_{2A} : 20% remain distance of section AB + 50% distance of adjacent section BC

Z_{3A} : Remaining 50% distance of adjacent section BC

Comments:

1) Distance relay are 3 types

1) Impedence Relay
2) Reactance Relay
3) Admittance / Mho relay

2) An impedance relay is a voltage restrained over current relay.

3) The reactance relay is directional restrained over current relay.

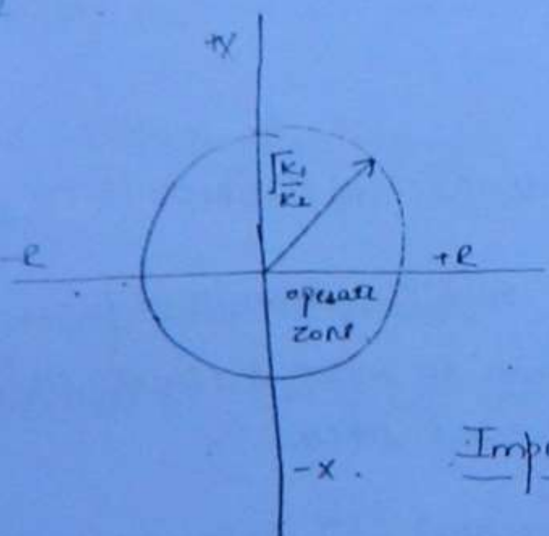
4) The MHO relay is voltage restrained directional relay

5) A MHO relay is inherently directional

→ The characteristic of distance relay is

$c^2 = a^2 + b^2$ — eqn of circle

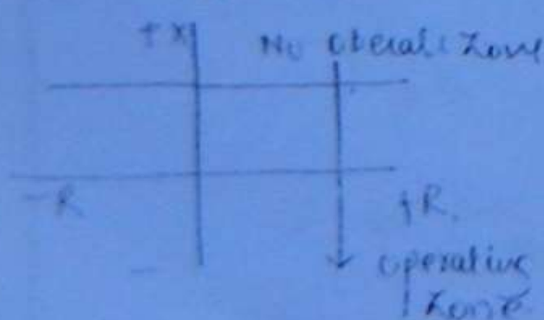
$Z^2 = R^2 + X^2$



A circle having origin as center

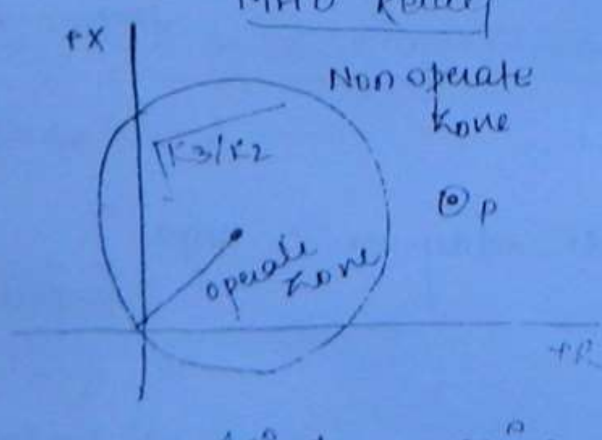
Impedance Relay

→ X-relay

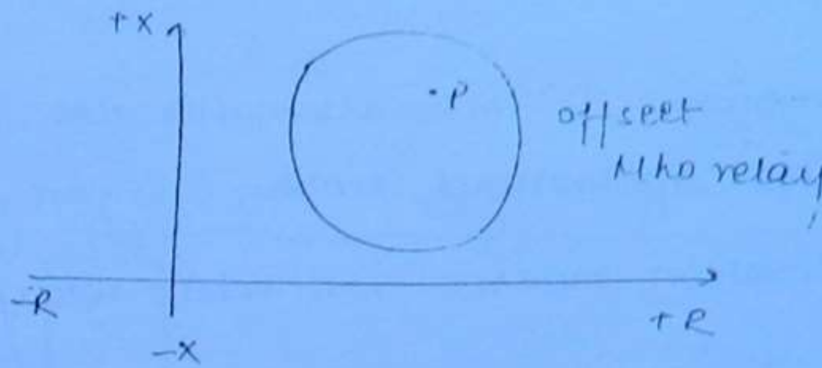


A straight line parallel to real axis

MHO Relay



A circle passing through origin



Universal torque equatⁿ:

$$\boxed{\text{Net torque } T = K_1 I^2 + K_2 V^2 + K_3 V I \cos(\theta - \tau) + K_4}$$

- Over current → $T = K_1 I^2 - K_4$
- Overvoltage → $T = K_2 V^2 - K_4$

7). For earth fault ~~zero~~ reactance relay are normally used.

8). For phase faults.

Short line → X - relay

Medium line → Z - relay

Long line → Mho relay

9). Where the power swings are high Mho relay is used.

10) For ~~some~~ over load protectⁿ of G/r thermal relays are used

11) For severe unbalance condition of alternator negative.

sequence relay is used ~~as~~

2) when prime mover/turbine is lost alternator acts like ~~induction generator~~ synchronous motor.

for this problem direction reverse wattmetric relay is relay is used.

3). when the excitation is lost alternator acts as ~~synchronous motor~~ induction G/r. for this problem offset mho relay is used.

4) for ~~in-tur~~ inter-turn fault differential ~~fault~~ protection can not be used. for this problem split-phase relay is used.

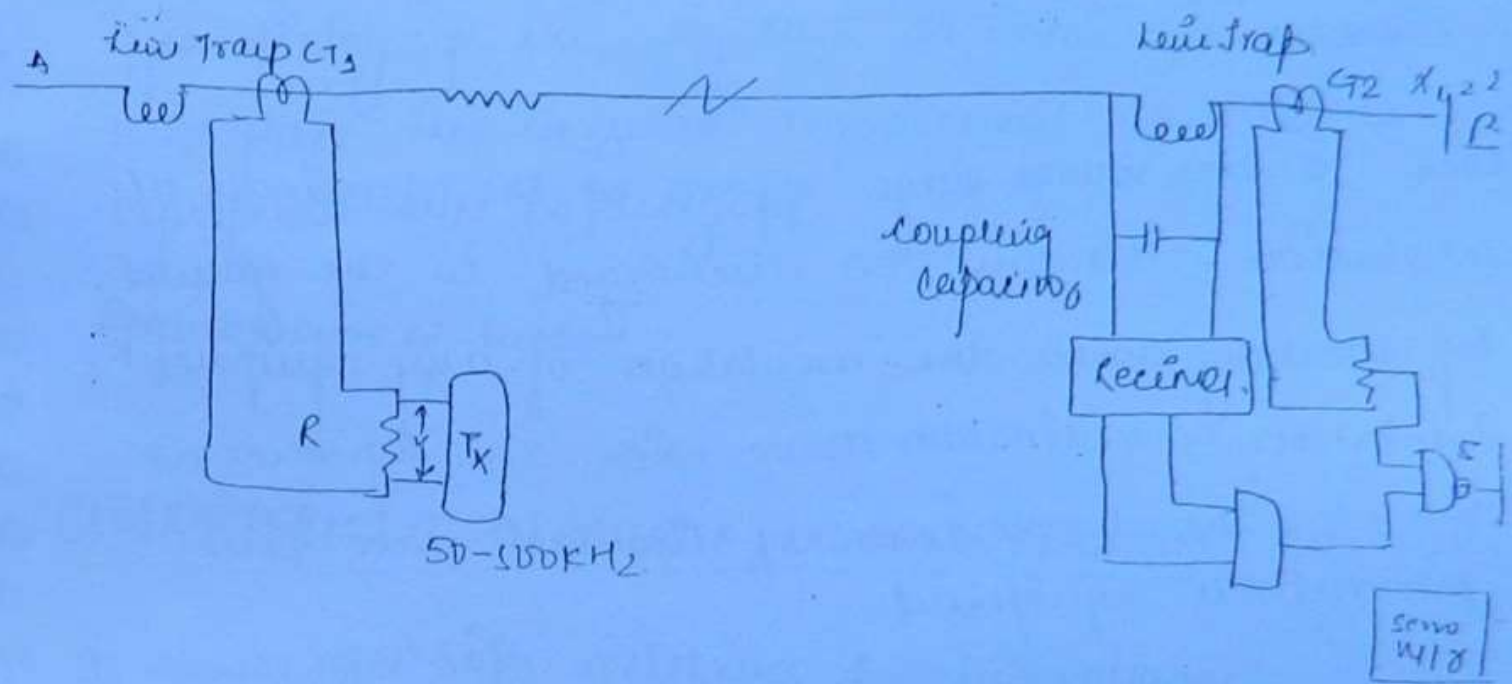
5). for stator winding protectn differential protectn is used.

16). A differential protection comparing voltages is known as translay relay.

17). to avoid the 'mal operation' of relays due to initial inrush currents of 2nd harmonic restrain relay is used..

18) Pilot wire relaying is not economical for the protection of long line. for such line differential protectn is provided using carrier communicatn scheme.

#



→ The frequency of ~~carry~~ carrier signal will be in range 50 X 500 KHz and some time it may go to GHz depending upon distance of T.L

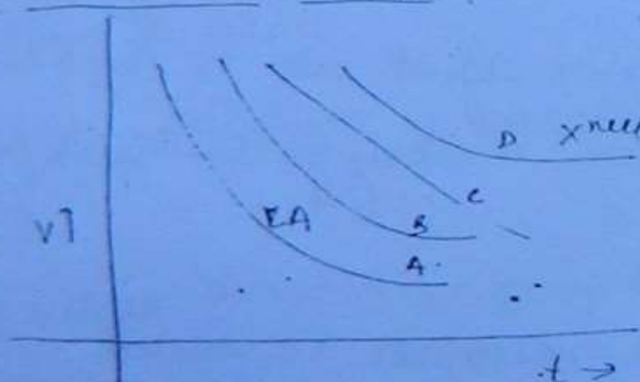
→ A line or wave trap is a resonate LC circuit, shall be resonate for carrier frequency and bi-passes 50Hz signal. In other words they offer high resistance for carrier signal and low resistance for 50 Hz

→ A coupling capacitor blocks the 50Hz signal and transmits the carrier signal

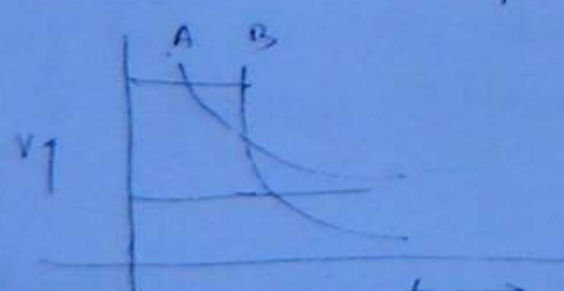
INSULATION CONDITION Co-ordination.

- When a over voltage surge appears on the terminals of substation this can be discharged to the ground. by breaking down the insulation of any equipment. Insulation co-ordination deals with the sequence at which the breakdown of insulatn take place in various equipment.

Breakdown characteristic:



- For proper insulation coordinatn of lighting arrestor must be found below than any other equipment breakdown characteristic and the breakdown characteristic of most important equipment should be place above all other equipment.



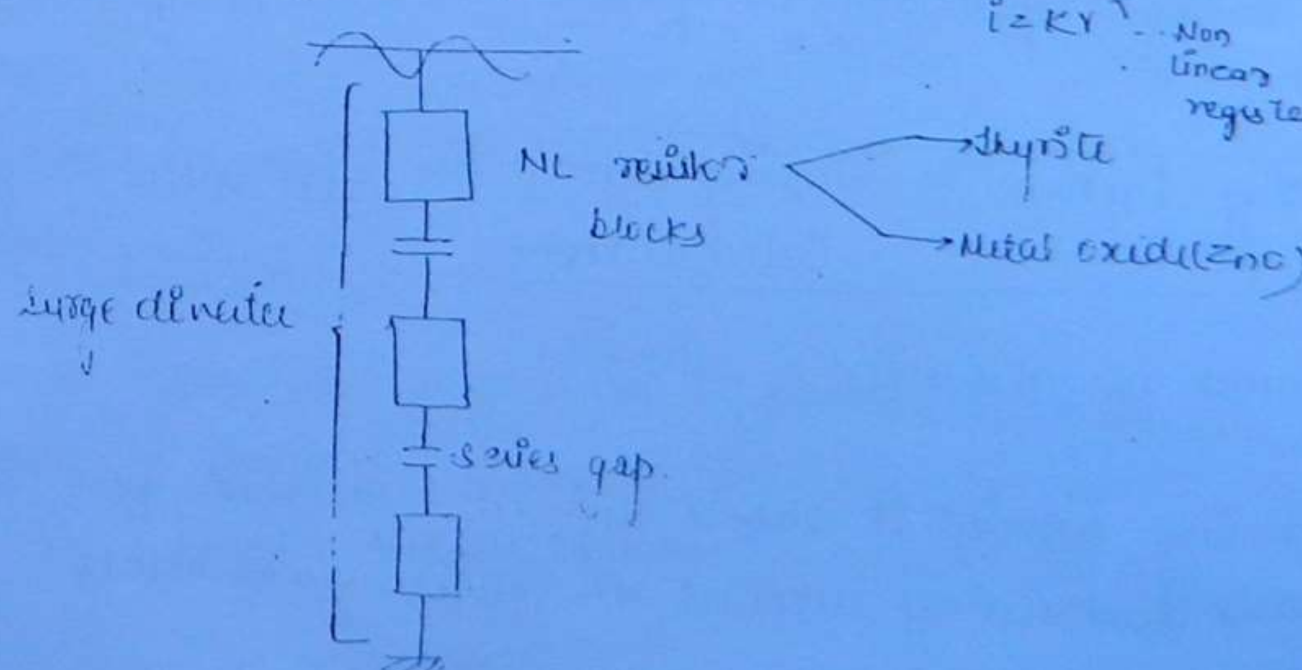
- For proper insulation co-ordinat^n, the breakdown charac. should not cut and over lap each other.

- After fixing up the sequence at which breakdown take place. the insulatⁿ requirement for various equipment will be designed.

~~Requirements of surge~~

CHARACTERISTIC OF SURGE DIVERTOR / LIGHTING ARESTOR

1) It should offer high resistance for low voltages
2) It should offer low resistance for high voltage.
3) Arcing should not be not be continued due to power frequency follow currents.



Types of Lighting arrestors:-

Lighting Arrestor

Station type	Line type	Distribution type
V: 3-512KV	V: 20 to 73KV	V: 8 to 15KV
I > 100KA	I: 65-100KA	I< 65KA

- These voltages are ~~3~~ phase voltages of switching voltage.
- In decending order of cost of fused material the various fused material are Platinum, gold, silver, copper, Aluminium, Tin, lead.
- For current upto 10A Tin fuse, above 10A Copper fuses are used.
- $\boxed{\text{Fusing factor} = \dfrac{\text{Fusing Current}}{\text{Rated current}}}$, this value should be around 2.
- fusing current is rated current at which fuse melt and ~~curr~~ cut-off current actual current at which fuse melts.
- Fuse should low melting point temp.

• A fuse protect equipment from prospective current.

ECONOMIC SCHEDULING

• the problem of economic scheduling first begin with unit commitment. A unit commitment problem suggest the schedule of the unit must be kept on or off. unit commitment problem is more complex because of variety of constraint present in the problem. ~~by~~ following the schedule, the economic scheduling problem allocate the load among the unit in service in such a way the total cost of generation is minimum.

• Optimum power flow ~~pto~~ problem is similar to economic scheduling problem. The only difference is OPF is very complex ~~during~~ due concentration of large variety of constraints.

Dated
15 Nov 2010

Economic scheduling Problem :-

→ is an optimization problem.

→ objective function

$$\min\left[C_T(P)\right] = \min\left[\sum_{i=1}^{n} C_i(P_i)\right]$$

→ Subject to the satisfaction of equation equality/ inequality constraint.

Constraint

Equality

1) Load flow solution must be obtained

2) $\sum P_i - P_D = 0$

--- without losses

$\sum P_i - P_D - P_{loss} = 0$

--- with loss

Inequality

1) Generator power limits

$P_{i\,min} \le P_i \le P_{i(max)}$

2) Transformer tap setting

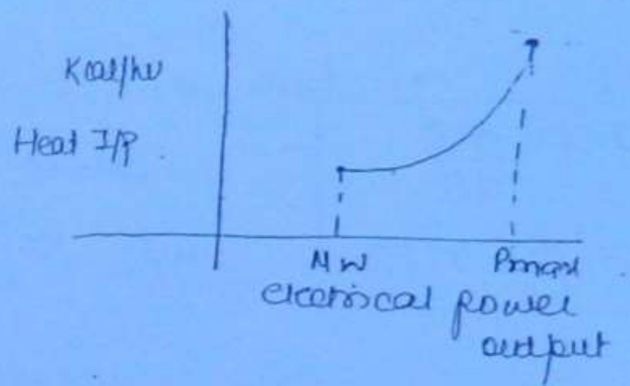
$t_{min} \le t \le t_{max}$

(3) voltage limits.

(4) T.L thermal capabilities

CHARACTERISTIC OF THERMAL UNIT

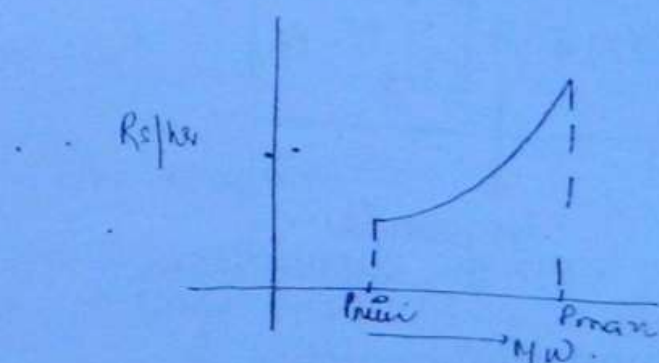
1) HEAT CURVE :



- slope of this graph is known as "Heat rate"

$$\boxed{\text{slope} = \text{Heat rate} = \frac{dF_i}{dP_i}}$$

2) COST CURVE :-



— using the parabolic eqn, the equatn of cost curve is

$$\boxed{C_i = \alpha_i + \beta_i P_i + \gamma_i P_i^2}$$

$\alpha_i, \beta_i, \gamma_i$ - - - cost coefficient of ith M/C

for $i = 1, 2, \ldots n$.

- The slope of this curve is known as "Incremental cost of production (IC).

$$\boxed{\text{slope} = IC_i = \frac{dC_i}{dP_i} = \beta_i + \gamma_i P_i .}$$ unit Rs/MWh

Economic scheduling Problem by neglecting losses:

(Method of Lagrangian)

- we define Lagrangian funcⁿ as

$$\boxed{L = \sum_{i=1}^{n} C_i(P_i) - \lambda \left[\sum_{i=1}^{n} P_i - P_D \right]}$$

Lagrangian Multiplier.

- for objective function minimization

$$\frac{dL}{dP_i} = 0 \quad i = 1, 2, \ldots n.$$

$$\frac{dL}{dP_i} = \frac{dC_i}{dP_i} - \lambda [1] = 0$$

condition of cost minization is

$$\frac{dC}{dP} \quad \boxed{\frac{dC_1}{dP_1} = \frac{dC_2}{dP_2} - - - - - = \frac{dC_n}{dP_n} = \lambda}$$ coordinate eq^n

- The unit of $\lambda \rightarrow$ Rs/MWh, and it is also known as cost of recieved power.

Algorithm :-

1. Start with $\lambda = \lambda^0$

2. $P_D = P_1 + P_2 + - - - P_n$

3. Solve for using

$$\frac{dC_i}{dP_i} = \lambda^0 = \beta_i + \gamma_i P_i$$
for $i = 1, 2, - - - n$

3. Check $\left| \sum_{i=1}^{n} P_i - P_D \right| \le \epsilon$ $\quad \epsilon$ = error

Give solution

If $\sum P_i - P_D \rightarrow$ large negative (demand more, it less) ...... increase λ

On $\sum P_i - P_D \rightarrow$ large position (gen more demand less) - - decrease λ.

4. Repeat problem

- In the iteration process if any unit violates the limit then set the generation of that unit as $P_i = P_{min}$ or

$P_i = P_{i(max)}$ at the remaining load $P_D - P_i$ is optimally allocated in the remaining $(n-1)$ units (generating).

Numerical:

Increment cost of production in rupees Rs/MWh for a plant consisting of two unit

$$IC_1 = \frac{dC_1}{dP_1} = 0.2P_1 + 40 \quad \cdots (1)$$

$$IC_2 = \frac{dC_2}{dP_2} = 0.25P_2 + 30 \quad \cdots (2)$$

1
56
0.2
172

Assume both the unit in operation vary, a total load varies from 40 to 250MW

$P_D = 40 \rightarrow 250MW$
P_i min $= 20MW$
$P_{i(max)} = 125 MW$ for $i = 1, 2$

Solution:

How will the load is shared b/w 2 unit when the load varies from 40MW to 250MW.

1) $P_D = 40MW$

Let $P_1 = P_2 = 20MW$

$IC_1 = 0.2 \times 40 + 40$
$= 44$ Rs/MWh

$IC_2 = 0.25 \times 20 + 30$
$= 35$ Rs/MWh

P_1	P_2	P_D'	Plant λ
—	40MW2	40W	—
—	60MW	60MW	—
20MW	56MW	76MW	44.
33.33	66.66	100	46.6
61.33	88.88	150	52.2
88.89	111.11	200	57.7
106.95	125MW	245	61.25

→ Begining of economic stability

→ Economic ... [illegible]

- For minimum load we start Plant 2

- When a minimum load of 20MW

$IC_1 = 44$ Rs/MWh for what load of

P_2 $IC_2 = 44$ Rs/MWh

$44 = 0.25 \times P_2 + 30$

$P_2 = 56$ MW

120	125	245	—
125	125	250	—

3) $P_D = 150$ MW

i.e $P_1 + P_2 = 150$ MW.

$\longrightarrow IC_1 = IC_2$

so $0.2P_1 - 0.25P_2 = -10$.

$P_1 = 83.33$ MW

$P_2 = 66.66$ MW.

* When any plant reaches 125 MW the economic count stops.

With 125 MW

$IC_1 = 0.2 \times 125 + 40 = $ Rs 65/MWh

$IC_2 = 0.25 \times 125 + 30 = $ Rs 61.25/MWh

Question:-

The incremental generating cost of two generating unit are given by

$IC_1 = 0.1x + 20$

$IC_2 = 0.15y + 18$ Rs/MWh.

For a total load demand of 300 MW the value

value of x and y?

$$x+y = 300$$

$$\cancel{0.1x + 20 +}$$

$$0.1x - 0.15y = -2$$

$$x = 172 MW \quad y = 128 MW.$$

The incremental cost of production of ~~two~~ 3 units are.

$$IC_1 = 0.00284 P_1 + 7.2$$

$$IC_2 = 0.00388 P_2 + 7.85$$

$$IC_3 = 0.00964 P_3 + 7.97$$

Find optimum scheduling for total load of 850MW.

$$\text{Sol.} \; P_1 + P_2 + P_3 = 850 \quad - (1)$$

$$IC_2 = IC_2$$

$$IC_3 = IC_1$$

$$0.00284 P_1 + 7.2 = 0.00388 P_2 + 7.85$$

$$\frac{0.00284 P_1 + 7.2 - 7.85}{0.00388} = P_2$$

$$\frac{0.00284 P_1 + 7.2 - 7.97}{0.00964} = P_3$$

$$P_1 + (0.731 P_1 - 167.52) + (0.294 P_1 - 79.875) = 850$$

$\Rightarrow$

$P_1 = 541.92\,MW$.

$P_2 = 228.62\,MW$

$P_3 = 794.4\,MW$

Economic ~~sorra~~ Solution (considering the losses)

- objective function

$$\min\left(\sum_{i=1}^{n} C_i \cdot P_i\right).$$

- subject to

$$\sum_{i=1}^{n} P_i - P_D - P_{loss} = 0$$

Lagrangian fn. is defined as

$$L = \sum_{i=1}^{n} C_i(P_i) - \lambda\left[\sum_{i=1}^{n} P_i - P_D - P_{loss}\right]$$

objective function is minimised when

$$\frac{dL}{dP_i} = 0 \Rightarrow \frac{dL_i}{dP_i} - \lambda\left[1 - \frac{dP_{loss}}{dP_i}\right]$$

Let $\frac{dP_{loss}}{dP_i}$ = Incremental T.L losses

Penality factor $L_i = \frac{1}{1 - \frac{\partial P_{loss}}{\partial P_i}}$ for $i = 1, 2 \ldots n$.

then

$$\boxed{L_i \frac{dC_1}{dP_1} = L_2 \frac{dC_2}{dP_2} = \cdots = L_n \frac{dC_n}{dP_n} = \lambda}$$

-- co-ordinate equatn

Penality factor of i^{th} M/C is

$$L_i = \frac{1}{1 - \frac{\partial P_{loss}}{\partial P_i}}$$

the loss equation for a two plant system is

$$P_{loss} = \sum_{m=1}^{n} \sum_{n=1}^{n} B_{mn} P_m P_n$$

where $P_m, P_n \rightarrow$ generation of two units

$B_{mn}, B_{nm} \rightarrow$ loss co-efficients

→ let $m=1$

$n=1$ $P_{loss} = B_{11} P_1 P_1$

$= B_{11} P_1^2$

$n=2$ $P_{loss} = B_{12} P_1 P_2$

$m=2$

$n=1$ $P_{loss} = B_{12} P_2 P_2$

$= B_{22} P_2^2$

total loss $\boxed{P_{loss} = B_{11} P_1^2 + 2 B_{12} P_1 P_2 + B_{22} P_2^2}$

$$\boxed{B_{12} = B_{21}}$$

Case 1: Load connect near plant 1:

load.

$$P_{loss} = B_{22} P_2^2$$

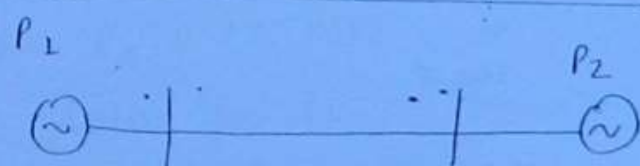
$$B_1 = B_{12} = B_{21} = 0$$

Penality factor L_1

$$L_1 = \frac{1}{1 - \frac{\partial P_{loss}}{\partial P_1}} = \frac{1}{1-0} = 1$$

$$L_2 = \frac{1}{1 - \frac{\partial P_{loss}}{\partial P_2}} = \frac{1}{1 - 2B_{22}P_2} > 1$$

Case 2: Load connected near plant 2



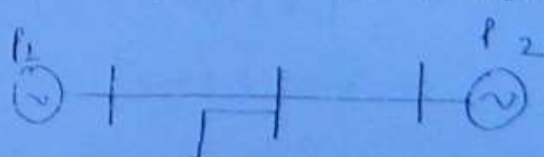
$$P_{loss} = B_{11} P_1^2$$

$$B_{22} = B_{21} = B_{21} = 0$$

$$L_1 = \frac{1}{1 - 2B_{11}P_1} > 1$$

$$L_2 = \frac{1}{1-0} = 1$$

Case 3. Load connected near both loads. Plants



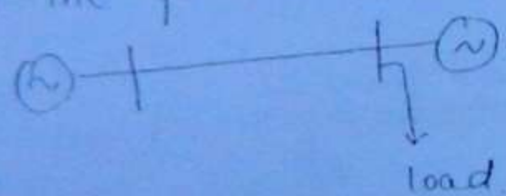
$$P_{loss} = B_{11}P_1^2 + 2B_{12}P_1P_2 + B_{22}P_2^2$$

$$L_1 = \frac{1}{1-\frac{\partial P_{loss}}{\partial P_1}} = \frac{1}{1-(2B_{11}P_1+2B_{12}P_2)} > 1$$

$$L_2 = \frac{1}{1-\frac{\partial P_{loss}}{\partial P_2}} = \frac{1}{1-(2B_{22}P_2+2B_{12}P_2)} > 1$$

Numerical

A two bus sys is shown in figure, if 100MW power is transfer plant 1 to load. a 100 transmission loss 10MW is occured. Find the required g/r^n for each plant and the power reached by the load when sys λ is 25Rs/MWh.



P

$IC_1 = 0.02P_1 + 16\ Rs/MWh$

$IC_2 = 0.04P_2 + 20\ Rs/MWh$

Soln

$$P_{loss} = B_{11}P_1^2$$

$$10MW = B_{11} \times 100^2\ MW$$

$$B_{11} = \frac{10}{100\times100}$$

$$= 0.001\ MW^{-1}$$

$$P_{loss} = 0.001P_1^2$$

$$L_1 = \frac{1}{1-\frac{\partial P_{loss}}{\partial P_1}} = \frac{1}{1-0.002P_1} \quad -(1)$$

$$L_2 = \frac{1}{1-0} = 1 \quad - - . (2)$$

coordinate eqn.

$$L\frac{dC_1}{\partial P_1} = \lambda \quad - \cdot \cdot \cdot (3).$$

$$= \frac{1}{1-0.002P_1} \times (0.02P_1 + 16) = 25$$

$$L_2 \frac{\partial C_2}{\partial P_2} = \lambda.$$

$= 0.04P_2 + 20 = 25$ Rs/MWh

$0.04P_2 = 5$ Rs/MWh

solving P_2 $P_2 = 125$ MW

Solve for P_1

$P_1 = 128.5$ MW

$P_{loss} = 0.001 P_1^2$.

$= 0.001 \times 128.5^2$

~~solving $P_1 = P_2$~~

$P_D = P_1 - P_2 - P_{loss}$

$= 237.04$ MW

Given the incremental production cost of two unit

$IC_1 = P_1 + 85$ Rs/MWh

$IC_2 = 1.2P_2 + 72$ Rs/MWh

Given the B matrix.

$$B = \begin{bmatrix} 0.015 & -0.001 \\ -0.001 & 0.02 \end{bmatrix}$$

for $\lambda = 150$ Rs/MWh

find P_1, P_2, P_{loss}, P_D

Soln

$$P_{loss} = 0.015 P_1^2 - 2 \times 0.001 P_1 P_2 + 0.02 \cancel{B_{22}} P_2.$$

Ans

$P_1 = 12.4$ MW

P_2 11.3 MW

$P_{loss} = 4.64$ MW

$P_D = 19.88$

$$\frac{\partial P_{loss}}{\partial P_1} = 0.03 P_1 - 0.002 P_2$$

$$\frac{\partial P_{loss}}{\partial P_2} = -0.002 P_1 + 0.04 P_2$$

$$L_1 = \frac{1}{1 - \frac{\partial P_{loss}}{\partial P_1}} = \frac{1}{1 - 0.03 P_1 - 0.02 P_2}$$

1.5

0.03

$$L_1 \frac{\partial C_1}{\partial P_1} = L_2 \frac{\partial C_2}{\partial P_2} =$$

$$\frac{1}{1 - 0.03P_1 + 0.002P_2} \times (P_1 + 85) = 150.$$

&

$$\frac{1}{1 + 0.02P_1 - 0.04P_2} \times (1.2P_2 + 72) = 150.$$

Power System Stability

→ power of any m/c $\propto D^2 L n_s$ where $D \rightarrow$ diameter
$L \rightarrow$ length of shaft
$n_s \rightarrow$ speed.

- power s/m stability refers to the ability of ~~power s/m~~ machines working in power s/m to maintain synchronism after the disturbance.
- whenever there is imbalance the mechanical input and electrical power output the rotor of alternator may ~~acce~~ accelerate or deaccelerate. If all the machine are accelerating or deaccelerating at the same rate then they form a co-herent group. Coherent group of machines will not give a problem of synchronism. Practically ~~going~~ Owing to the differences in inertias, size and rating the machines can not form a co-herent group.

- If the synchronism is lost there will be wild fluctuations in voltage and currents. That may lead to tripping of machine and collapse of the machine.

- Power system stability problem is also known as angular stability problem, is occurring mainly due to generator dynamics

- Volatage stability problem is due to load dynamics whereas angular ~~stang~~ stability problem is due to generator dynamics

FORMS OF STABILITY

- Small signal stability
  - → the amplitude of disturbance is small and occur for long duration
  - → Non-linearity are ignored
  - Steady state stability
  - Dynamic stability

- Large signal Transient stability
  - → the amplitude of disturbance is quite large and occur sudden
  - ex Loss of major load, 400 KV lines tripping, sudden increase in mech I/P, short ckt.

→ Steady state stability
- The action of control s/m (AVR) exciter d.c. are not included
- Pessimistic Result
→ Dynamic stability
- The control s/m components are considered
- Optimistic Results.

→ Non-linearity are considered and they play vital role in the st
→ Study is completed in 1sec
→ The action of AVR, exciter are not included since these are slow acting devices

Steady state stability	Dynamic stability	Transient stability
—	• study period is from several min to hours	• study period < 1sec

NOTE :

Dynamic study is evaluated by developing the matrices $\boxed{\dot{x} = Ax + Bu}$, where [A] is s/m matrix, after developing the system matrix A we find the eigen values of A. For s/m to be stable the values must be found on left hand side of the scale. Various types of stabalizer and controllers are designed to maintain stability. As these stabalizers used the linearized ~~s/m~~ power s/m model their effectiveness for transient stability problem is less

STABILITY LIMIT :-

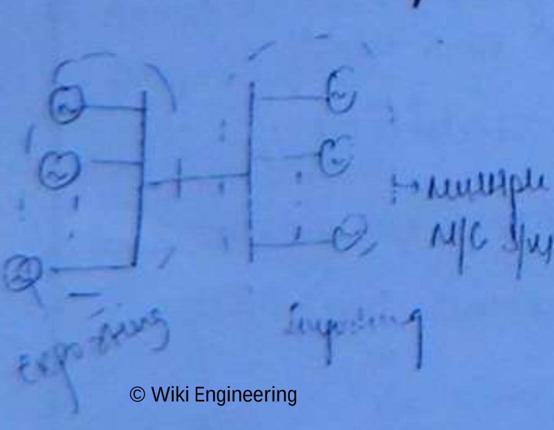
- ~~Sensitivity~~ . The amount of power that will be transfered to the point of disturbance to maintain the stability is known as stability limit.
- Compare Dynamic stability limit is highest and Transient stability limit is lowest.
- Transient stability limit can be improved up to steady state stability limit but beyond this is not possible.

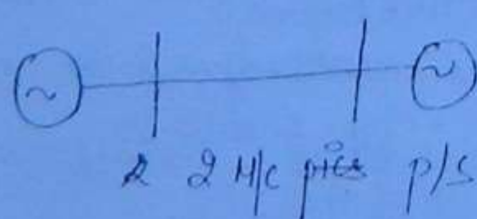
Q. system highest steady stability limit is garanteed for high transient stability ?

- No, because system non-linearity play a vital roles.

[A s/m with high transient stability gaurantees the high steady state stability]

MODELLING ISSUES





If an alternator is connected to Induction M/r, Sym ~~must~~ may become unstable, but stability (synchronism) is never lost, However if an alternator is connected to synchronous M/r, system may become unstable or it may loss the stability (Synchronism)

A two M/c system are is further reduced to a single M/c a single machine connected to infinite bus system. In such SMIP sym., if the disturbance is present it effects only generated dynamics.

SWING EQUATION

- this equation describes Rotor dynamics of synchronous M/C
- whenever there is an imbalance bt mech. input to electrical power output, the rotor of alternator either accelerate or deaccelerate.

Acceleration Torque

$$\boxed{T_a = T_m - T_e = I \cdot \frac{d^2\delta}{dt}} \rightarrow \text{acceleratn}$$

T_a → accelerating Torque

T_m → mechanical I/p

T_e → mech equivalent torque

I : Inertia constant in $kg\text{-}m^2$

multiplying on both sides with 'ω'

$$T_a \cdot \omega = T_m \cdot \omega - T_e \omega = I\omega \cdot \frac{d^2\delta}{dt^2}$$

i.e

$$\boxed{P_a = P_m - P_e = M\frac{d^2\delta}{dt^2}}$$

M = Inertia constant

M can be obtained from $M = I\omega$ eqn.

or by using another inertia constant 'H'

$$H = \frac{\text{stored KE (in MJ)}}{\text{Rating of M/C G (MVA)}}$$

from above stored K.E = G.H.

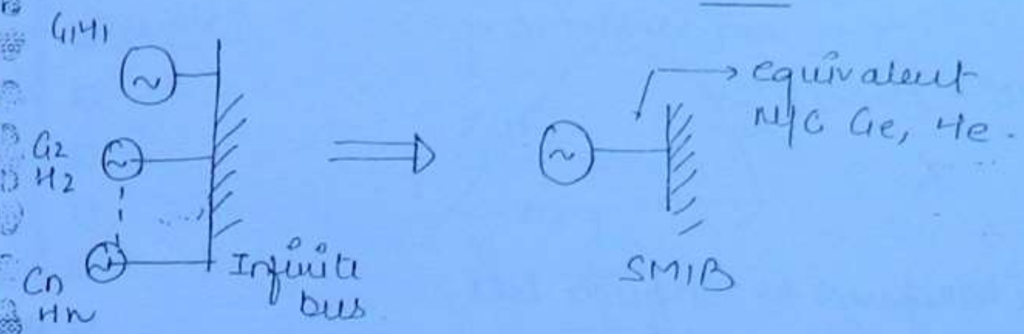
from Law of Mechanics

$*$ Stored K.E $= \frac{1}{2} I\omega^2 = \frac{1}{2} M\omega$

Stored KE $= \frac{1}{2} M\omega = GH$.

$$M = \frac{GH}{\pi f} \frac{\text{MW-sec}}{\text{elect rad}}.$$

$$\rightarrow \frac{GH}{180f} \frac{\text{MW-sec}}{\text{elec-rad degree}}$$



Multiple M/s stored KE = GeHe

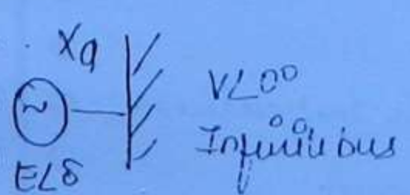
$$= G_1H_1 + G_2H_2 + \cdots G_nH_n$$

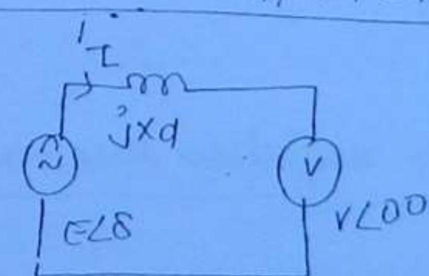
$$H_e = \left(\frac{G_1H_1}{G_e}\right) + \left(\frac{G_2H_2}{G_e}\right) + \cdots \left(\frac{G_nH_n}{G_e}\right)$$

If $G_e = G_{base}$

$$\boxed{H_e(\text{in p.u}) = \frac{G_1H_1}{G_{base}} + \frac{G_2H_2}{G_{base}} + \cdots \frac{G_nH_n}{G_{base}}}$$

POWER ANGEL CURVE AND TRANSFER REACTANCE





$$I = \frac{E\angle\delta - V\angle 0^\circ}{jX_d} = \frac{E\angle\delta - V\angle 0^\circ}{jX_d} \times \frac{j}{j}$$

$$= \frac{(E\angle\delta - V\angle 0^\circ) \times j}{j^2 X_d}$$

$$I = j\,\frac{V\angle 0^\circ - E\angle\delta}{X_d}.$$

$$= \frac{V\angle 90^\circ - E\angle \delta+90^\circ}{X}$$

complex power transferred to infinite bus.

$$S = VI^* = VE \times \left[\frac{V\angle -90^\circ - E\angle -\delta - 90^\circ}{Xd} \right]$$

$$S = \frac{V^2\angle -90^\circ - EV\angle(\delta - 90^\circ}{Xd.}$$

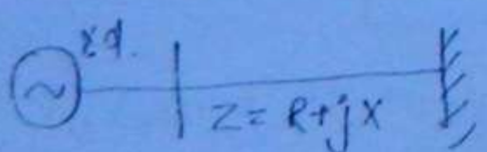
$$S = \frac{-jV^2 - EV(\cos(\delta+90^\circ) - j\sin(\delta+90^\circ))}{Xd.}$$

$$\rightarrow \frac{-jV^2 - EV[-\sin\delta - j\cos\delta]}{Xd}$$

$$S = \frac{EV}{Xd}\sin\delta - j\left[\frac{V^2}{Xd} - \frac{EV}{Xd}\cos\delta\right]$$

$$S = P - jQ.$$

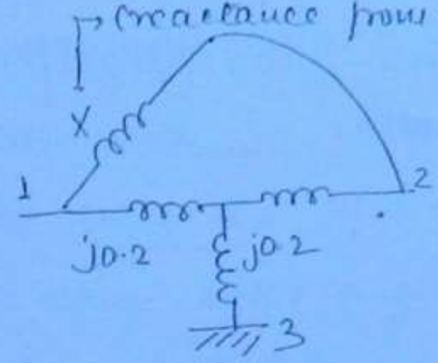
Generator connected to infinite bus through Impedence:-

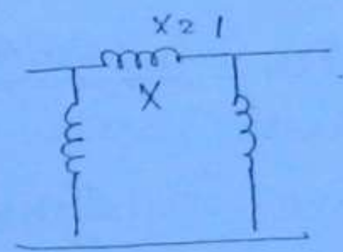


$$Pe = \frac{EV}{X}\sin\delta$$

$$X = Xd + X_{line}$$

it is the reactance that appear at sending end and receiving end terminal example :-





$$\boxed{X = X_1 + X_2 + \frac{X_1 X_2}{X_3}}$$

at $\boxed{x = \sqrt{3}R \rightarrow \text{max}^{m} \text{ power transfer}}$

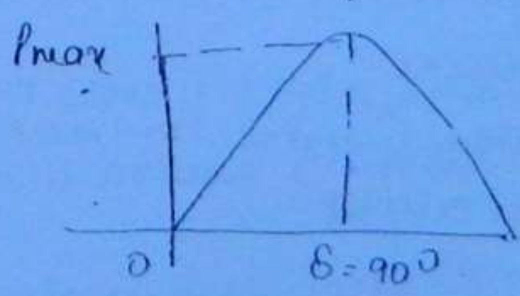
Power angle curve :-

P_e = electrical power transferred

$= \frac{EV}{X}\sin\delta$.

$\frac{EV}{X} \rightarrow$ steady state power limit

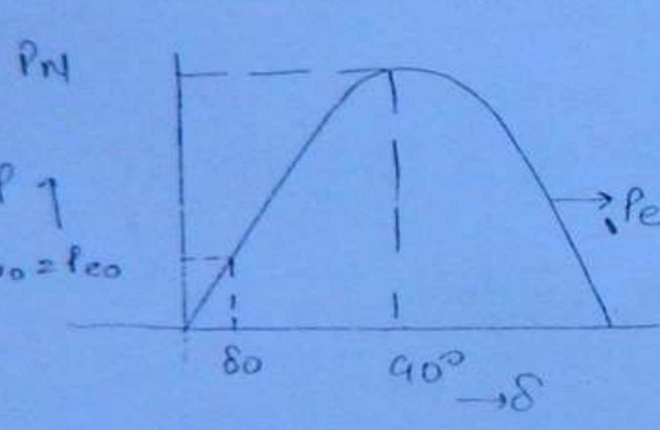
X : transfer reactance



- In ac T.L for transfer of electrical power reactance is compulsory, resistance is not required the condition for maximum power transfer in a short T.L is $X=\sqrt{3}R$.

STABILITY STATE

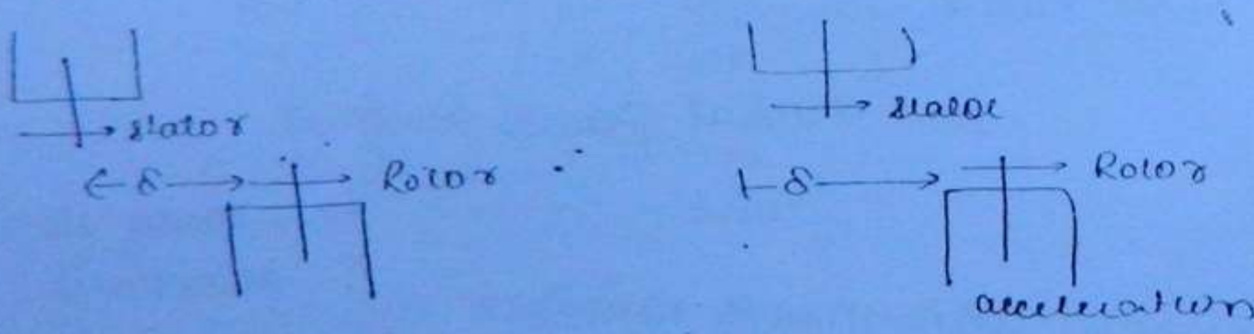
Steady state Stability: EVALUATION TECH



$\frac{dP}{d\delta} > 0$ at $\delta < 90^\circ$

$\frac{dP}{d\delta} = 0$ at $\delta = 90^\circ$

$\frac{dP}{d\delta} < 0$ at $\delta > 90^\circ$



- when δ increases P_e increases
- when δ cross 90°, any further increases in mech. I/P decrease the electrical output.
- $\frac{dP_e}{d\delta}$ = synchronising power coefficient (stiffness of electrical M/C)
  $= P_m \cos\delta$.

when δ is changing from 0-90°, the electrical power output increase and for delta above 90°, the electrical power output decreases. If a mechanical input is increased. when rotor angle [$\delta = 90°$] (say) the extra mechanical input store as K.E in the rotor, the rotor start accelerate and delta increases. the increase in del 'δ' reduces electrical power output this gives further acceleration and increase in 'δ'. finally the system will reach the point when $P_e = 0$

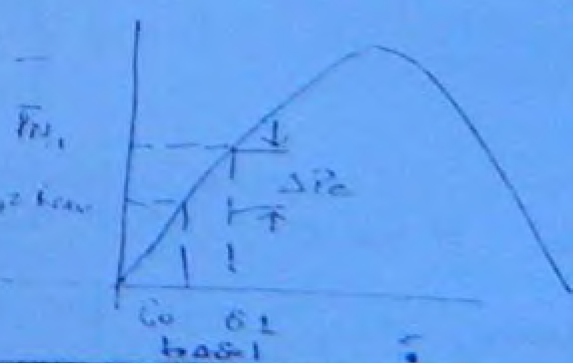
NOTE:

- System has steady state stability as long as $\frac{dP}{d\delta} > 0$
- system loss stability when $\frac{dP}{d\delta} < 0$
- $\frac{dP}{d\delta} > 0$ when $0 < \delta < 90$, beyond $\delta = 90°$, $\frac{dP}{d\delta}$ is -ve.
- system cannot have steady state stability beyond $\delta = 90°$, In power system in order to have good steady state stability margins, δ is maintained around 30° to 40°

Eq Evaluation technique-2:

$$\frac{\Delta P_{e0}}{\Delta \delta_0} = \frac{dP_e}{d\delta}$$

- linearized diff. eqn -



$$\Delta P_{e0} = \left(\frac{dP_e}{d\delta}\right) \cdot \Delta\delta_0 \quad \text{--- (1)}$$

accelerating energy

$$\boxed{P_a = P_{m0} - (P_{e0} + \Delta P_{e0})}$$

$$P_a = P_{m0} - (P_{e0} + \Delta P_{e0}) = M\frac{d\delta^2}{dt^2}$$

$$\cancel{P_{e0}} - \cancel{P_{e0}} - \Delta P_{e0} = M\frac{d^2\delta}{dt^2}$$

$$M\frac{d^2\delta}{dt^2} = -\Delta P_{e0} \quad \text{--- (2)}$$

substitute eqn (2) in (1)

$$M\frac{d^2\delta}{dt^2} + \left(\frac{dP_e}{d\delta}\right)^0 \cdot \Delta\delta_0 = 0$$

let operator $p = \frac{d}{dt}$; $p^2 = \frac{d^2}{dt^2}$

$$\left(Mp^2 + \frac{dP_e}{d\delta}\right)\Delta\delta = 0$$

roots of characteristic equation are

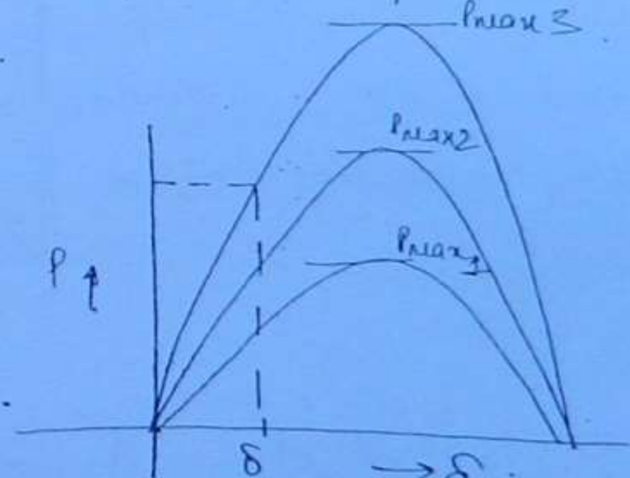
$$p = \mp\left[\frac{-\left(\frac{dP_e}{d\delta}\right)^0}{M}\right]^{0.5} = \pm j\omega_n.$$

- When $\frac{dP}{d\delta} > 0$, s/m has 2 conjugate poles on imaginary axis for this condition system is stable with undamped frequency of acceleration However the inertial force are considered. Then accelerat will be damped after some time

- when $\frac{dP}{d\delta} < 0$, the s/m has two real poles, one on right side and other on left side. Indication of poles on R.H.S is indication for loss of stability.

Improvement of Steady state stability:-

$P_e = P_{max} \sin\delta$.



- By improving SS power limit for given value of δ we can transfer more electrical power.

$$\boxed{P_{max} = EV/X}$$

1) Operate T.L at high voltage

2) Reduce the reactance X.

- use parallel line
- use bundled conductor
- series capacitance.

For bundle

$L = 2\times10^{-7} \ln \frac{D_m}{D_s}$

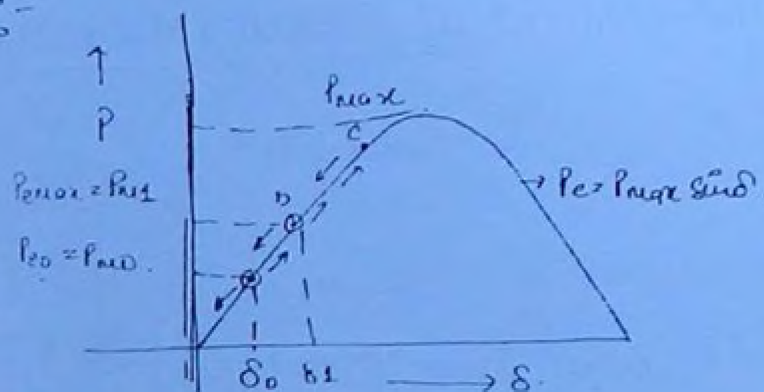
$D_s \uparrow L \downarrow$.

series → capacitor → improve steady state power limit
series → Reactor → $I_{sc}\downarrow$

shunt reactor → to reduce ferranti effect
shunt → capacitor → to impro

Dated
17 Nov 2010

TRANSIENT STABILITY :-



Operating point	δ value	rotor speed	Acceleration & Deceleration	P_a	Remark
a	$\delta = \delta_0$	$N_r = N_s$	None	$P_a = 0$	equilibrium [mechanical suddenly raised]
a-b	$\delta\uparrow$	$N_r > N_s$	Acceleration	$P_a > 0$	—
b	$\delta = \delta_1$	$N_r > N_s$	Acceleration stops	$P_a = 0$	—
b-c	$\delta\uparrow$	$N_r > N_s$	Deceleration	$P_a < 0$	δ increases due to inertia
c	$\delta = \delta_2$	$N_r = N_s$	Deceleration	$P_a < 0$	Inertia absent
c-b	$\delta\downarrow$	$N_r < N_s$	-do-	-do-	

b	$\delta = \delta_1$	$N_r < N_s$	Deacceleratⁿ STOP	$P_a = 0$	—	
b-a	$\delta \downarrow$	$N_r < N_s$	Acceleratⁿ	$P_a > 0$	due to inertia	speed here increases.
a	$\delta = \delta_0$	$N_r = N_s$	— do —	$P_a > 0$	Inertia absent.	

cycle repeats further.

NOTE:

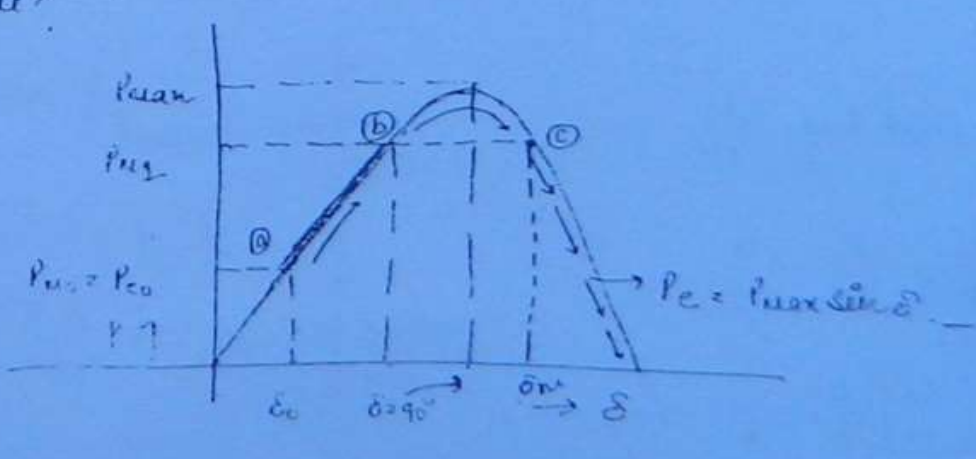
- During this transient period. $\frac{d\delta}{dt}$ for some time it is positive and for another type time it is negative.

When these oscillation are died. system restores ~~from~~ stability condition, in other words transient stability is achieved when.

$$\boxed{\frac{d\delta}{dt} = 0}$$

LIMITING CASE :-

From the present value of mechanical I/P to any value?



- electrical power input at point (b) and (c) are same.

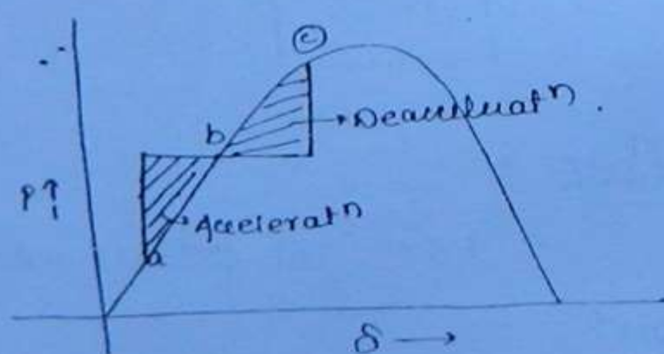
$$\boxed{P_{max} \sin \delta_2 = P_{max} \sin \delta_{m}}$$

$$\sin \delta_2 = \sin \delta_m$$

$$\underbrace{\boxed{\delta_m = \pi - \delta_2}}_{\text{critical angle.}}$$

- If the mechanical input raised corresponding to ($\delta = \delta_c$) the system is critically stable. During first swing rotor will travel upto ~~delta~~ [δ_m] and may likely come back. During the first swing. if δ crosses δ_c. then system loss stability.

EQUAL - AREA CRITERION



swing equatⁿ

$$M \frac{d^2\delta}{dt^2} = P_a$$

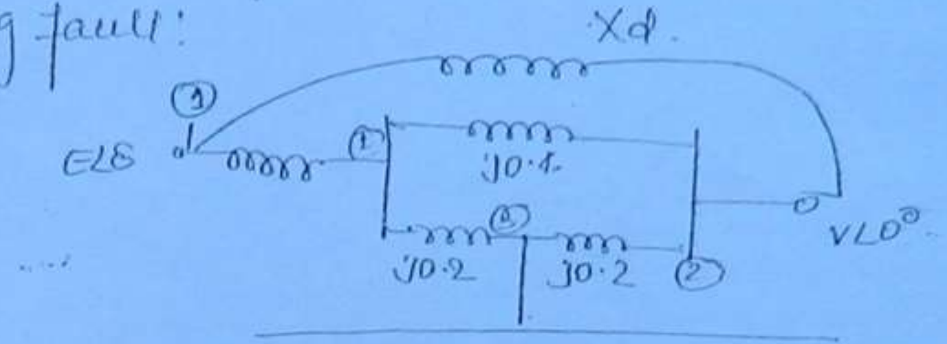
$$\frac{d^2\delta}{dt^2} = \frac{P_a}{M}$$

multiply both side by $\frac{d\delta}{dt}$

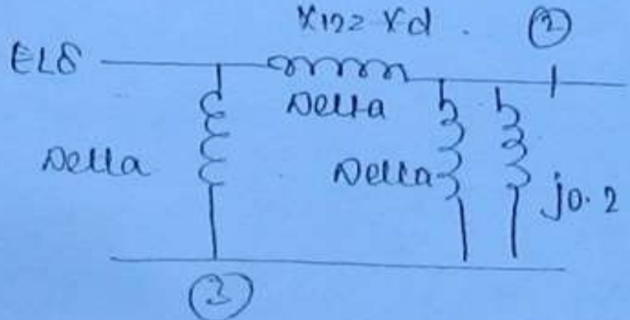
$$\frac{d\delta}{dt} \cdot \frac{d^2\delta}{dt} = \frac{P_a}{M} \cdot \frac{d\delta}{dt}$$

$$\frac{1}{2}\left[\frac{d}{dt}\left(\frac{d\delta}{dt}\right)^2\right] = \frac{P_a}{M} \cdot \frac{d\delta}{dt}$$

during fault:



Convert star, reactance b/t (1)(N), (2)N and (3)N



$X_{12} = X_1 + X_2 + \frac{X_1 X_2}{X_3}$

$= j0.2 + j0.4 + \frac{j0.2 \times j0.4}{j0.2}$

$= j1$

$P_{maxd} = \frac{1.2 \times 1}{1} = 1.2 \text{ p.u}$

$P_{ed} = 1.2 \sin\delta.$

68.53

after fault

$X_a = X_d' + X_1 = 0.6 \text{ p.u}$

$P_{maxa} = \frac{1.2 \times 1}{0.6}$

$\boxed{P_{ea} = 2 \sin\delta}$

$\delta_m = \pi - \sin^{-1}\left(\frac{P_{mo}}{P_{maxa}}\right).$

$= \pi - \sin^{-1}\left(\frac{1.5}{2}\right)$

$= 131.4$

$\delta_0 = 30°$

POWER SYSTEM – II