ROHINI COLLEGE OF ENGINEERING & TECHNOLOGY, PALKULAM

Accredited by NAAC with A+ Grade

(AUTONOMOUS)

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

INTERNAL ASSESSMENT TEST - I

Academic Year 2023-2024 (Even Semester)

SUBJECT NAME: Transmission and Distribution
YEAR/BRANCH: II BE EEE
DATE: 17-04-2024
DURATION:3 Hours

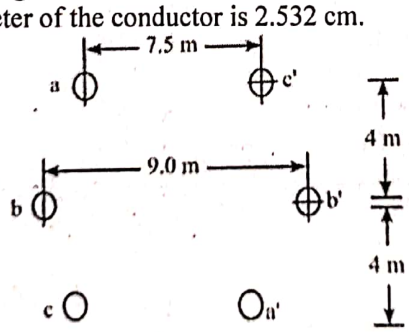
SUB CODE:EE3401
SEMESTER: IV
TIME: 09.30am-12.30pm
MAX. MARKS:100

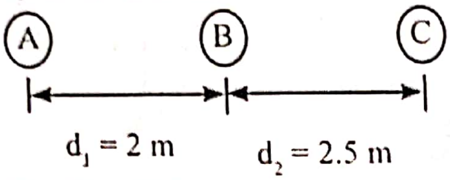
K1-REMEMBERING	K3-APPLYING	K5-EVALUATING
K2-UNDERSTANDING	K4-ANALYZING	K6-CREATING

PART A (10 x 2 = 20 marks)

Ques No	Question	Mark	CO mapping	Blooms Taxonomy
1	Infer the advantages of using bundled conductors.	2	21C212.1	K2
2	List out the parameters affecting skin effect in transmission line.	2	21C212.1	K1
3	Outline the term 'proximity effect.'	2	21C212.1	K2
4	List the different types of overhead conductors.	2	21C212.1	K1
5	Interpret the effect of leading load power factor on voltage regulation of a short transmission line.	2	21C212.2	K2
6	What are the disadvantages of corona?	2	21C212.2	K1
7	How will you reduce the corona loss?	2	21C212.2	K1
8	Infer the significance of surge impedance loading on transmission line.	2	21C212.2	K2
9	List the types of line supports used in transmission and distribution systems.	2	21C212.3	K1
10	What are the factors affecting the sag in a transmission line?	2	21C212.3	K1

PART B (5 x 16 = 80 marks)

Question No	Question	Mark	CO mapping	Blooms Taxonomy
11.a.	Model the inductance per km of a transposed double circuit 3-phase line shown in figure. Each circuit of the line remains on its own side. The diameter of the conductor is 2.532 cm. 	16	21C212.1	K3
	(or)			
11.b.	A 3-phase, 50Hz, 66kV overhead line conductors are placed in a horizontal plane as shown in figure. The conductor diameter is 1.25cm. if the line length is 100km, solve the: (i) capacitance per phase	16	21C212.1	K3

	(ii) charging current per phase, assuming complete transposition of the line.  			
12.a.	Model the expression for inductance of unsymmetrically spaced three phase line.	16	21C212.1	K3
	(or)			
12.b.	Model the expression of capacitance of a bundled conductor.	16	21C212.1	K3
13.a.	A 3-phase, 50Hz transmission line 100km long delivers 20MW at 0.9 pf lagging and at 110kV. The resistance and reactance of the line per phase per km are 0.2Ω and 0.4Ω respectively. The capacitive admittance is 2.5×10^{-6} S/km/phase. Identify: (i) the voltage at the sending end and (ii) efficiency of transmission. Use nominal T method.	16	21C212.2	K3
	(or)			
13.b.	A 275kV transmission line has the following line constants: $A=0.85\angle 5^{o}$ and $B=200\angle 75^{o}$. Identify the power at unity power factor that can be received if the voltage profile at each end is to be maintained at 275kV.	16	21C212.2	K3
14.a.	Utilize the rigorous method to model the long transmission line.	16	21C212.2	K3
	(or)			
14.b.	Illustrate the phasor diagram of a short transmission line and derive an expression for voltage regulation and transmission efficiency.	16	21C212.2	K3
15.a.	The tower of height 30m and 90m respectively support a transmission line conductor of water crossing. The horizontal distance between the towers is 500m. If the tension in the conductor is 1600kg, identify the minimum clearance of the conductor and water and clearance mid-way between the supports. Weight of conductor is 1.5kg/m. Bases of the towers can be considered to be at water level.	16	21C212.3	K3
	(or)			
15.b.	Each line of a 3-phase system is suspended by a string of 3 similar insulators. If the voltage across the line unit is 17.5kV, solve the line to neutral voltage. Assume that the shunt capacitance between each insulator and earth is 1/8th of the capacitance of the insulator itself. Also find the string efficiency.	16	21C212.3	K3

IAT I

Answer Key

Part A

1) Advantages of using bundled conductors (2 marks)

→ Self GMD increases and reactance decreases
→ Corona losses gets reduced
→ Radio interference gets reduced
→ Surge impedance loading is increased

2) Parameters affecting skin effect (2 marks)

* Nature of material
* Diameter of conductor
* Shape of conductor
* Supply frequency

3) Proximity effect (2 marks)

The non-uniform distribution of alternating current in a conductor due to the presence of other current carrying conductors in the vicinity is called proximity effect.

* It increases the conductor resistance.

4) Different types of overhead (OH) conductors (2 marks)

(i) Solid conductor
(ii) Stranded conductor
(iii) Bundled conductor
(iv) Hollow conductor
(v) AAC conductor
(vi) ACSR conductor

5) For leading load power factor, (2 marks)

(*) $\% \text{Voltage regulation} = \frac{IR\cos\phi_R - IX_L\sin\phi_R}{V_R} \times 100$

(*) $IX_L\sin\phi_R > IR\cos\phi_R \Rightarrow$ voltage regulation is negative

$\Rightarrow V_R > V_S$

(*) voltage regulation decreases with decrease in power factor

6) Disadvantages of corona (2 marks)

→ Corona affects transmission efficiency
→ Energy loss
→ Voltage drop and current are non-sinusoidal
→ Ozone gas production
→ Causes corrosion
→ Causes inductive interference.

7) Corona loss can be reduced by (2 marks)

* increasing conductor size
* increasing spacing between conductors
* using bundled conductors

8) Significance of surge impedance loading (2 marks)

a) To find the maximum permissible power transfer capability
b) To determine the compensation requirements of a line
c) It represents ideal loading
d) Power factor is unity
e) If load = SIL, voltage and current are uniform along the line
f) If load < SIL ⟹ reactive power is generated
load > SIL ⟹ reactive power is consumed

9) Different types of line supports (2 marks)

→ Wooden poles
→ Reinforced concrete poles
→ Steel poles
→ Latticed steel towers

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10) Factors affecting sag in transmission line (2 marks)

* Conductor weight
* Conductor location
* Length of span
* Temperature
* Tensile strength
* Tension

Part - B

11) Given:
a)

$$GMR = \frac{2.532}{2} \times 0.7788 = 0.986\ cm = 0.986 \times 10^{-2} m$$

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

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

$$= \sqrt[4]{(0.986 \times 10^{-2}) \times (10.96) \times (10.96) \times (0.986 \times 10^{-2})}$$

$$D_{s1} = 0.57m = D_{s3}$$

$$D_{s2} = \sqrt[4]{D_{bb} \times D_{bb'} \times D_{b'b} \times D_{b'b'}}$$

$$= \sqrt[4]{(0.986 \times 10^{-2})^2 \times 9^2}$$

$$D_{s2} = 0.3m$$

$$\therefore \boxed{D_s = 0.46m}$$

(8 marks)

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

$D_{AB} = \sqrt[4]{D_{ab} \times D_{ab'} \times D_{a'b} \times D_{a'b'}} = \sqrt[4]{7.5 \times 9.17 \times 9.17 \times}$

$= 8.3\,m$

$D_{BC} = 8.3\,m$

$D_{CA} = \sqrt[4]{D_{ca} \times D_{ca'} \times D_{c'a} \times D_{c'a'}} = \sqrt[4]{8 \times 7.5 \times 7.5 \times 8}$

$= 7.7\,m$

$D_m = 8.09\,m$

Inductance/phase/m $= 2 \times 10^{-7} \ln \frac{D_m}{D_s}$ (8 marks)

$= 5.73 \times 10^{-7}$

$= 0.573 \times 10^{-3}\,mH$

Inductance/phase/km $= 0.573\,mH$

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11) b) Equilateral spacing, $d = \sqrt[3]{d_1 \times d_2 \times d_3}$

$= \sqrt[3]{2 \times 2.5 \times 4.5} = 2.82\,m$

Radius, $r = \frac{1.25}{2} = 0.625\,cm$

Spacing, $d = 2.82\,m = 282\,cm$ (8 marks)

(i) Capacitance per phase, $C = \frac{2\pi\varepsilon_0}{\ln \frac{d}{r}} = 0.0091 \times 10^{-9}\,F/m$

$= 0.0091\,\mu F/km$

$\therefore$ C (for length of 100 km) $= 0.91\,\mu F$

(ii) Charging current per phase (8 marks)

$I_c = \frac{V_{ph}}{X_c} = \frac{66000/\sqrt{3}}{1/2\pi f C} = 10.9\,A$

Inductance of unsymmetrically spaced 3ϕ line

* diagram (5 marks)

* Inductance (11 marks)

) Capacitance of bundled conductor

) * diagram (5 marks)

* Capacitance (11 marks)

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3) 2) Given:

$R = 0.2 \times 100 = 20\,\Omega$

$X_L = 0.4 \times 100 = 40\,\Omega$

$Y = 2.5 \times 10^{-6} \times 100 = 2.5 \times 10^{-4}\,S$

$Z = 20 + j40$

$V_R = \frac{110 \times 10^3}{\sqrt{3}} = 63508\,V$

$I_R = \frac{20 \times 10^6}{\sqrt{3} \times 110 \times 10^3 \times 0.9} = 116.6\,A$

$\cos\phi_R = 0.9$

$\sin\phi_R = 0.435$

(10 marks)

(i) $\vec{V_R} = 63508\,V$

$\vec{I_R} = I_R(\cos\phi_R - j\sin\phi_R) = (105 - j50.7)$

Capacitor voltage, $\vec{V_1} = \vec{V_R} + \vec{I_R}\frac{\vec{Z}}{2} = (65572 + j1593)$

$\vec{I_c} = jY\vec{V_1} = (-0.4 + j16.4)$

$\vec{I_s} = \vec{I_R} + \vec{I_c} = (104.6 - j34.3)$

$\vec{V_s} = \vec{V_1} + \vec{I_s}\frac{\vec{Z}}{2} = (67304 + j3342)$

$|\vec{V_s}| = \sqrt{67304^2 + 3342^2} = 67387\,V$

Sending end line voltage, $V_S = 67387 \times \sqrt{3} = 116.717\,kV$

(ii) Total line losses $= 3I_S^2 \frac{R}{2} + 3I_R^2 \frac{R}{2}$ (6 mar[ks]

$= 0.770 \text{ MW}$

Transmission efficient $= \frac{20}{20+0.770} = 96.29\%$

13) b) Given: $A = 0.85\angle 5^\circ$; $B = 200\angle 75^\circ$; $V_S = V_R = 275 kV$; $\alpha = 5^\circ$; $\beta =$

Solution : Power delivered at unity pf , $P = \frac{V_S V_R}{B} \cos(\beta - \delta) -$

To finds : $Q = \frac{V_S V_R}{B} \sin(\beta-\delta) - \frac{A V_r^2}{B} \sin(\beta-\alpha) = 0 \Longrightarrow \delta = 22^\circ$ | cos((8 ma[rks]

$\therefore P = 118 \text{ MW}$ (8 marks)

14) a) Long transmission line (Rigorous method)

Diagram (4 marks)

V_R, I_R (6 marks)

V_S, I_S (6 marks)

14) b) Short transmission line

Circuit diagram (4 marks)

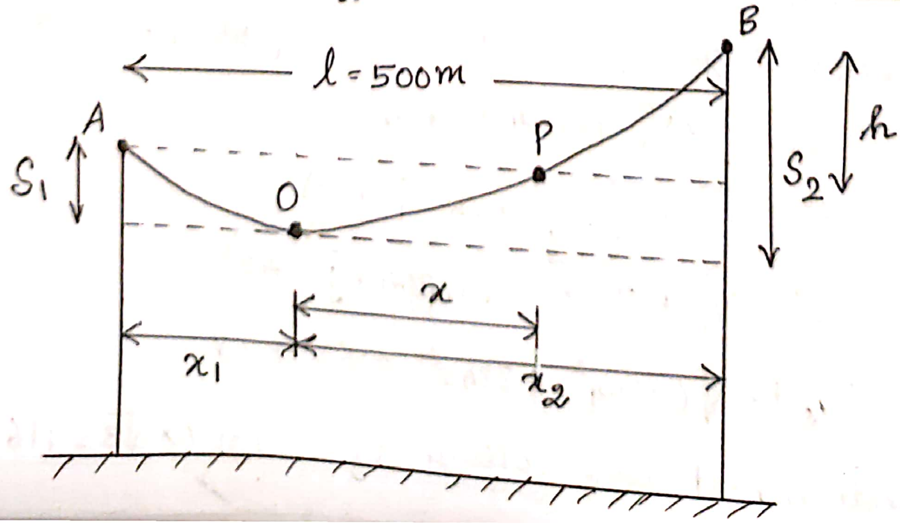
Phasor diagram (4 marks)

Derivations (4 marks)

Voltage regulation (2 marks)

Transmission efficiency (2 marks)

15) a)



(2 mar[ks]

Given:

$l = 500m$

$w = 1.5 kg/m$

$T = 1600 kg$

h = Height difference of towers $= 90 - 30 = 60m$

Solution:

Let $x_1 + x_2 = 500$ —— (1)

Sag, $S_1 = \frac{w x_1^2}{2T}$

$S_2 = \frac{w x_2^2}{2T}$

We know, $h = S_2 - S_1$

$60 = \frac{w x_2^2}{2T} - \frac{w x_1^2}{2T}$

$= \frac{w}{2T}(x_2^2 - x_1^2)$

$= \frac{w}{2T}(x_2 + x_1)(x_2 - x_1)$

$60 = \frac{1.5}{2 \times 1600} \times 500 \, (x_2 - x_1)$

$\therefore x_2 - x_1 = 256$ —— (2)

Solving (1) & (2) $\Rightarrow$ $x_1 = 122m$ (8 marks)

$x_2 = 378m$

$S_1 = \frac{1.5 \times 122^2}{2 \times 1600} = 7m$

Clearance of lowest point O from water level = 30.7

$x = 250 - x_1$

$= 250 - 122 = 128\,m$

$$S_{mid} = \frac{wx^2}{2T} = \frac{1.5 \times 128^2}{2 \times 1600} = 7.68\,m$$ (8 ma...

Clearance of mid point P from water level = 23 + 7.68 = 3...

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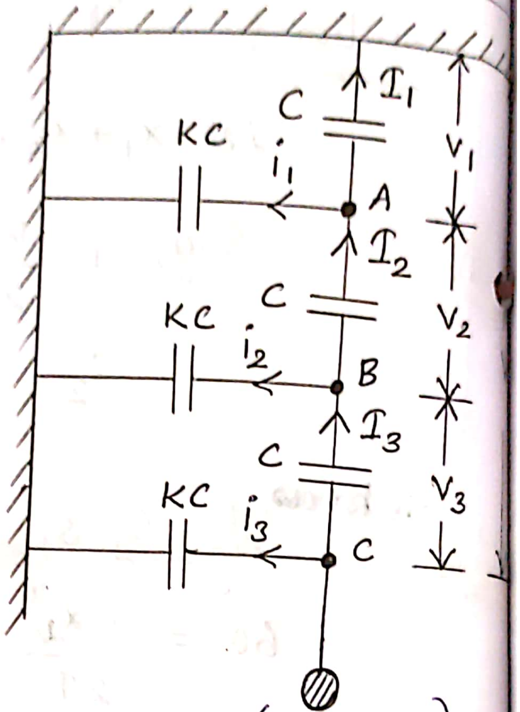
15) b) Given :

$n = 3$

$V_3 = 17.5\,kV$

$K = \frac{1}{8} = 0.125$



(6 marks)

Solution :

At A,

$I_2 = I_1 + i_1$

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

$V_2 = V_1 (1 + K)$

$V_2 = 1.125\,V_1$ —— ①

At B,

$I_3 = I_2 + i_2$

$V_3 \omega C = V_2 \omega C + (V_1 + V_2)\,\omega K C$ (6 marks)

$V_3 = V_2 (1 + k) + V_1 K$

$= [(1.125\,V_1) \times (1.125)] + 0.125\,V_1$

$V_3 = 1.39\,V_1$ —— ②

$\therefore V_1 = \frac{V_3}{1.39} = \frac{17.5}{1.39} = 12.59\,kV$

$V_2 = 1.125\,V_1 = 14.16\,kV$

Line to neutral voltage = $V_1 + V_2 + V_3 = 44.25\,kV$;

(4 mar...)

String efficiency

$\eta = \frac{\text{Voltage across the string}}{n \times \text{Voltage across the unit nearest to conductor}}$

$= \frac{44.25}{3 \times 17.5} \times 100$

$\eta = 84.28\,\%$

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PROGRESS THROUGH KNOWLEDGE

INTERNAL ASSESSMENT NOTE BOOK

Internal Assessment : First / Second / Third

Name of the Student	S. Ari Ram				
Roll No.	09	Register Number	963322105010		
College Code	9 6 3 3	College Name	Rohini College of Engineering & Technology		
Degree/Branch	BE/EEE	Section	-	Semester	04
Subject Code	EE3401	Date & Session	17/4/24		
Subject Title	Transmission and Distribution				

No. of Pages Used	11	All Particulars Given are Verified	Signature of the Hall Superintendent with Date
		Name of Hall Superintendent	Rajiv Cechil

PART - A				PART - B & C					
						(I)		(II)	
QUESTION No.	CO	MARKS		QUESTION No.		CO	MARKS	CO	MARKS
1	2	6	2	11	A				
					B	16			
2	2	7	2	12	A	16			
					B				
3	2	8		13	A	12			
					B				
4	2	9	2	14	A				
5	2	10	2		B	16			

15 A/B 16

Grand Total (in words)	90/100	Signature of the Examiner
Grand Total		

Instructions to the Candidates :

1. Write your register number at the top right hand side of the QUESTION PAPER
2. Check THE REGULATION, DEGREE, BRANCH, SEMESTER, SUBJECT CODE / TITLE OF THE QUESTION PAPER BEFORE ANSWERING THE QUESTIONS.
3. Answers must be legibly written in ink (Blue or Black)
4. POSSESSION OF ANY INCRIMINATING MATERIAL AND MALPRACTICE OF ANY NATURE SHALL BE PUNISHABLE AS PER RULES.
5. Do not write anything apart from REGISTER NUMBER IN THE QUESTIONS PAPER.

VISION

To be an academic institute of continuous excellence towards education and research in rural regime and provide service to nation in terms of nurturing potentially higher social, ethical and engineering companion graduands.

MISSION

- To foster and promote technically competent graduands by imparting the state of art Engineering education in rural regime.
- To enunciate research assisted scientific learning by dissemination of knowledge towards science, agriculture, industry and national security.

V-2

PART - A			PART - B & C					
QUESTION No.	CO	MARKS	QUESTION No.		(I) CO	(I) MARKS	(II) CO	(II) MARKS
1			6	A				
2				B				
3			7	A				
4				B				
5			8	A				
				B				
			9	A				
				B				

Grand Total (in words)	
Grand Total	

Signature of the Examiner

Part - A

1.) *) Self increased ~~Gap~~ GMD and
*) corona loss is less
*) Radio interference is low
*) Surge impedance load is increased

2.) *) Nature of the material
*) shape of the conductor
*) size of the conductor
*) frequency of the supply

3.) The non-uniform distribution of ~~an~~ alternating current in a conductor due to the presence of the current carrying conductor in the vicinity is called proximity effect.

4.) *) solid conductor
*) stranded conductor
*) Hallow conductor
*) Bundled conductor
*) ~~ASR~~ ACSR conductor
*) AAC conductor

5.) % voltage regulation = $\frac{IR\cos\phi_R - IX_L\sin\phi_R}{V_R} \times 100$

if $IX_L\sin\phi_R > IR\cos\phi_R$, ~~The vol~~ it will be negative
$V_R > V_S$

6.) *) Energy loss
*) lower the efficiency
*) produce ozone gas
*) starts corossion

2

7.) *) By increasing the capacitor size
*) By increasing the distance between the conductors.
*) By using Bundled conductor.

2

8.)

9.) *) wooden poles
*) Reinforced concrete poles
*) steel poles
*) latticed steel poles

2

10.) *) weight of the conductor
*) location of the conductor
*) Temperature
*) Tensile strength
*) wind

2

Part-B

11.) b.) Given:-

$d_1 = 2m$

$d_2 = 2.5m$

$d_3 = 4.5m$

$d = 1.25cm$

$r = \frac{1.25}{2} = 0.625\ cm$

$S = \sqrt[3]{d_1 d_2 d_3}$

$= \sqrt[3]{2+2.5+4.5} = 2.82\ m$

$S = 282cm$

i) Capacitance per phase:-

$C = \frac{2\pi\varepsilon_0}{\ln d/r} =$

$= \frac{2\times3.14\times8.854\times10^{-12}}{\ln\frac{1.25}{0.625}}$

$= 0.91\times10^{-6}\ \mu F/m$

~~C = 0.91 μF/km~~

$= 0.91\times10^{-3}\ \mu F/Km$

for 100 Km 0.091 μF

ii) charging current per phase :-

$$I_c = \frac{\frac{6600}{\sqrt{3}}}{\frac{1}{2\pi \times 50 \times 0.91}}$$

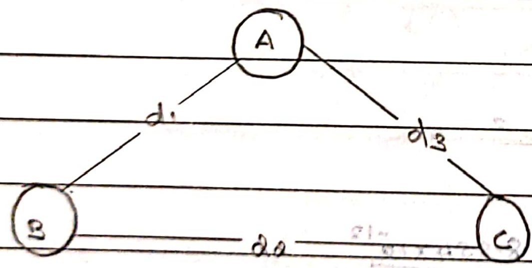
$$I_c = 10.9\ A$$

Result :-

$C = 0.91 \times 10^{-3}\ \mu F/km$

$I_c = 10.9\ A$

12.) a.) Consider a 3 phase conductors A, B, C carrying a curr... of I_A, I_B, I_C with a equal distance between the Conductors with a distance of d_1, d_2, d_3



when they are carrying equal amount of current then,

$$I_A + I_B + I_C = 0 \quad \text{——} (1)$$

when the distance between the conductors are not equal and at equidistant from each other conductors, this case is called unsymmetrically spaced three phase line. Due to this the inductance and capacitance will act and change the current in the conductors.

In order to equalize the current in the conductors, its positions will be changed. This is called as transposition. Even though the supply voltage is equal, the voltage in the conductors will differ due to the unequal distance of the conductors.

Let us consider that the conductors are at equidistance and the voltage (or) current in the conductors are equal, Then,

$$I_A = (1 + j0)$$

$$I_B = (-0.5 \mp j0.866)$$

$$I_C = (-0.5 + j0.866)$$

$$\psi_A = \frac{\mu_0}{2\pi}\left[(1/4 + \ln r) I - I(-0.5 - j0.866) \ln d_2 - I(-0.5 + j0.866) \ln d_3 \right]$$

$$= \frac{\mu_0 I}{2\pi}\left[1/4 + \ln r + 0.5 \ln d_2 + 0.5 \ln d_3 + j0.866 \ln d_2 - j0.866 \ln d_3 \right]$$

$$= \frac{\mu_0}{2\pi}\left[\ln(e^{1/4}) + \ln \frac{\sqrt{d_2 d_3}}{r} + j0.866 \ln + \ln \frac{d_3}{d_2} \right]$$

$$\frac{\psi_A}{I_A} = \frac{\psi_n}{I} = \frac{4\pi\times10^{-7}}{2\pi}\left[\ln\frac{1}{r'} + \ln\sqrt{d_2d_3} + \ln\sqrt{01.732d}\ \sqrt{d_3/d}\right]$$

$$L_A = 2\times10^{-7}\left[\ln\frac{1}{r'} + \ln\sqrt{d_2d_3} + \ln\sqrt{d_3/d_2}\right] \text{ H/m}$$

$$L_B = 2\times10^{-7}\left[\ln\frac{1}{r'} + \ln\sqrt{d_3d_1} + \ln\sqrt{d_3/d_2}\right] \text{ H/m}$$

$$L_C = 2\times10^{-7}\left[\ln\frac{1}{r'} + \ln\sqrt{d_1d_2} + \ln\sqrt{d_3/d_2}\right] \text{ H/m}$$

13.2a) Soln:-

$R = 0.2\times100 = 20\ \Omega$

$X_L = 0.4\times100 = 40\ \Omega$

$Y = 2.5\times10^{-6}\times100 = 2.5\times10^{-4}$ S

$Z = (20+j40)$

$$V_R = \frac{110\times10^3}{\sqrt{3}} = 63508.5$$

$P_R = 20MW$ (or) 2×10^6

$$I_R = \frac{2\times10^6}{\frac{110\times10^{-3}}{\sqrt{3}}\times0.9} =$$

$\cos\phi_R = 0.9$

$\sin\phi_R = 0.435$

$\vec{V_R} = 63508.5$

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

$\vec{V_1} = \vec{V_R} + \vec{I_R} + \vec{Z}/2$

ii) efficiency transmission :-

$$= 3I_R^2 \, R/2 + 3I_S^2 \, R/2$$

$$\frac{20}{20+0.770} =$$

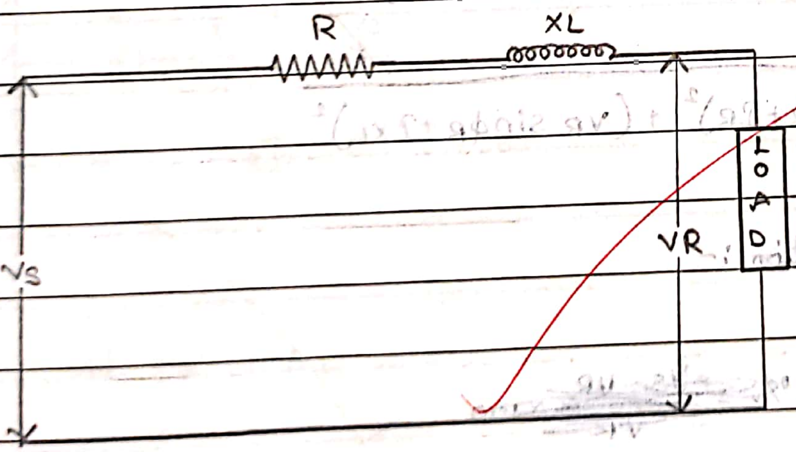
= ~~0.770~~

$$= 0.962$$

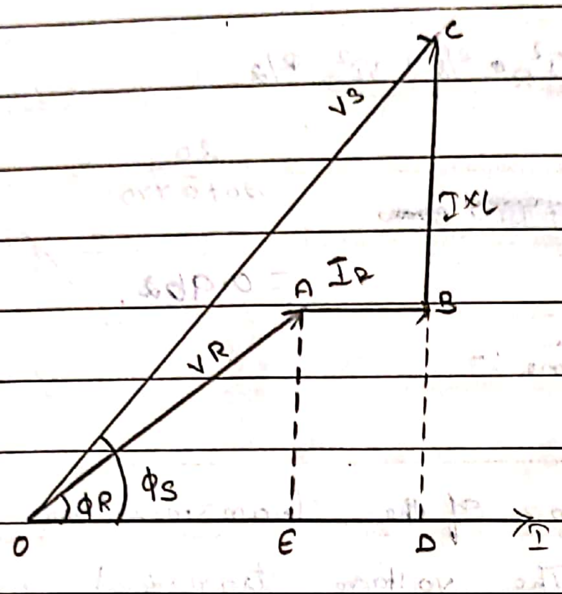
14b) short transmission line :-

The distance of the transmission line must be less than 50 Km. The voltage transfered will be less than 22 KV and also due to the short distance, the capacitance won't act in this transmission. only the inductance and Resistance will act on this short transmission line.

Circuit Diagram :-



Phasor diagram :-



In the right angle triangle

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

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

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

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

i) % Voltage Regulation :-

$$\% = \frac{V_S - V_R}{V_R} \times 100$$

$$\% = \frac{IR\cos\phi_R + IX_L \sin\phi_R}{V_R} \times 100$$

$$\cos\phi_R = \frac{OD}{OC} = \frac{I_R \cos\phi_R}{V_R}$$

$$\boxed{\frac{V_F \cos\phi_R + I R}{V_R}}$$

(To be continued...)

15.) b.)

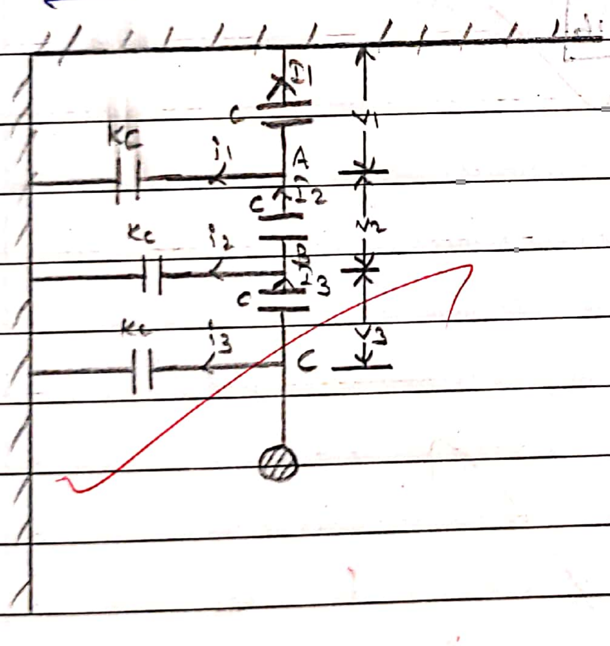
Gn:-

$V_3 = 17.5$ kV

$n = 3$

$k = 1/8 = 0.125$

Diagram:-



At point A,

$I_2 = I_1 + i_1$

$V_2 = V_1(1+K)$

$\boxed{V_2 = 1.125 V_1}$

At point B,

$V_3 = V_2(1+K) + V_1 K$

$= ((1.125 V_1) \times 1.125) + 0.0125 K$

$V_3 = 0.159 V_1$

$V_1 = \frac{V3}{0.159}$

$V_1 = \frac{17.5}{0.159}$

$V_1 = 12.59$ kV $V_2 = 14.16$

line to neutral voltage

$= V_1 + V_2 + V_3$

$= 12.59 + 14.16 + 17.5$

$= 44.25$ kV

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iii) string efficiency :-

$\eta = \frac{44.25}{3 \times 17.5}$

$\eta = 84.28\ \%$

Part B

4.b) ii) Transmission efficiency :-

$$\eta = \frac{\text{Power delivered}}{\text{Power supplied}} \times 100$$

$$= \frac{V_R I_R \cos\phi_R}{V_S I_S \cos\phi_S} \times 100$$

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

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

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