Benha University
Faculty of Engineering
Electrical Engineering Department

Semester ❶ (3th year Power &Control)
Electrical Power Systems (E1333)
Semester 2016- 2017

Final Written Examination.

9/1/2017

Time all: 3 hrs.

Answer the following questions

Question One: **[28 Marks]**

a) What is the most general criterion for the classification of underground cables? Draw the sketch of a single-core low tension cable and label the various parts.

— Cables for underground service may be classified in two ways according to

(i) the type of insulating material used in their manufacture

(ii) the voltage for which they are manufactured.

However, the latter method of classification is generally preferred

(i) Low-tension (L.T.) cables – up to 1000 V

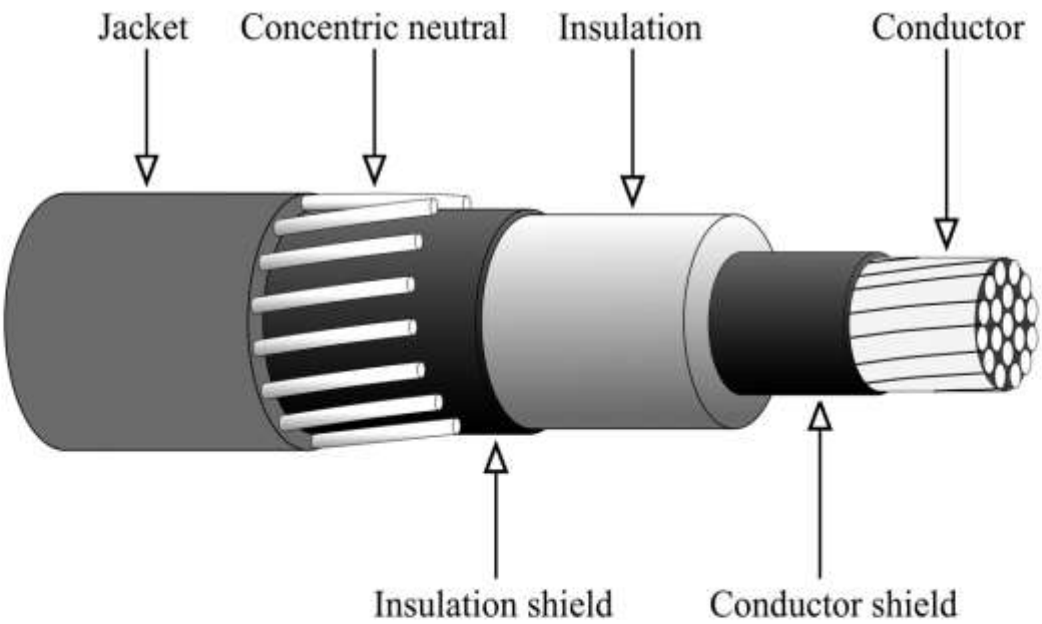
(ii) High-tension (H.T.) cables – up to 11,000 V

iii) Super-tension (S.T.) cables - from 22 kV to 33 kV

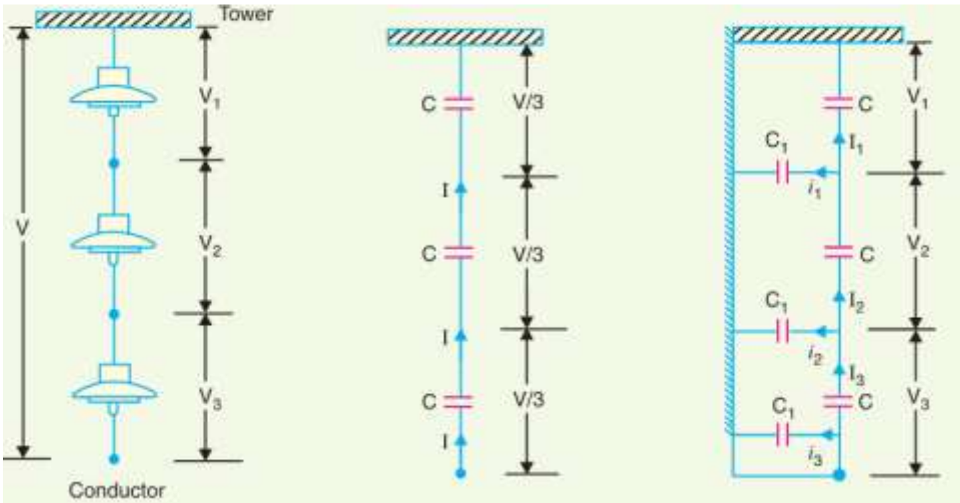
(iv) Extra high-tension (E.H.T.) cables - from 33 kV to 66 kV

(v) Extra super voltage cables - beyond 132 kV

— A cable may have one or more than one core depending upon the type of service for which it is intended. It may be (i) single-core (ii) two-core (iii) three-core (iv) four-core etc.



b) Discuss with the equations why the disc nearest to the conductor has the highest voltage across it in the suspension insulators?



$$I_2 = I_1 + i_1$$

or $$V_2 \omega C^* = V_1 \omega C + V_1 \omega C_1$$

or $$V_2 \omega C = V_1 \omega C + V_1 \omega K C$$

$\therefore$ $$V_2 = V_1 (1 + K) \qquad \ldots(i)$$

Applying Kirchhoff's current law to node *B*, we get,

$$I_3 = I_2 + i_2$$

or $$V_3 \, \omega C = V_2 \omega C + (V_1 + V_2) \, \omega C_1^{\dagger}$$

or $$V_3 \, \omega C = V_2 \omega C + (V_1 + V_2) \, \omega K C$$

or $$V_3 = V_2 + (V_1 + V_2)K$$
$$= KV_1 + V_2 (1 + K)$$
$$= KV_1 + V_1 (1 + K)^2$$
$$= V_1 [K + (1 + K)^2]$$

$\therefore$ $$V_3 = V_1[1 + 3K + K^2]$$

Voltage between conductor and earth (*i.e.*, tower) is

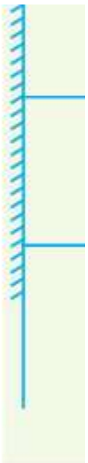
$$V = V_1 + V_2 + V_3$$
$$= V_1 + V_1(1 + K) + V_1 (1 + 3K + K^2)$$
$$= V_1 (3 + 4K + K^2)$$

$\therefore$ $$V = V_1(1 + K)(3 + K)$$

From expressions (*i*), (*ii*) and (*iii*), we get,

$$\frac{V_1}{1} = \frac{V_2}{1 + K} = \frac{V_3}{1 + 3K + K^2} = \frac{V}{(1 + K)(3 + K)}$$

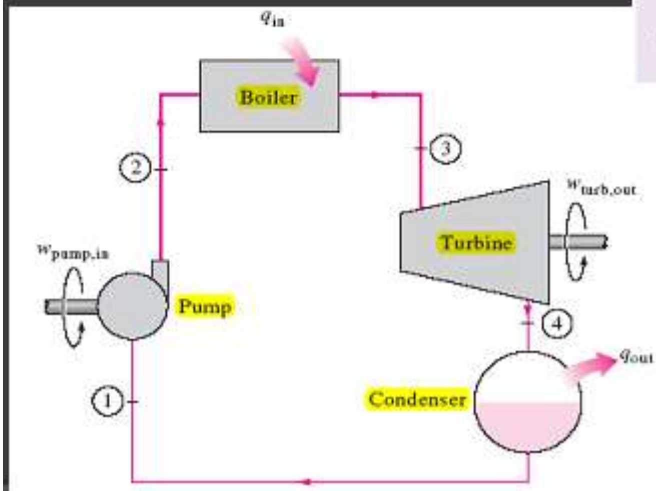
$\therefore$ Voltage across top unit, $$V_1 = \frac{V}{(1 + K)(3 + K)}$$

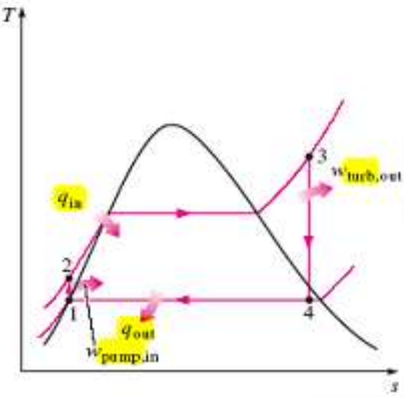


c) Describe with drawing the gas, steam & combined power station?

1- Steam turbine plants use the dynamic pressure generated by expanding steam to turn the blades of a turbine. Almost all large non-hydro plants use this system. About 90% of all electric power produced in the world is by use of steam turbines.

$$\eta_{thermal} = \frac{\text{Heat equivalent of mech. energy transmitted to turbine shaft}}{\text{Heat of coal combustion}}$$





2- Gas turbine plants use the dynamic pressure from flowing gases (air and combustion products) to directly operate the turbine. Natural-gas fuelled (and oil fueled) combustion turbine plants can start rapidly and so are used to supply "peak" energy during periods of high demand, though at higher cost than base-loaded plants. These may be comparatively small units, and sometimes completely unmanned, being remotely operated. This type was pioneered by the UK, Princetown[9] being the world's first, commissioned in 1959.

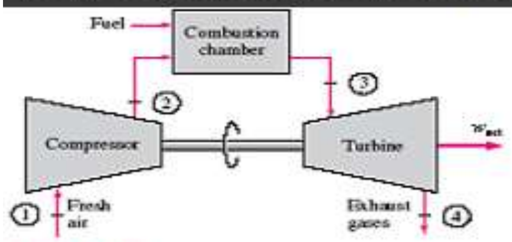


FIGURE 9–29
An open-cycle gas-turbine engine.

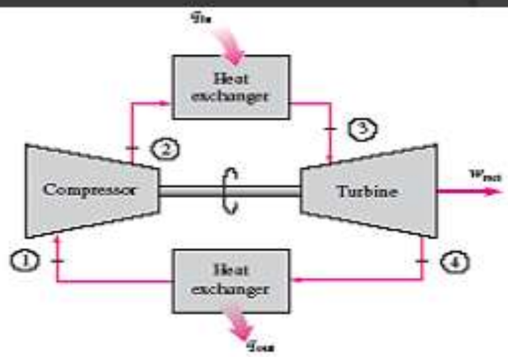


FIGURE 9–30
A closed-cycle gas-turbine engine.

3- Combined cycle plants have both a gas turbine fired by natural gas, and a steam boiler and steam turbine which use the hot exhaust gas from the gas turbine to produce electricity. This greatly increases the overall efficiency of the plant, and many new base load power plants are combined cycle plants fired by natural gas.

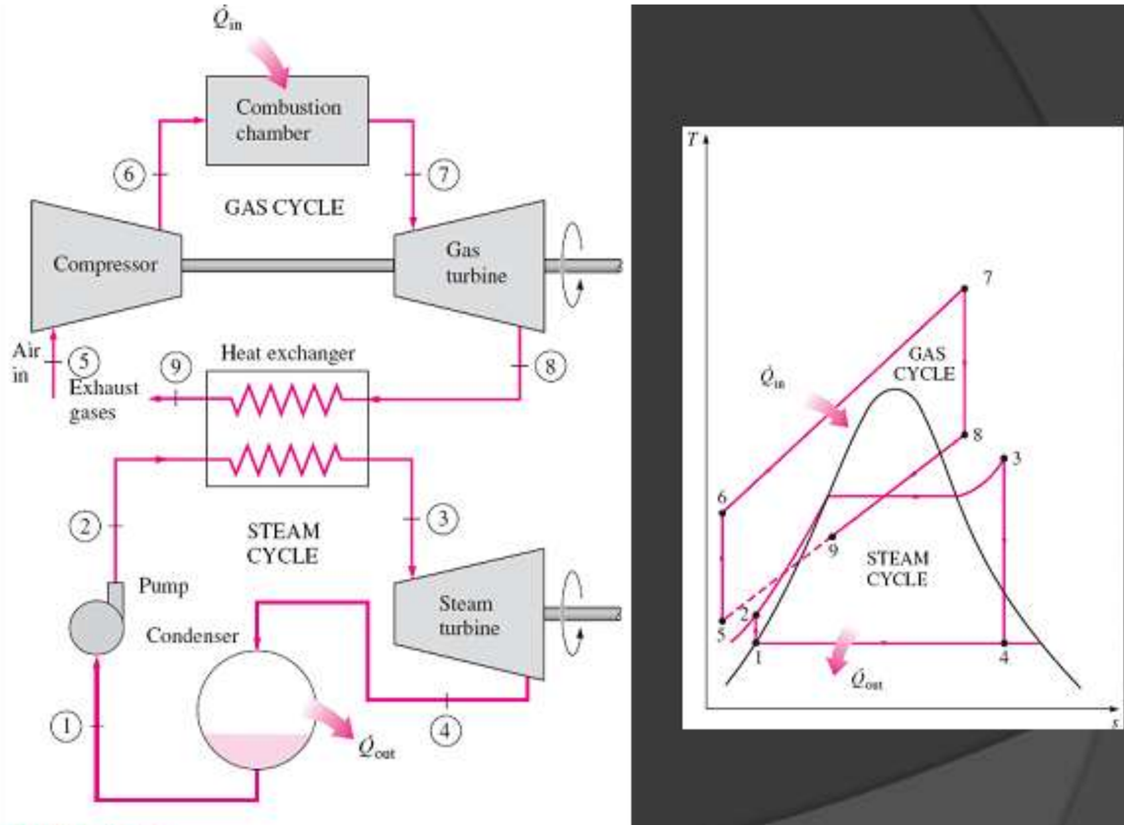


FIGURE 10–24
Combined gas–steam power plant.

d) Derive an expression for line to neutral capacitance for a 3-phase overhead transmission line when the conductors are unsymmetrically placed but transposed.

Electric Potential

- The electric potential at a point due to a charge is the work done in bringing a unit positive charge from infinity to that point.
- capacitance in a circuit is defined as the charge per unit potential.

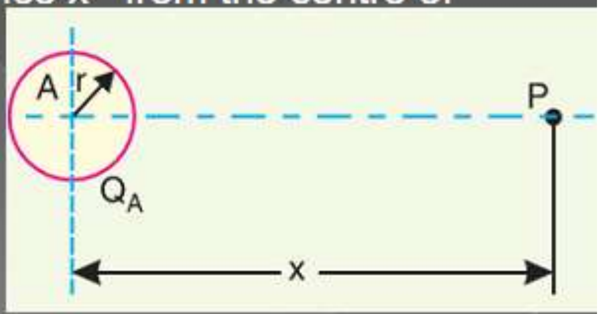
(i) Potential at a charged single conductor.

The electric intensity E at a distance x from the centre of the conductor in air is given by:

$$E = \frac{Q_A}{2\pi x \varepsilon_0} \text{ volts/m}$$

Q_A = charge per metre length

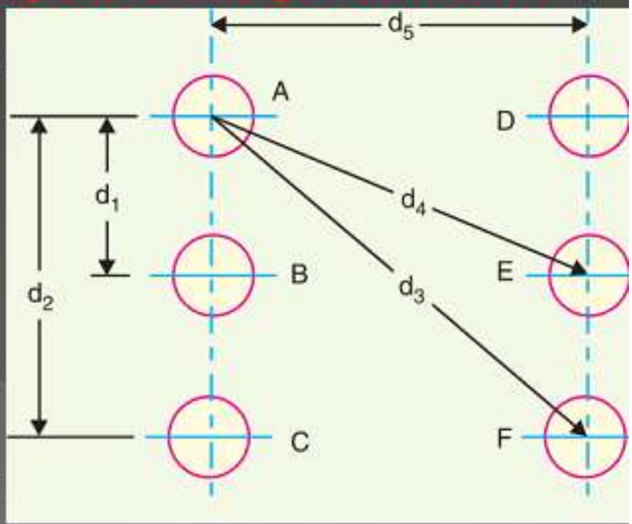
ε_0 = permittivity of free space



As x approaches infinity, the value of E approaches zero.

$$V_A = \int_r^\infty \frac{Q_A}{2\pi x \varepsilon_0} dx = \frac{Q_A}{2\pi\varepsilon_0} \int_r^\infty \frac{dx}{x}$$

(ii) Potential at a conductor in a group of charged conductors.



Potential at conductor A due to charge QA

$$= \int_r^\infty \frac{Q_A}{2\pi x \varepsilon_0} dx$$

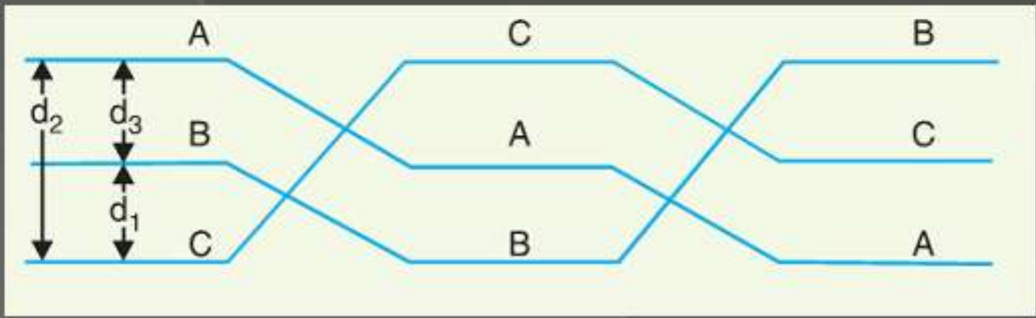
Potential at conductor A due to charge QB

$$= \int_{d_1}^\infty * \frac{Q_B}{2\pi x \varepsilon_0} dx$$

Potential at conductor A due to charge QC

$$= \int_{d_2}^\infty \frac{Q_C}{2\pi x \varepsilon_0} dx$$

(ii) Unsymmetrical spacing. a 3-phase transposed line havin unsymmetrical spacing. Let us assume balanced conditions i.e. QA + QB + QC = 0.



Potential of 1st position, $V_1 = \frac{1}{2\pi\varepsilon_0}\left(Q_A \log_e \frac{1}{r} + Q_B \log_e \frac{1}{d_3} + Q_C \log_e \frac{1}{d_2}\right)$

Potential of 2nd position, $V_2 = \frac{1}{2\pi\varepsilon_0}\left(Q_A \log_e \frac{1}{r} + Q_B \log_e \frac{1}{d_1} + Q_C \log_e \frac{1}{d_3}\right)$

Potential of 3rd position, $V_3 = \frac{1}{2\pi\varepsilon_0}\left(Q_A \log_e \frac{1}{r} + Q_B \log_e \frac{1}{d_2} + Q_C \log_e \frac{1}{d_1}\right)$

Average voltage on condutor A is

$$V_A = \frac{1}{3}(V_1 + V_2 + V_3)$$

$$= \frac{1}{3 \times 2\pi\varepsilon_0} * \left[Q_A \log_e \frac{1}{r^3} + (Q_B + Q_C) \log_e \frac{1}{d_1 d_2 d_3}\right]$$

As $Q_A + Q_B + Q_C = 0$, therefore, $Q_B + Q_C = -Q_A$

$$\therefore \quad V_A = \frac{1}{6\pi\varepsilon_0}\left[Q_A \log_e \frac{1}{r^3} - Q_A \log_e \frac{1}{d_1 d_2 d_3}\right]$$

$$= \frac{Q_A}{6\pi\varepsilon_0} \log_e \frac{d_1 d_2 d_3}{r^3}$$

$$= \frac{1}{3} \times \frac{Q_A}{2\pi\varepsilon_0} \log_e \frac{d_1 d_2 d_3}{r^3}$$

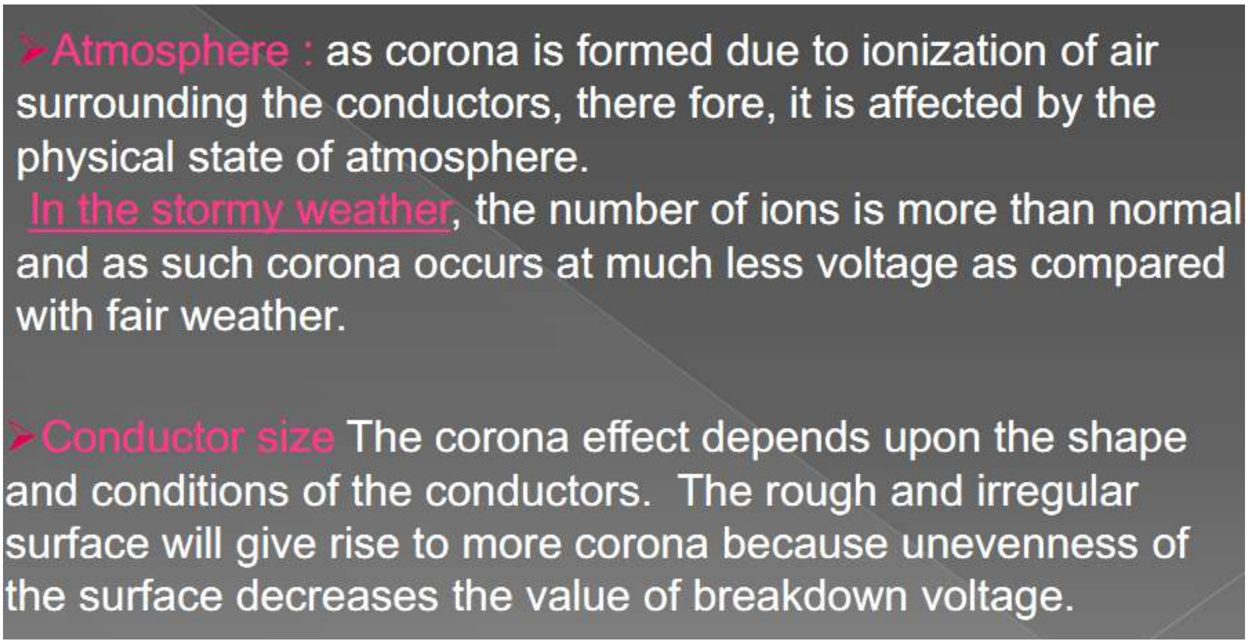
$$= \frac{Q_A}{2\pi\varepsilon_0} \log_e \left(\frac{d_1 d_2 d_3}{r^3}\right)^{1/3}$$

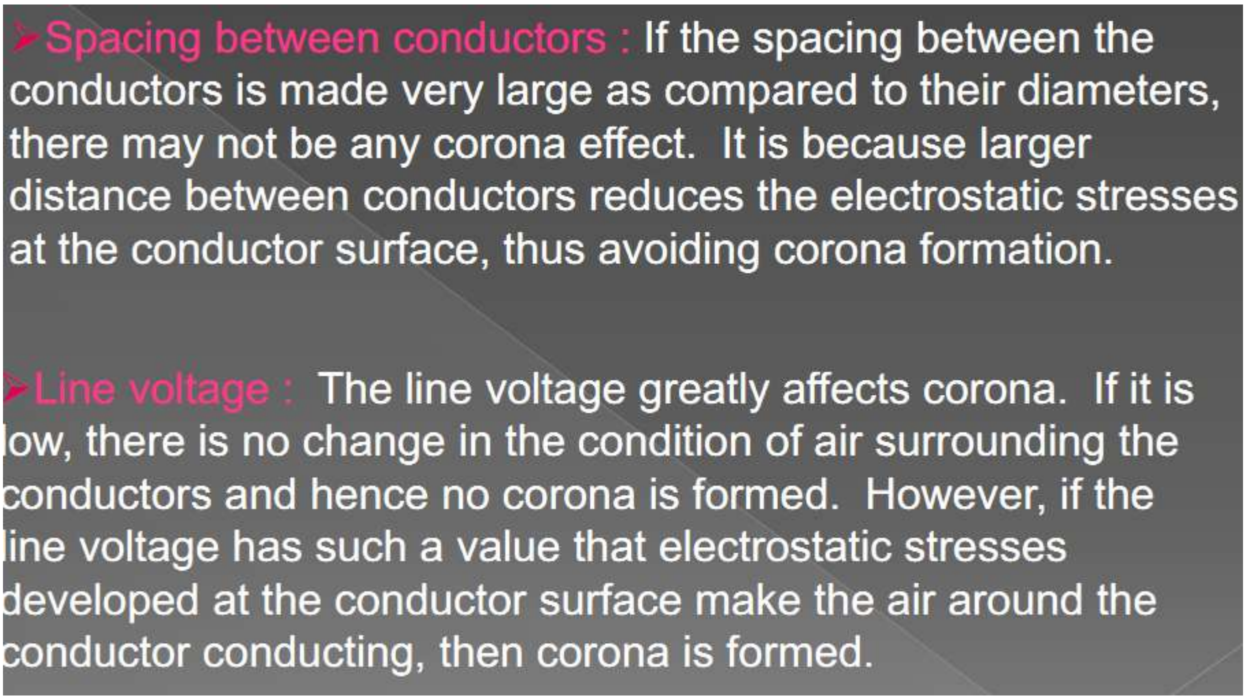
$$= \frac{Q_A}{2\pi\varepsilon_0} \log_e \frac{(d_1 d_2 d_3)^{1/3}}{r}$$

$\therefore$ Capacitance from conductor to neutral is

$$C_A = \frac{Q_A}{V_A} = \frac{2\pi\varepsilon_0}{\log_e \frac{\sqrt[3]{d_1 d_2 d_3}}{r}} \, F/m$$

e) Describe the various methods for reducing corona effect in an overhead transmission line.





<u>Question Two:</u> Answer Briefly **[20 Marks]**

a) Discuss the major different between the belted & screen cables.

Screen layer to avoid & reduced voltage gradient

b) How does skin effect vary with conductor material?

Shape of wire – less for stranded conductor than the solid conductor.

c) Discuss how we can control the overhead transmission line parameters values (R, L&C)?

$$R_2 = R_1 \, [1 + \alpha_1 \, (t_2 - t_1)]$$

where

$$\alpha_1 = \frac{\alpha_0}{1 + \alpha_0 \, t_1}$$

$$\alpha_0 = \text{temperature coefficient at } 0^\circ \text{ C}$$

$$L_A = 10^{-7}\left[\frac{1}{2} + 2\log_e \frac{d}{r}\right] \text{H / m}$$

$$C_A = \frac{Q_A}{V_A} = \frac{2\,\pi\,\varepsilon_0}{\log_e \frac{\sqrt[3]{d_1 d_2 d_3}}{r}} \; F/m$$

d) Discuss the effect of power factor improvement on transmission line efficiency?

When power factor increased this means low reactive power & low T.L current & then decreased loss

e) What is the justification in neglecting line capacitance in short transmission lines?

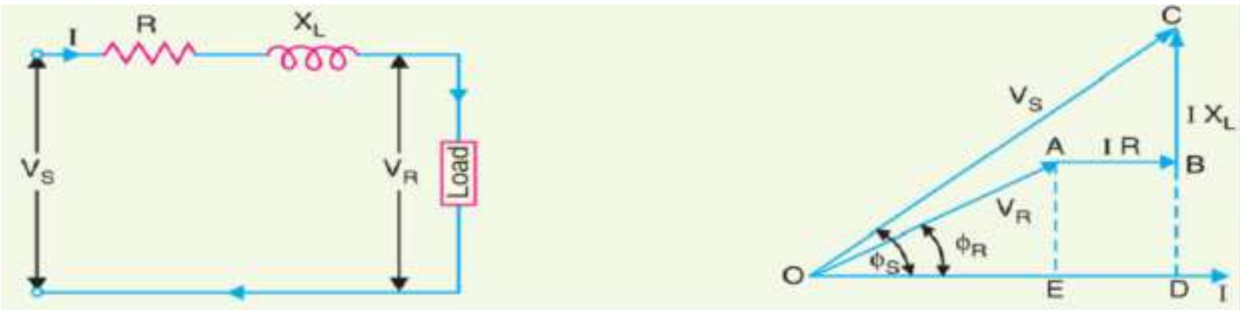
Due to smaller length and lower voltage, the capacitance effects are small and hence can be neglected.

Question Three: **Design with Drawing** **[27 Marks]**

a) The Eight Country Interconnection Project (named EIJLLPST) as shown in figure below, this project involves interconnecting the electrical grids of Egypt, Iraq, Jordan, Libya, Lebanon, Palestine, Syria, and Turkey. The interconnection line between Egypt-Jordan with some distance via Aqaba Gulf and other interconnection between all countries over land.

1) Select all system parts [Tower materials/types, Overhead T.L materials/types, Insulator materials/types, Cables construction & laying method] to connected grid between all countries.

2) Design with drawing the best performance model of overhead transmission lines between Turkey & Syria, and also between Syria & Lebanon with determine the regulation and the transmission efficiency.



$$(OC)^2 = (OD)^2 + (DC)^2$$

or $$V_S^2 = (OE + ED)^2 + (DB + BC)^2$$

$$= (V_R \cos\phi_R + IR)^2 + (V_R \sin\phi_R + IX_L)^2$$

$\therefore$ $$V_S = \sqrt{(V_R \cos\phi_R + IR)^2 + (V_R \sin\phi_R + IX_L)^2}$$

(*i*) %age Voltage regulation $= \dfrac{V_S - V_R}{V_R} \times 100$

(*ii*) Sending end *p.f.*, $\cos\phi_S = \dfrac{OD}{OC} = \dfrac{V_R \cos\phi_R + IR}{V_S}$

(*iii*) Power delivered $= V_R I_R \cos\phi_R$

Line losses $= I^2 R$

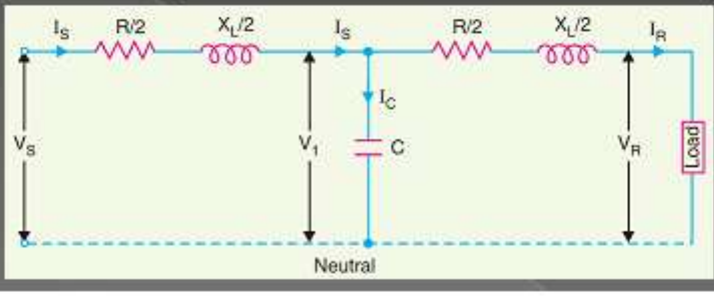
Power sent out $= V_R I_R \cos\phi_R + I^2 R$

%age Transmission efficiency $= \dfrac{\text{Power delivered}}{\text{Power sent out}} \times 100$

$$= \frac{V_R I_R \cos\phi_R}{V_R I_R \cos\phi_R + I^2 R} \times 100$$

(ii) Nominal T method

the whole line capacitance is assumed to be concentrated at the middle point of the line and half the line resistance and reactance are lumped on its either side



Let I_R = load current per phase ; R = resistance per phase

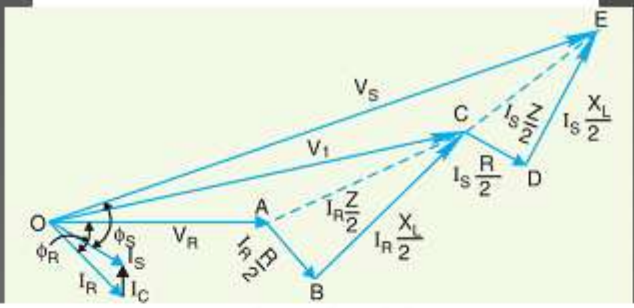
X_L = inductive reactance per phase ; C = capacitance per phase

$\cos\phi_R$ = receiving end power factor (*lagging*) ; V_S = sending end voltage/phase

V_1 = voltage across capacitor C

Receiving end voltage, $\vec{V_R} = V_R + j0$

Load current, $\vec{I_R} = I_R(\cos\phi_R - j\sin\phi_R)$



Voltage across C, $\vec{V_1} = \vec{V_R} + \vec{I_R}\vec{Z}/2$

$= V_R + I_R(\cos\phi_R - j\sin\phi_R)\left(\frac{R}{2} + j\frac{X_L}{2}\right)$

Capacitive current, $\vec{I_C} = j\omega C\vec{V_1} = j2\pi fC\vec{V_1}$

Sending end current, $\vec{I_S} = \vec{I_R} + \vec{I_C}$

Sending end voltage, $\vec{V_S} = \vec{V_1} + \vec{I_S}\frac{\vec{Z}}{2} = \vec{V_1} + \vec{I_S}\left(\frac{R}{2} + j\frac{X_L}{2}\right)$

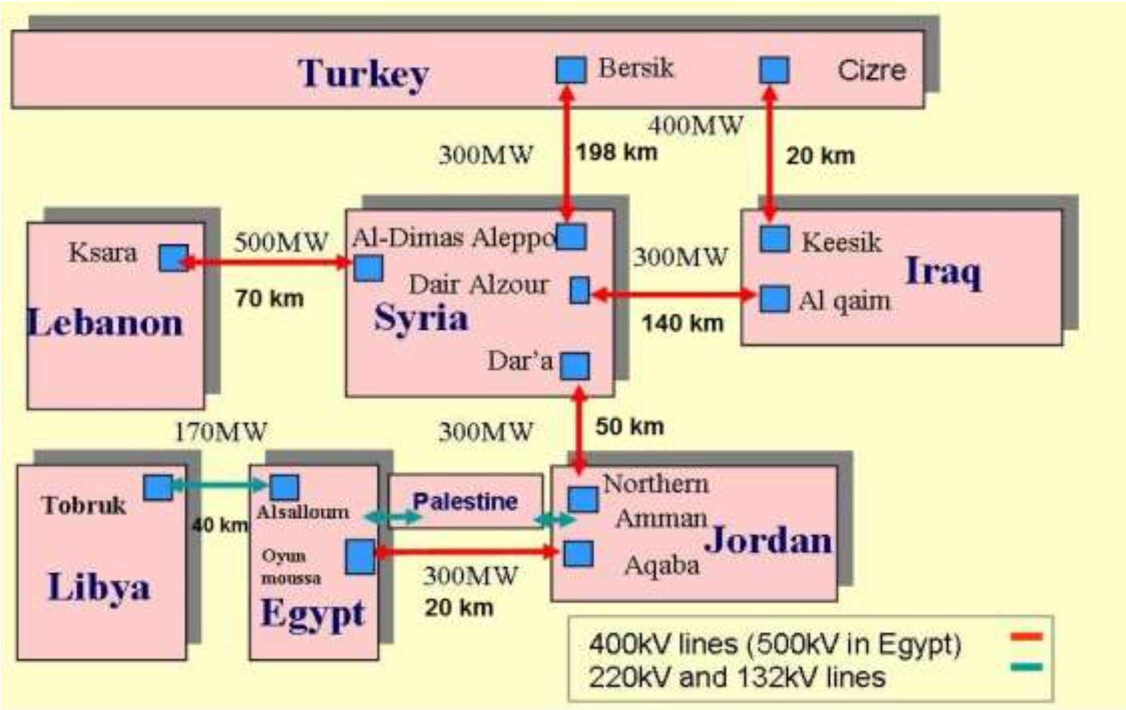
3) Design/select the underground cable rating to transmit 300 MW/500 kV between Jordan and Egypt with some distance laying in the desert, if: pf of 0.9, cable rated temperature of 90 ºC, air temperature of 45 ºC ground temperature of 45 ºC, soil resistivity of 150 ºC.cm/watt, Flat formation, four number of circuit touching, laid direct in the ground & load factor of one.

P=1.74*V*IRATED*PF

IRated= 300*1000000/1.74*500*1000*0.9=383 A

I cable= IRated/ST factor*ATfactor*SR factor*Nuber of circuit factor

=383/0.9*0.9*0.91*0.63=824 A FROM TABLE OF CABLE SELECT 800mm^2



Question Four: **[15 Marks]**

a) A 132 kV line with 1·956 cm dia. conductors is built so that corona takes place if the line voltage exceeds 210 kV (r.m.s.). If the value of potential gradient at which ionization occurs can be taken as 30 kV per cm, find the spacing between the conductors.

Solution.

Assume the line is 3-phase.

Conductor radius, $r = 1{\cdot}956/2 = 0{\cdot}978$ cm

Dielectric strength of air, $g_o = 30/\sqrt{2} = 21{\cdot}2$ kV (*r.m.s.*) per cm

Disruptive voltage/phase, $V_c = 210/\sqrt{3} = 121{\cdot}25$ kV

Assume smooth conductors (*i.e.*, irregularity factor $m_o = 1$) and standard pressure and tempera-ıre for which air density factor $\delta = 1$. Let d cm be the spacing between the conductors.

∴ Disruptive voltage (*r.m.s.*) per phase is

$$V_c = m_o g_o \delta r \log_e (d/r) \text{ kV}$$
$$= 1 \times 21{\cdot}2 \times 1 \times 0{\cdot}978 \times \log_e (d/r)$$

or $$121{\cdot}25 = 20{\cdot}733 \log_e (d/r)$$

or $$\log_e \frac{d}{r} = \frac{121{\cdot}25}{20{\cdot}733} = 5{\cdot}848$$

or $$2{\cdot}3 \log_{10} d/r = 5{\cdot}848$$

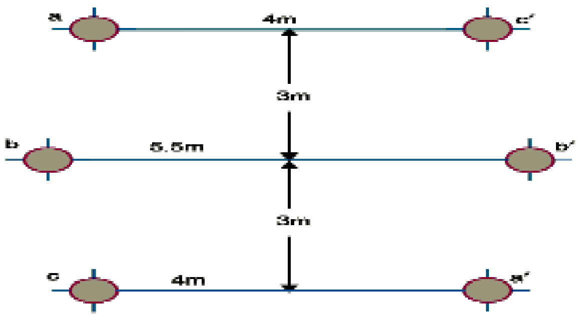
or $$\log_{10} d/r = 5{\cdot}848/2{\cdot}3 = 2{\cdot}5426$$

or $$d/r = \text{Antilog } 2{\cdot}5426$$

or $$d/r = 348{\cdot}8$$

∴ Conductor spacing, $$d = 348{\cdot}8 \times r = 348{\cdot}8 \times 0{\cdot}978 = \mathbf{341\ cm}$$

b) Find the inductance per phase per km of double circuit 3-phase line shown in Figure below. The conductors are transposed and are of radius 0·75 cm each. The phase sequence is ABC.



Solution.

G.M.R. of conductor = $0\cdot75 \times 0\cdot7788 = 0\cdot584$ cm

Distance a to b $= \sqrt{3^2 + (0\cdot75)^2} = 3\cdot1$ m

Distance a to b' $= \sqrt{3^2 + (4\cdot75)^2} = 5\cdot62$ m

Distance a to a' $= \sqrt{6^2 + 4^2} = 7\cdot21$ m

Equivalent self G.M.D. of one phase is

$$D_s = \sqrt[3]{D_{s1} \times D_{s2} \times D_{s3}}$$

where $$D_{s1} = \sqrt[4]{D_{aa} \times D_{aa'} \times D_{a'a'} \times D_{a'a}}$$

$$= \sqrt[4]{\left(0\cdot584 \times 10^{-2}\right) \times (7\cdot21) \times \left(0\cdot584 \times 10^{-2}\right) \times (7\cdot21)}$$

$$= 0\cdot205 \text{ m} = D_{s3}$$

$$D_{s2} = \sqrt[4]{\left(D_{bb} \times D_{bb'} \times D_{b'b'} \times D_{b'b}\right)}$$

$$= \sqrt[4]{\left(0\cdot584 \times 10^{-2}\right) \times (5\cdot5) \times \left(0\cdot584 \times 10^{-2}\right) \times 5\cdot5} = 0\cdot18 \text{ m}$$

$\therefore$ $$D_s = \sqrt[3]{0\cdot205 \times 0\cdot18 \times 0\cdot205} = 0\cdot195 \text{ m}$$

Equivalent mutual G.M.D. is

$$D_m = \sqrt[3]{D_{AB} \times D_{BC} \times D_{CA}}$$

where $$D_{AB} = \sqrt[4]{D_{ab} \times D_{ab'} \times D_{a'b} \times D_{a'b'}} = \sqrt[4]{3\cdot1 \times 5\cdot62 \times 5\cdot62 \times 3\cdot1}$$

$$= 4\cdot17 \text{ m} = D_{BC}$$

$$D_{CA} = \sqrt[4]{D_{ca} \times D_{ca'} \times D_{c'a} \times D_{c'a'}}$$

$$= \sqrt[4]{6 \times 4 \times 4 \times 6} = 4\cdot9 \text{ m}$$

$\therefore$ $$D_m = \sqrt[3]{4\cdot17 \times 4\cdot17 \times 4\cdot9} = 4\cdot4 \text{ m}$$

$\therefore$ Inductance/phase/m $= 10^{-7} \times 2 \log_e D_m/D_s = 10^{-7} \times 2 \log_e 4\cdot4/0\cdot195$ H

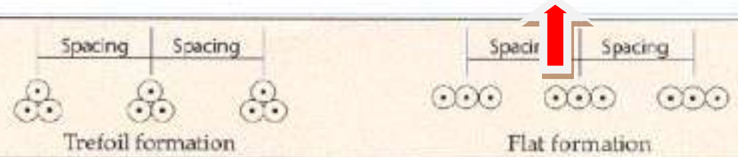
$= 6\cdot23 \times 10^{-7}$ H $= 0\cdot623 \times 10^{-3}$ mH

Inductance/phase/km $= 0\cdot623 \times 10^{-3} \times 1000 =$ **0·623 mH**

Ground temperature °C	25	30	35	40	45	50	55
PVC cables rated 70 °C	1.13	1.07	1.00	0.93	0.85	0.76	0.65
XLPE cables rated 90 °C	1.09	1.04	1.00	0.95	0.90	0.85	0.80

Air temperature °C	25	30	35	40	45	50	55
PVC cables rated 70 °C	1.22	1.15	1.08	1.00	0.95	0.82	0.71
XLPE cables rated 90 °C	1.14	1.10	1.05	1.00	0.90	0.89	0.84

Soil thermal resistivity in °C. Cm/Watt	80	90	100	120	150	200	250
Rating factor	1.17	1.12	1.07	1.0	0.91	0.80	0.73



Number of circuits	Touching		Spacing = 0.15 M		Spacing = 0.30 M	
nr	Trefoil	Flat	Trefoil	Flat	Trefoil	Flat
2	0.77	0.80	0.82	0.85	0.88	0.91
3	0.66	0.69	0.73	0.76	0.80	0.83
4	0.60	0.63	0.68	0.71	0.74	0.77
5	0.56		0.64	0.67	0.72	0.75
6	0.53	[illegible]	0.61	0.64	0.70	0.73

Ampacity

		Buried in soil û ûû	Buried in soil û ûû	Buried in soil ûûû	Buried in soil ûûû	In free air û ûû	In free air ûûû
	Load Factor	0.7	1.0	0.7	1.0	-	-
mm^2	kcmil	A	A	A	A	A	A
630	1250	954	806	1026	882	1053	1152
800	1600	1076	901	1170	998	1211	1341
1000	2000	1268	1055	1377	1166	1452	1608
1200	2400	1369	1134	1497	1261	1588	1772
1400	2750	1473	1215	1622	1361	1728	1944
1600	3200	1561	1286	1718	1440	1835	2068
2000	4000	1711	1403	1901	1585	2045	2326
2500	5000	1873	1522	2120	1751	2301	2670