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IIT(BHU) VARANASI

STUDENTS' NOTES

TOPIC-ELECTRICAL-I

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AAC → All aluminium conductor, AAAC → All alloy aluminium conductor
ACSR → Aluminium conductor steel reinforced, stranded for flexibility

$$H - H_1 = \frac{H_2 - H_1}{t_2 - t_1}(t - t_1)$$

$$H_{rms} = \sqrt{\frac{1}{T}\int_0^T (H(t))^2\, dt}$$

$$= \left[\frac{1}{T}\left[H_1^2 + H_2^2 + H_1 H_2\right]\frac{T}{3}\right]^{1/2}$$

Permissible limit of temp for different kind of insulat.

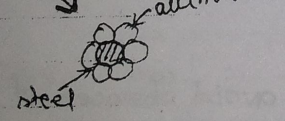
Y → 90°C
A → 105°C
E → 120°C
B → 130°C
F → 155°C
H → 180°C
C → >180°C

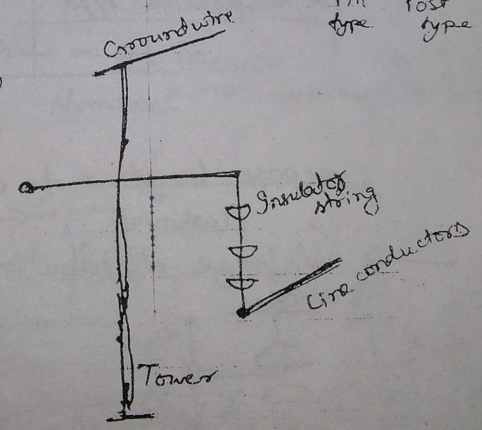
O.S.N
B.G.1.5

Power transmission.

Overhead power transmission components (low cost)

- Conductors (AAC, AAAC, ACSR etc) (for high voltage transmission)
- Ground wire
- Cross-arms, Towers.
- Transformer, surge arrestor, circuit breaker etc.
- Insulators
  - Pin type
  - Post type
  - Suspension type





Ground wire → To protect expensive equipment due to lightning which causes over voltage.
Tower provides supports and cross arms provide insulation to it with.

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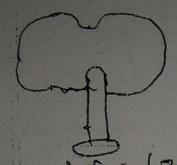
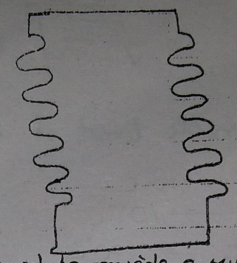
Insulators

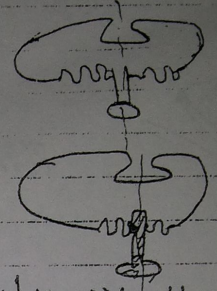
- Pin type
- Post type
- Suspension type



used for low voltage operation



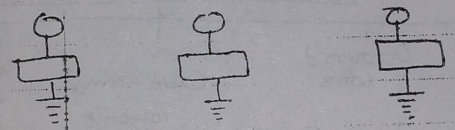
used to provide a support and also to provide insulation b/w ground & equipment



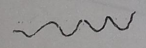
for high voltage

Surge arrestor is analogous to zener diode connected across ground and line conductors.

CBs are used to protect equipment against overcurrent.



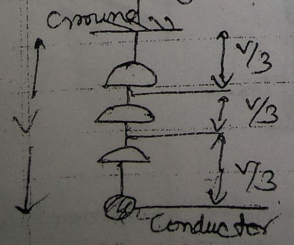
in suspension type



is used in pollutant areas

creepage length → to avoid chances of surface flashover

→ Voltage distribution in a string of insulator



ideally

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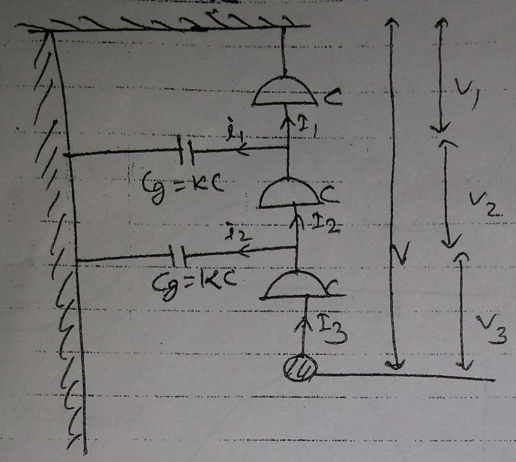
but in real case



$I_1 = V_1 \omega C$

$i_1 = V_1 \omega K C$

$I_2 = V_2 \omega C$

$= V_1 \omega C + K V_1 \omega C$

$V_2 = V_1 (1+K)$ — (1)

$I_3 = V_3 \omega C = I_2 + i_2$

$= V_2 \omega C + (V_1 + V_2) K \omega C$

$= V_1 K \omega C + V_2 (1+K) \omega C$

$I_3 = V_1 K \omega C + V_1 (1+K)^2 \omega C$

$\Rightarrow V_3 \omega C = V_1 K \omega C + V_1 (1+K^2) \omega C$

$\Rightarrow V_3 = V_1 (K + (1+K)^2)$

$\Rightarrow V_3 = V_1 (1+3K+K^2)$

$V = V_1 + V_2 + V_3$

$V = V_1 + V_1 (1+K) + V_1 (1+3K+K^2)$

$V_1 = \frac{V}{3+4K+K^2} = \frac{V}{(K+1)(K+3)}$

$V_2 = V_1 (1+K) = \frac{V}{(K+3)}$

$V_3 = \frac{1+3K+K^2}{3+4K+K^2} V$

If $K > 1$, voltage across string nearer to ground share lesser voltage and voltage across string nearer to conductor will be maximum.

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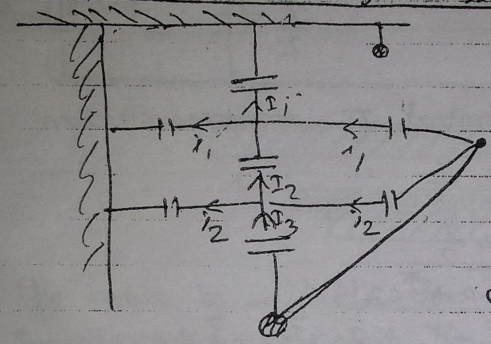
Non-uniform voltage distribution ~~causes~~ across the string causes reduction in efficiency of string.

$$\text{String efficiency} = \frac{\text{Total applied voltage across insulator string}}{n \times \text{voltage across insulator unit nearest to line conductor}}$$

where n = Total no of units.

Improving efficiency of string



(i) Guard ring

(ii) Increasing the length of cross-arms.

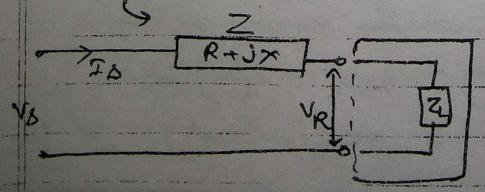
(iii) Chosing variable capacitance of each unit such that voltage distribution across each unit will be same

Another advantage of using guard ring is to protect against overvoltage.

O.S.N.
9.9.'14

Performance of overhead transmission line

- Short lines: length (l) < 80 km
- Medium length tr. lines: $80 < l < 250$ km
- Long tr. lines: $l > 250$ km (Not in syl)



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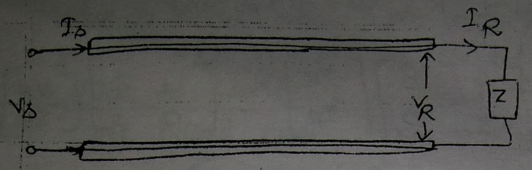
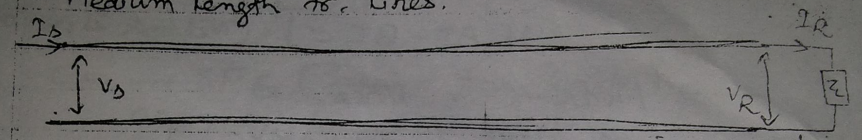
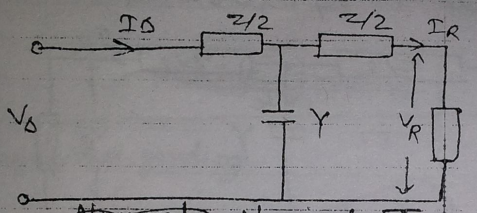


charging current in capacitance is negligible

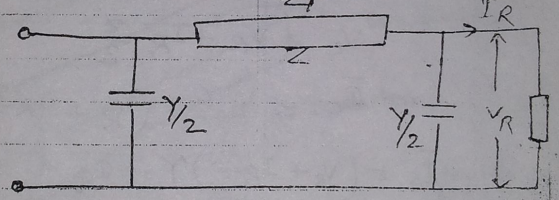
→ Medium length tr. lines.





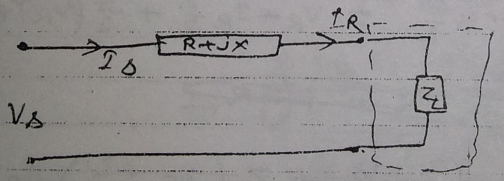
charging current in capacitance is significant

~~Normal~~ Nominal-T representation

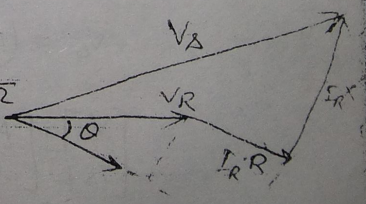


Nominal - π representation

→ Short lines.



$$V_S = \sqrt{(V_R\cos\theta + I_R R)^2 + (V_R\sin\theta + I_R X)^2}$$



$$= V_R + IX\sin\theta + IR\cos\theta$$

$$\frac{V_S - V_R}{V_R} = \frac{IR\cos\theta}{V_R} + \frac{IX\sin\theta}{V_R}$$

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of position of source, reciprocal network,

$$\frac{V_S - V_R}{V_R} = R_{pu}\cos\theta + X_{pu}\sin\theta$$

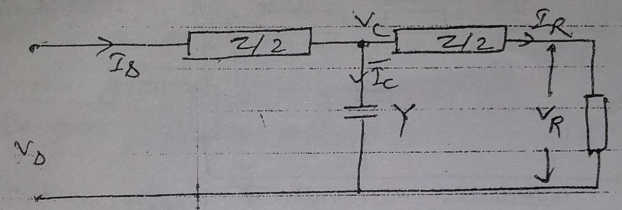
$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}\begin{bmatrix} V_R \\ I_R \end{bmatrix} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix}\begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

If $A = D$ (Network is symmetrical)

If $AD - BC = 1$ (Network is reciprocal)

→ Medium Tr. lines.

Nominal - T - representation.



$$V_C = V_R + I_R\frac{Z}{2}$$

$$\bar{I}_C = V_C Y = \left(V_R + I_R\frac{Z}{2}\right)Y$$

$$\bar{I}_S = \left(V_R + I_R\frac{Z}{2}\right)Y + I_R$$

$$\bar{I}_S = V_R Y + \left(1 + \frac{YZ}{2}\right)I_R$$

$$\bar{V}_S = V_C + I_S\frac{Z}{2} = V_R + I_R\frac{Z}{2} + \frac{Z}{2}\left(V_R Y + \left(1+\frac{YZ}{2}\right)I_R\right)$$

$$\cancel{\bar{V}_S = \left(1+\frac{YZ}{2}\right)V_R + Z\left(I_R\right.}$$

$$\bar{V}_S = \left(1 + \frac{YZ}{2}\right)V_R + Z\left(1 + \frac{YZ}{4}\right)I_R$$

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

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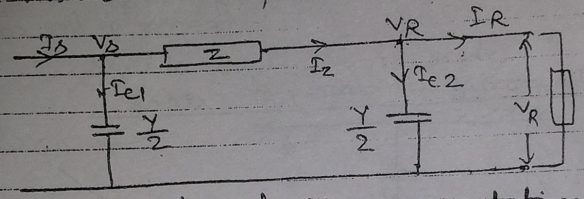
$A = D$ (network is symmetrical)

$$AD - BC = \left(1 + \frac{YZ}{2}\right)^2 - YZ\left(1 + \frac{YZ}{4}\right)$$

$$= 1$$

so network is reciprocal.

→ Nominal π - representation.



Nominal π - representation

$$I_{C2} = V_R \frac{Y}{2}$$

$$I_{C1} = V_S \frac{Y}{2}$$

$$I_Z = I_R + I_{C2}$$

$$I_S = I_Z + I_C = I_R + I_{C2} + I_{C1}$$

$$I_S = I_R + V_R \frac{Y}{2} + V_S \frac{Y}{2}$$

$$V_S = V_R + \left(I_R + V_R \frac{Y}{2}\right) Z = V_R\left(1 + \frac{YZ}{2}\right) + I_R Z$$

$$V_S = V_R\left(1 + \frac{YZ}{2}\right) + I_R Z$$

$$I_S = I_R + V_R \frac{Y}{2} + \left[I_R Z + V_R\left(1 + \frac{YZ}{2}\right)\right]\frac{Y}{2}$$

$$I_S = V_R\left(1 + \frac{YZ}{4}\right)Y + I_R\left(1 + \frac{YZ}{2}\right)$$

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

$A = D$ (Network is symmetrical)

$$AD - BC = \left(1 + \frac{YZ}{2}\right)^2 - YZ\left(1 + \frac{YZ}{4}\right) = 1$$

(Network is reciprocal)

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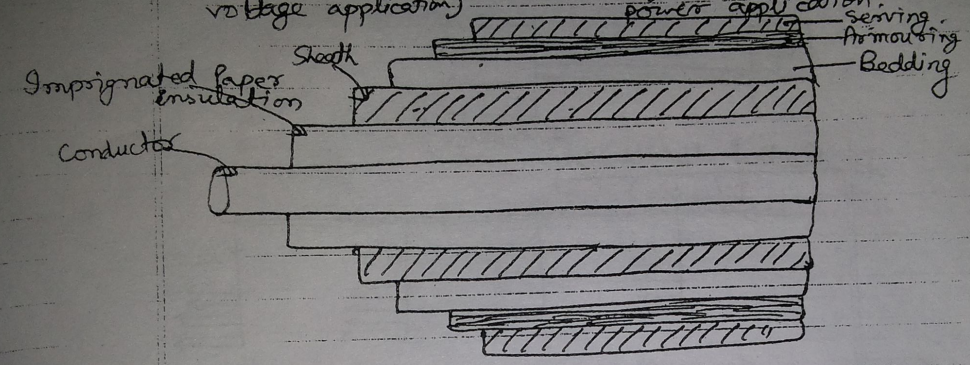
Underground Cables

- Solid insulated (Low power and low voltage application)
- Oil filled
- Gas filled

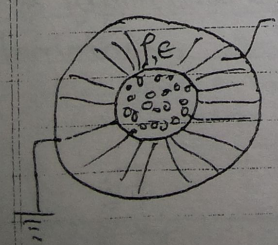
High voltage and high power application



U/g cable is suitable for loss length.
Impriginated → dipped in oil provide magnetic properties
Paper insulation is very sensitive to moisture so it is protected by seath. Seath has to be protected against erosion. Armouring contains small conductor. It provides mechanical support and doesn't carry current. Serving protects armouring from environmental attack.

O.S.N.
12-9-17

Paper insulation / Rubber / PVC



loss in cable → ohmic loss
Polarization loss in case of AC

In dc, no charging current, no skin effect, dipolar losses are absent

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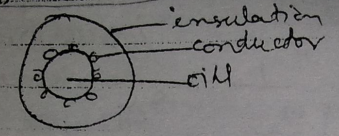
due to these advantages dc is preferred when power transmission is at higher distance

→ Due to heating, instead of solid conductors, oil filled conductors are used to absorb dipolar effect

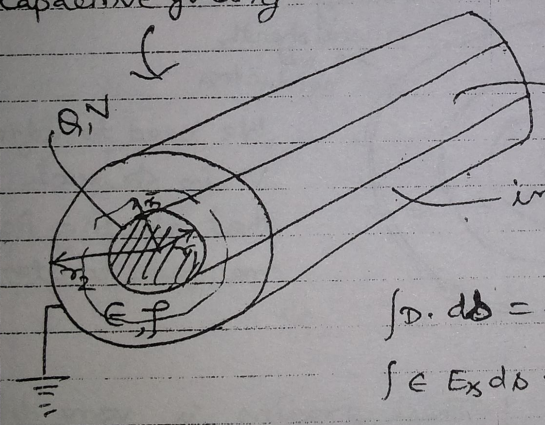


Gas → SF_6 (Sulphur hexafluoride)

GIS → Gas insulated substation.

Cable grading

- Capacitive grading
- Interpath grading



Inside conductor potential at every point is same

$$\int D \cdot ds = Q$$

$$\int \epsilon E_x \, ds = Q$$

$$\Rightarrow \int \epsilon E_x \, 2\pi x \, l \, dx = Q$$

for $l = 1$

$$E_x = \frac{Q}{2\pi \epsilon x}$$

electric field is maximum at the surface of conductor

It depends on permittivity and spacing from conductor

$$\Rightarrow \int E \cdot dl = V \Rightarrow \int \frac{Q}{2\pi\epsilon x} \cdot dl = V$$

$$\Rightarrow \frac{Q}{2\pi\epsilon} \ln \frac{r_2}{r_1} = V$$

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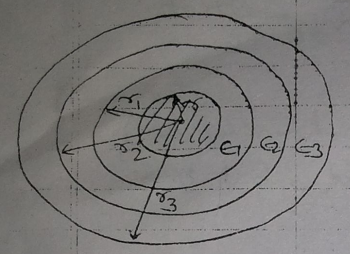
$E_x = \frac{\partial x}{\partial x}$

electrifield is varying in insulator so to keep the electric field distribution constant, instead of a single layer of insulating material, we use a no of layer of insulating material so that $\frac{1}{\epsilon x}$ constant. i.e. permittivity of insulating material should be keep on increasing because to maintain $\frac{1}{\epsilon x}$ constant

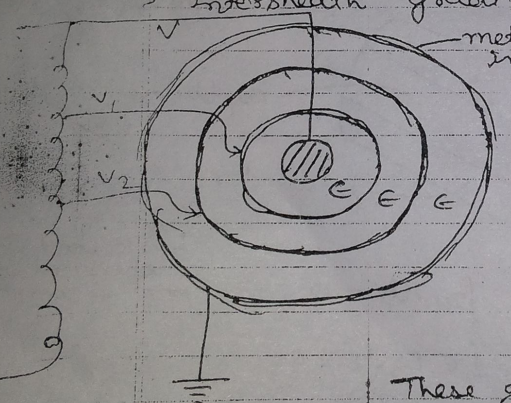


$$\frac{1}{\epsilon_1 r} = \frac{1}{\epsilon_2 r_1} = \frac{1}{\epsilon_3 r_2}$$

$$r < r_1 < r_2$$

so $\epsilon_1 > \epsilon_2 > \epsilon_3$.

→ Intersheath grading.



We need to adjust V_1, V_2, V in such a way that electric field maintains constant.

These grading is very difficult in realization because of less thickness of sheat, strength of cable will get reduced.

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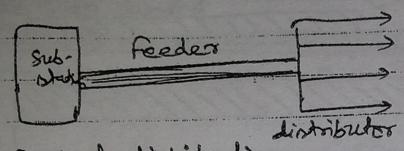
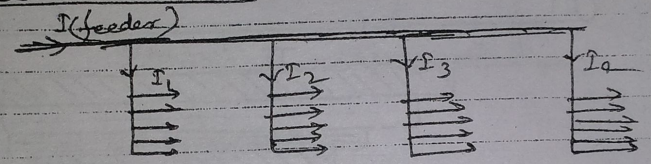
Fig. 6.10 Characteristics of a backward-bladed centrifugal fan (after MacFarlane).

Electrical Supply distribution system

- DC
  - radial distribution
  - Ring distribution
- AC
  - Radial distribution
  - Ring distribution



DC Radial distribution

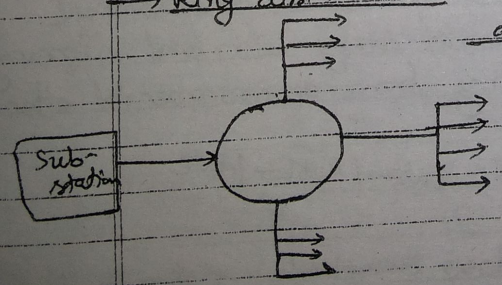


disadvantage

(i) Voltage keeps on decreasing as we ~~keep~~ go away from initial di

(ii) Any fault in feeder interrupts the distribution after that. (Continuity of power supply is not maintained)

DC Ring distribution



advantage

(i) Voltage drop will be lesser

~~(ii) Construction~~ is ~~easy~~ difficult.

~~(iii) Contin~~

(ii) Continuity of power supply is maintained.

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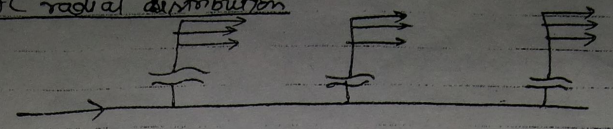
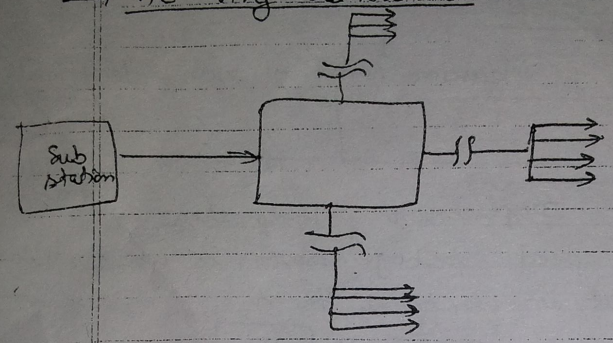
→ AC radial distribution



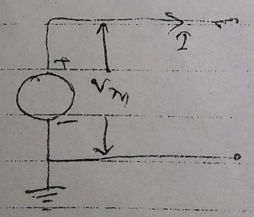
→ AC ring distribution



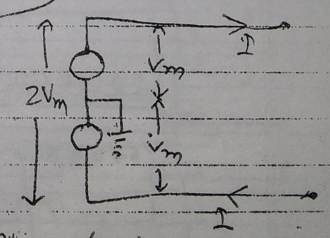
In AC distribution we have the option to step up or step down the voltage using transformer

Electric supply system (Comparision on volume of conductor requirement)

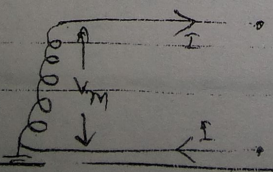
DC two wire (one conductor earthed)



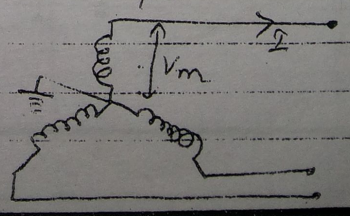
DC two wire (Mid point earthed)



AC single phase (one conductor earthed)



3 Phase / 3 wire.



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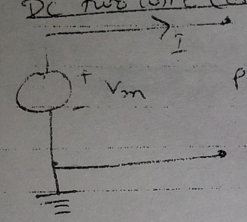
M

Comparision for equal delivered power and equal losses i.e. equal efficiency.

Assumption → Power delivered will be same and losses all systems are equally efficient

DC two wire (one conductor earthed)



$$I = \frac{P}{V_m}$$

$$W = 2I^2R = \left(\frac{P}{V_m}\right)^2 \rho$$

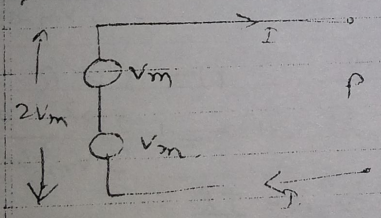
$$R = \frac{\rho l}{A} \Rightarrow W = \left(\frac{P}{V_m}\right)^2 \rho$$

$$R = \frac{\rho l}{a} \Rightarrow a = \frac{2}{W}\left(\frac{P}{V_m}\right)^2 \rho l$$

Total volume of conductor required

$$2al = \frac{4}{W}\left(\frac{P}{V_m}\right)^2 \rho l^2 = K \text{ (let)}$$

DC two wire (Mid point earthed)



$$I = \frac{P}{2V_m}$$

$$W = 2I^2R = 2\left(\frac{P}{2V_m}\right)^2 \rho$$

$$R = \frac{\rho l}{a}$$

$$\Rightarrow a = \frac{2}{W}\left(\frac{P}{2V_m}\right)^2 \rho l$$

$$a = \frac{P^2 \rho l}{2 W V_m^2}$$

Total volume of conductor required

$$2al = \frac{P^2 \rho l^2}{W V_m^2} = \frac{K}{4}$$

For the same amount of power delivered, second system is more economical

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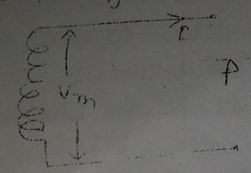
AC single phase



$$I = \frac{P}{\frac{V_m}{\sqrt{2}}\cos\phi}$$

$$P$$

$$W = 2 I^2 R$$

$$W = \frac{4P^2}{V_m^2\cos^2\phi} R$$

$$R = \frac{\rho l}{a}$$

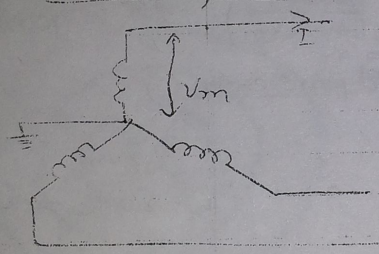
$$\Rightarrow a = \frac{2}{W}\frac{P^2}{V_m^2\cos^2\phi}\rho l$$

Volume of conductor.

$$2al = \qquad = \frac{2K}{\cos^2\phi}$$

it is less economical w.r.t. DC system.

AC three phase



$$\frac{P}{3} = \frac{V_m}{\sqrt{2}} I\cos\phi$$

$$\Rightarrow I = \frac{\sqrt{2}\,P}{3 V_m\cos\phi}$$

$$W = 3 I^2 R$$

$$= \frac{2P^2}{3V_m^2\cos^2\phi} R$$

$$\Rightarrow R = \frac{\rho l}{a}$$

$$\Rightarrow a = \frac{2P^2\rho l}{3V_m^2\cos^2\phi}$$

$\Rightarrow$ total volume of conductor required.

$$3al = \frac{2P^2\rho l^2}{V_m^2\cos^2\phi} = \frac{K}{2\cos^2\phi}$$

3ϕ AC transmission system is more efficient than 1ϕ and also than DC two wire (one conductor earthed) in terms of volume of conductor.

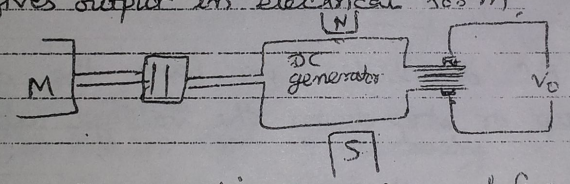
When the conductor volume & neutral wire is concerned, total volume of conductor required is $\frac{7}{12}\frac{K}{\cos^2\phi}$ which also it makes efficient transmission system.

Electrical transducers

Measurement of non-electrical quantity.

- Speed
- Displacement
- Temperature
- Force/weight

→ To measure speed, tachogenerator is used which gives output in electrical form.

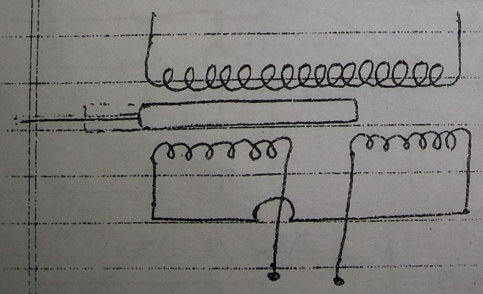


Permanent magnet is used for excitation.

$$E_G = \frac{P\phi Z}{60A}(N)$$

By measuring E_G, N is measured.

→ Displacement (LDVT)



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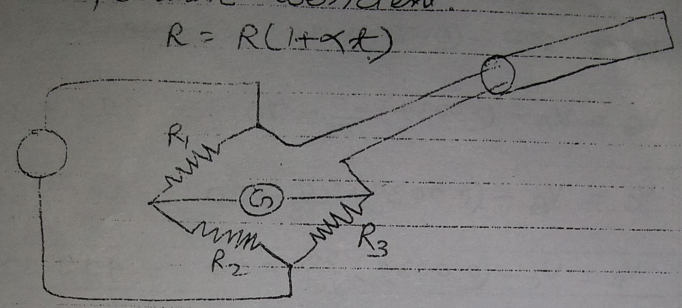
S.O.V

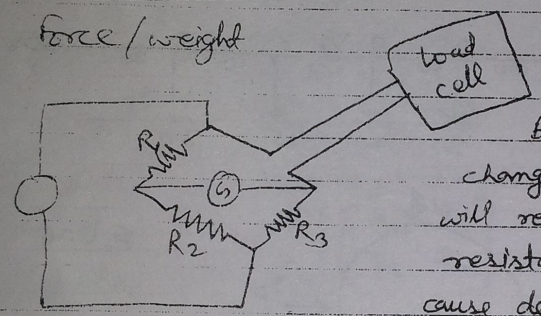
→ ~~Fo~~ Temperature

Used these conductors which have higher temperature coefficient.

$$R = R(1+\alpha t)$$



→ force / weight

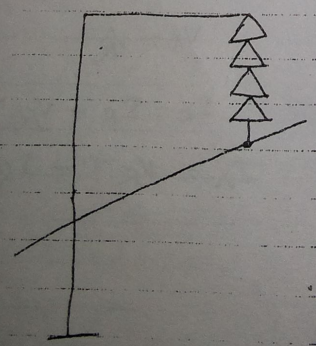


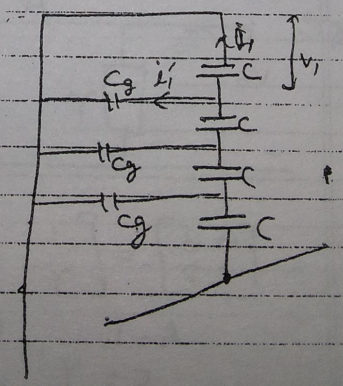
material sensitive ~~to force~~

By applying force change in dimension will result in change in resistance which will cause deflection in galvanometer

O.S.N.
15.9.19

Voltage distribution and string efficiency





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S.O.V # Spark over voltage (voltage at which flashover takes place

Let $\frac{C_g}{C} = K$

$i_1 = V_1 \omega C$, $i_1' = V_1 \omega C_g = V_1 \omega K C$

$i_2 = i_1 + i_1' = V_1 \omega C + V_1 \omega K C = V_1 \omega C (1+K)$

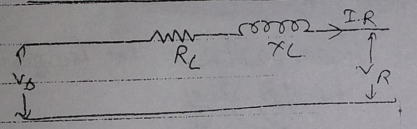
$\Rightarrow V_2 \omega C = V_1 \omega C (1+K)$

$\Rightarrow V_2 = \frac{i_2}{\omega C} = \frac{V_1 \omega C (1+K)}{\omega C}$

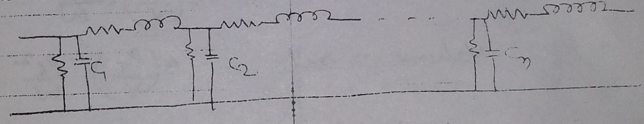
$\Rightarrow V_2 = V_1 (1+K)$

~~Vnc~~

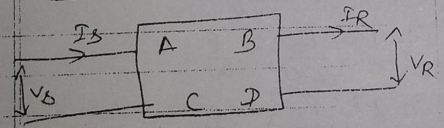
Short transmission line



Actual transmission line



ABCD constants



$V_S = V_R + I_R Z$

$I_S = I_R$

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

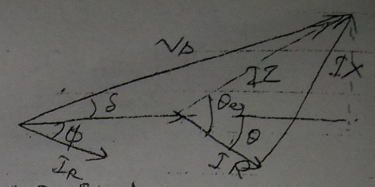
Voltage regulation

$$V_{Reg} = \frac{V_{RNL} - V_{RFL}}{V_{RFL}} \times 100$$

$$\boxed{V_{reg} = \frac{\frac{V_S}{|A|} - V_R}{V_R}} \text{ Pu}$$

$V_{RNL} = V_S$

$V_S - V_R = Z_{Pu}\cos(\theta_{eq} - \phi)$



$= Z_{Pu}\cos\theta_{eq}\cdot\cos\phi + Z_{Pu}\sin\theta_{eq}\sin\phi$

$= R_{pu}\cos\phi + X_{pu}\sin\phi$

O.S.N
22.9.17

A B C D Constants

Transmission system

Que. Let us consider a single phase DC wire $V = 220V$, Power delivered P_T

$I_1 = \frac{P_T}{V}$ losses $= 2I_1^2R$ Let length of the line l

$R = \frac{\rho l}{A}$

$W = \left(\frac{P_T}{V}\right)^2 \frac{\rho l}{a}$

$\Rightarrow a = \left(\frac{P_T}{V}\right)^2 \cdot \frac{2\rho l}{W}$

Volume $= 2al = 4\left(\frac{P_T}{V}\right)^2 \frac{\rho l^2}{W}$

amount of copper save when V is increased from 220 V to 500 V.

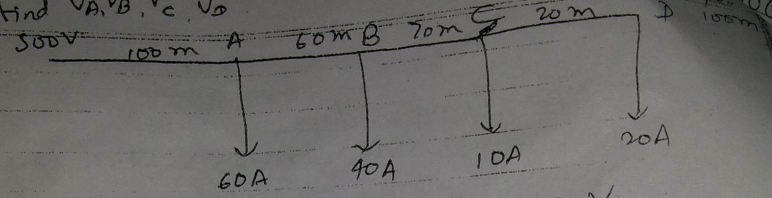
Volume $1(V_1) = 4l^2\left(\frac{P_T}{220}\right)^2 \frac{\rho}{W}$

Volume $2(V_2) = 4l^2\left(\frac{P_T}{500}\right)^2 \frac{\rho}{W}$

amount of copper save $= \frac{V_1 - V_2}{V_1} \times 100$

$= \left\{1 - \left(\frac{220}{500}\right)^2\right\} = 80.64\%$

Que. Find V_A, V_B, V_C, V_D



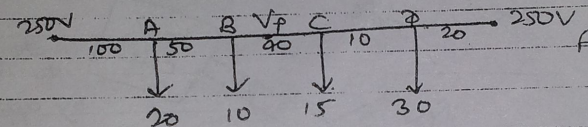
$V_A = 500 - (0.0034) \times 130 = 499.558\ V$

$V_B = V_A - (0.0034)\frac{60}{100} \times 70 = 499.4152\ V$

$V_C = V_B - (0.0034)\frac{70}{100} \times 30 = 499.3438\ V$

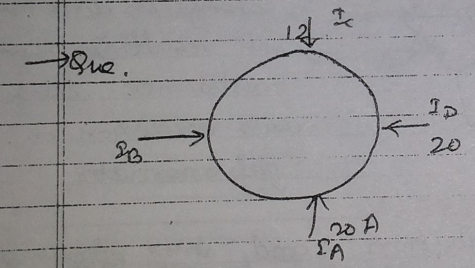
$V_D = V_C - (0.0034)\frac{20}{100} \times 20 = 499.3302$

Que



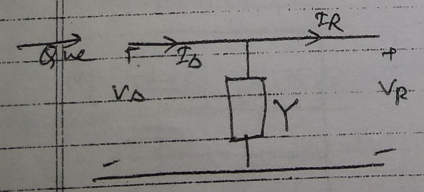
Find V_A, V_B, V_C, V_D

Que.



$\Sigma V = 0$

Que



$V_D = V_R$

$I_D = I_R + V_R Y$

$I_D = V_R Y + I_R$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix}$$

$A = 1, \quad B = 0$

$C = Y, \quad D = 1$

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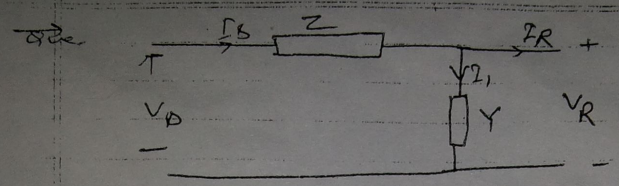
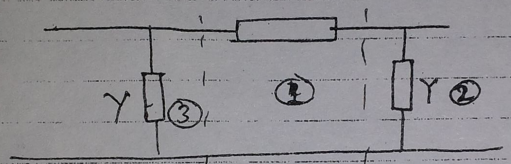


$I_1 = V_R Y$

$I_S = I_R + V_R Y$

$V_S = V_R + I_S Z$



$$\begin{bmatrix} A_3 & B_3 \\ C_3 & D_3 \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix}$$