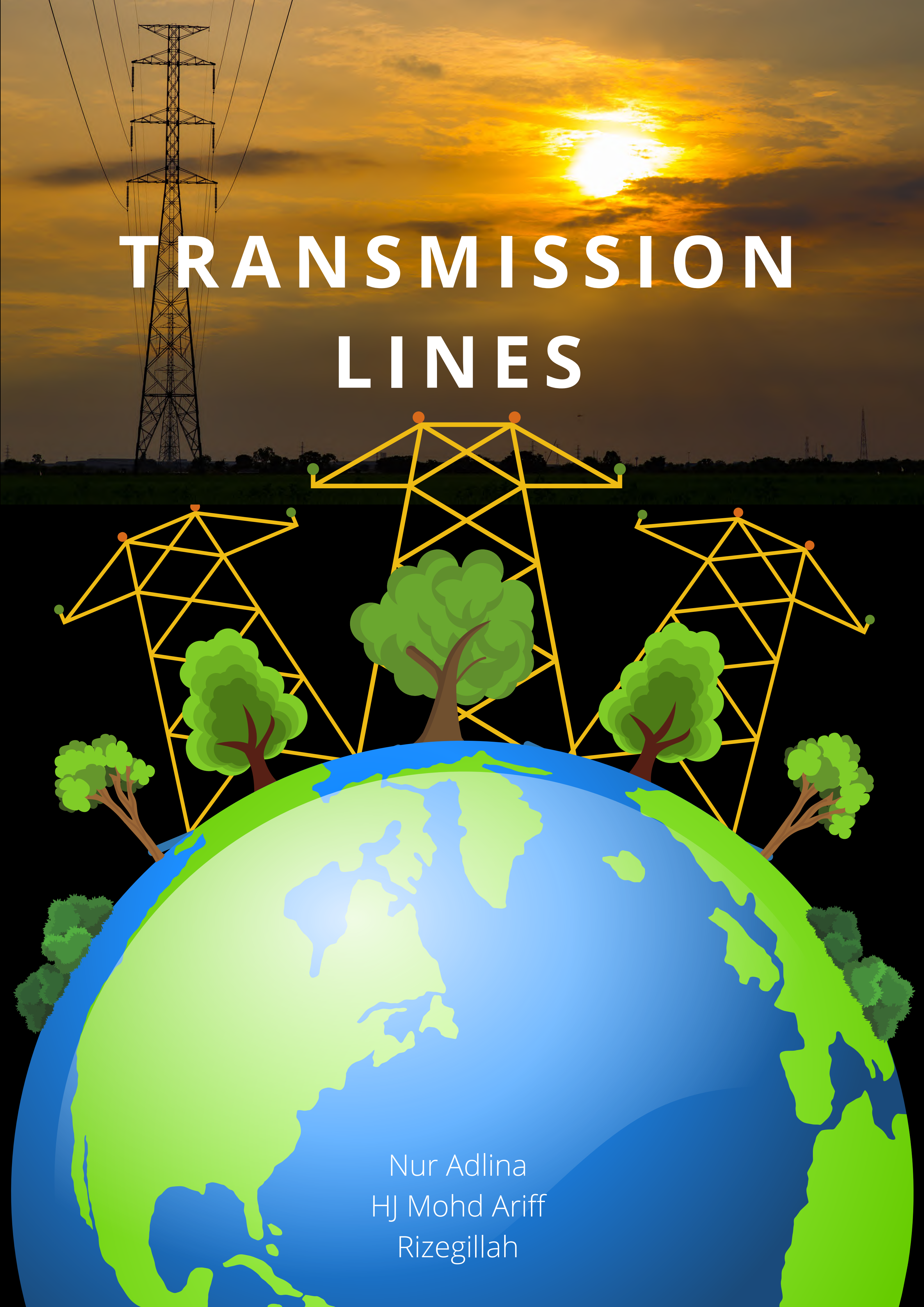
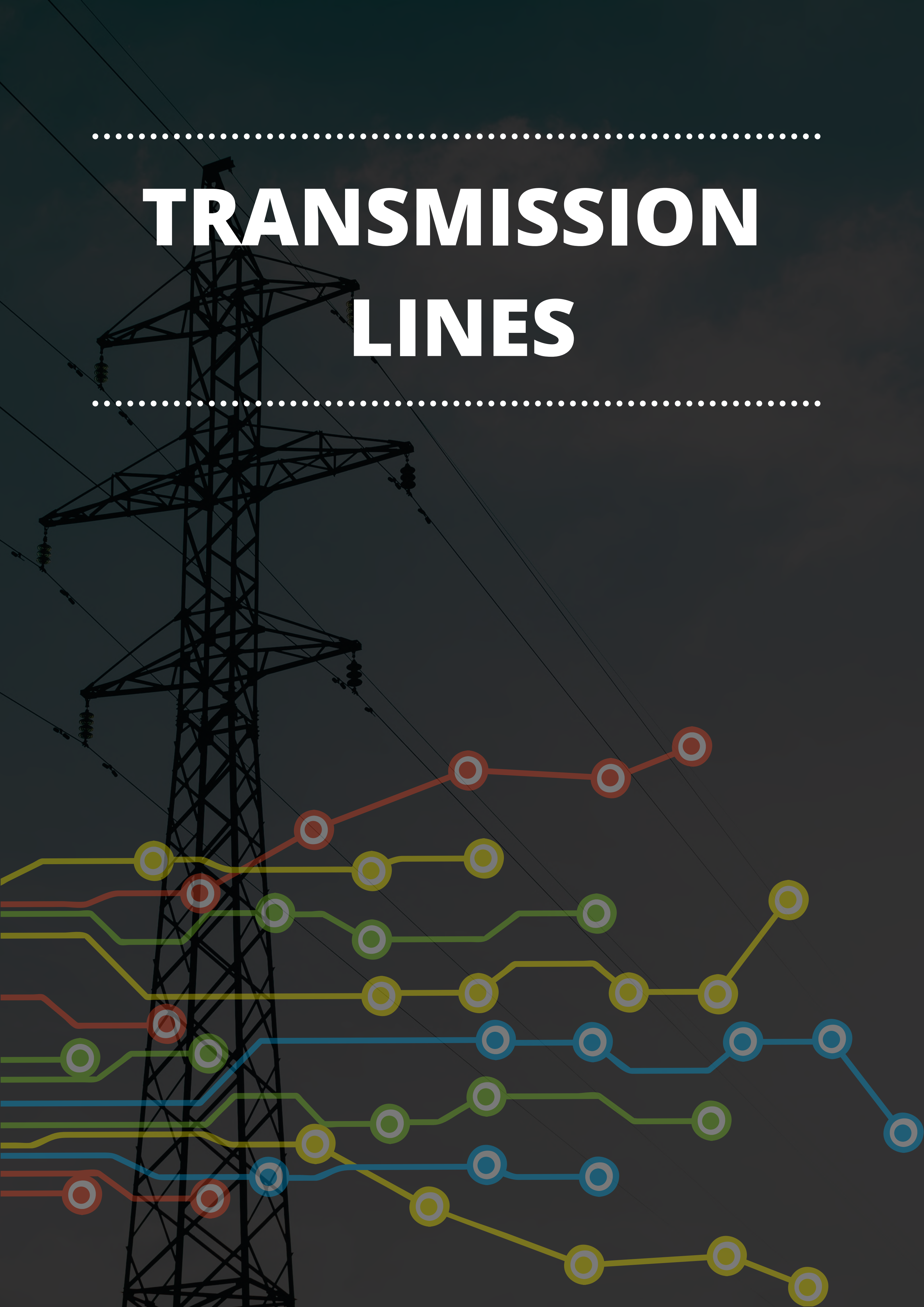
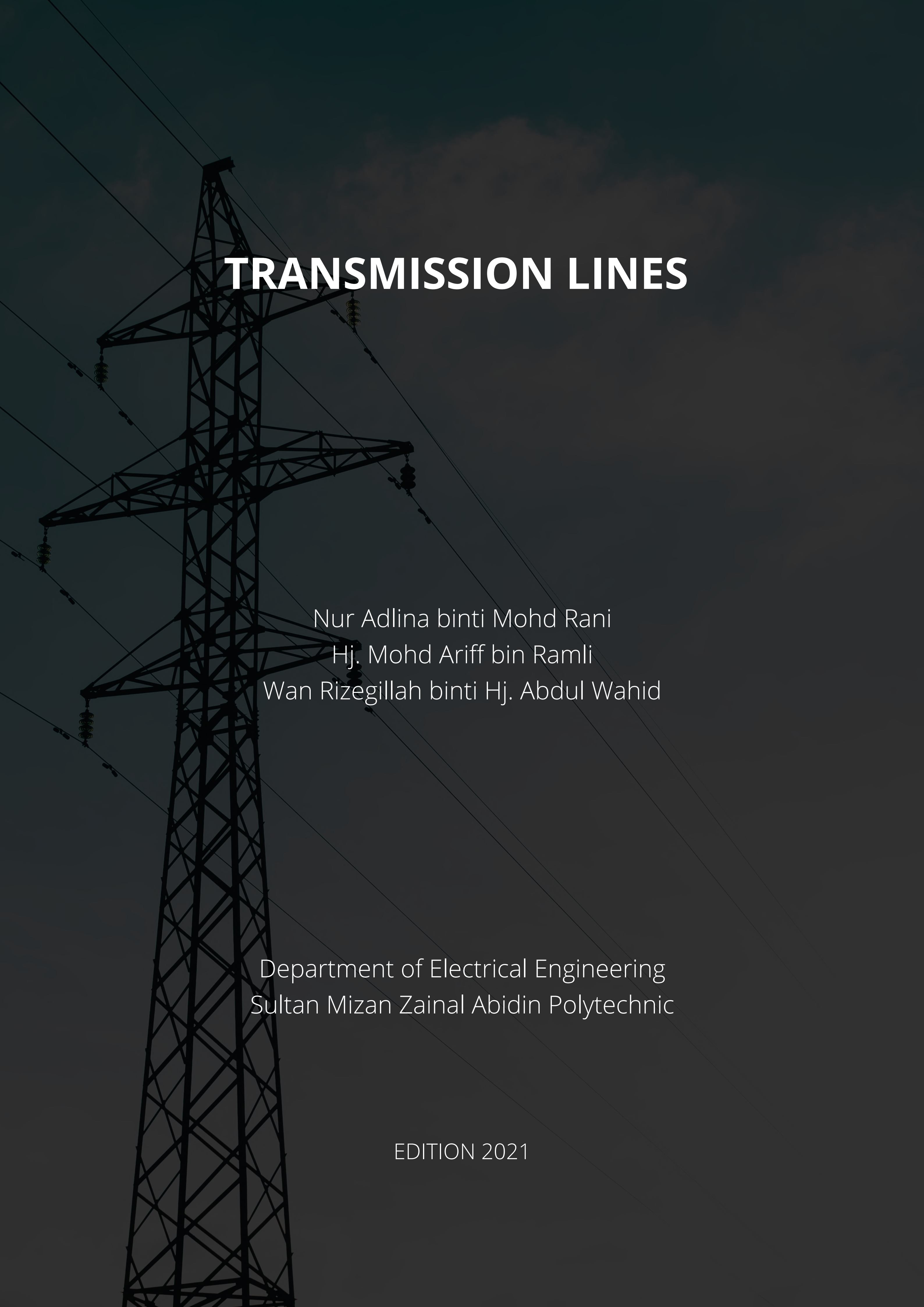


TRANSMISSION LINES

Nur Adlina
HJ Mohd Ariff
Rizegillah

TRANSMISSION LINES





TRANSMISSION LINES

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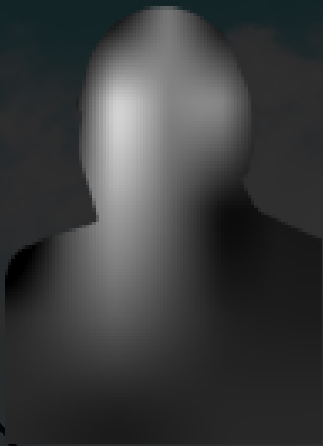
PREFACE

In the name of Allah, The Most Gracious and Merciful. All praise to Allah S.W.T for His great loving kindness and blessing, this E-book is successfully published.

The authors would like to express deepest appreciation to all those who provided the possibility in publishing this E-book especially friends and colleagues. Many thanks also go to the Electrical Engineering Department team for the support and guidance throughout the process of completing this E-book.

Thank You.

AUTHOR



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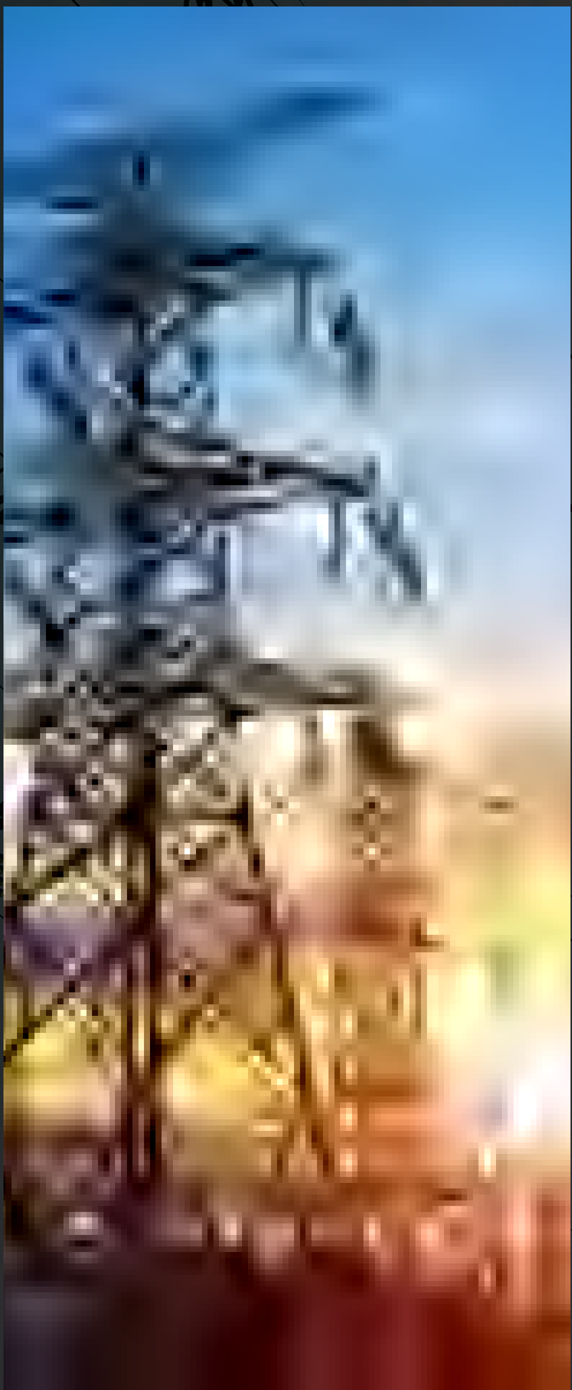
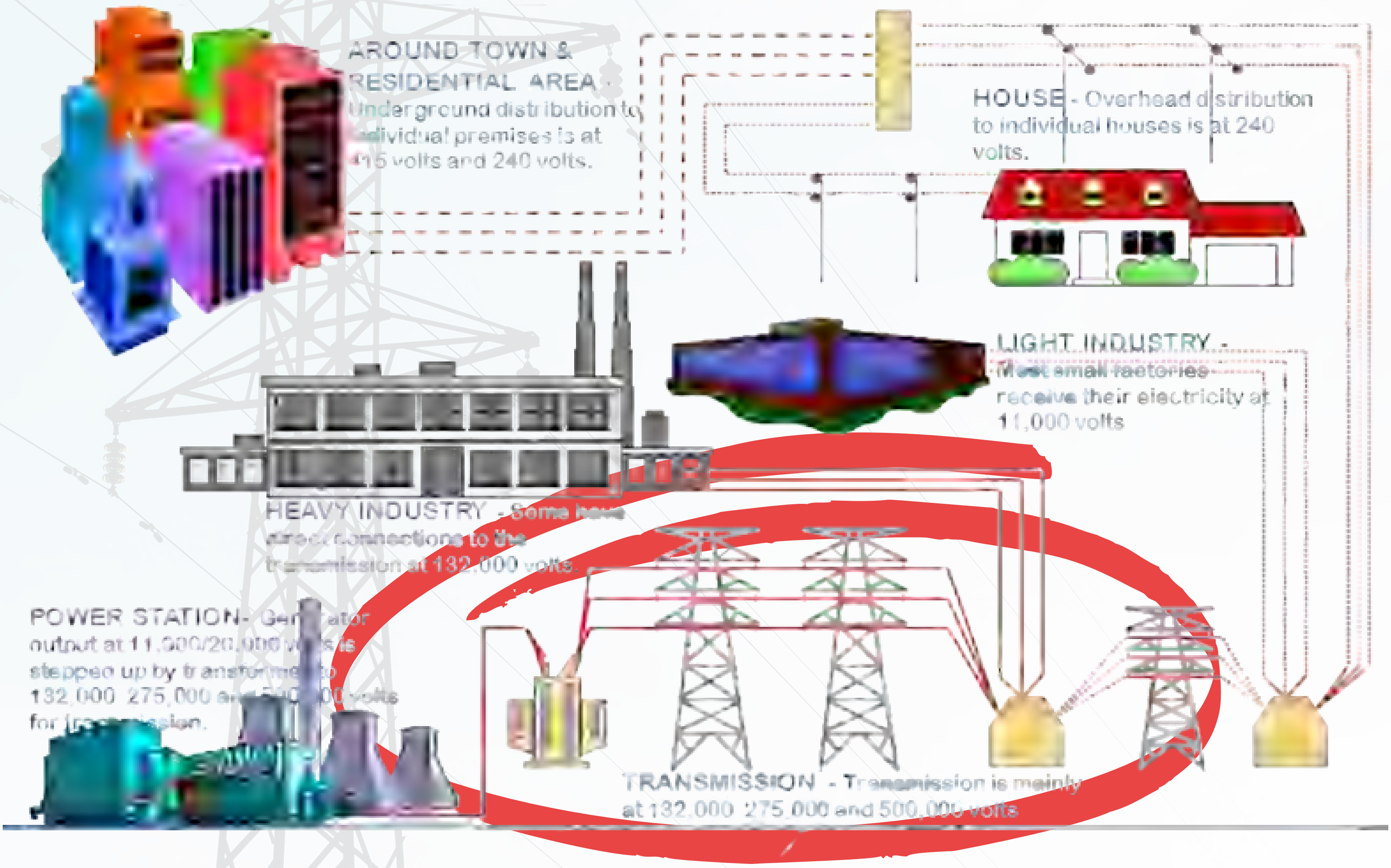


TABLE OF CONTENT

ABSTRACT

This digital writing will provide students with the concepts of transmission lines of electrical power system such as their functions, types of transmission lines, equivalent circuit diagram, single phase phasor diagram, voltage regulation, the losses in transmission line, and the transmission insulators. It is organized base on syllabus of Power System (DET30053) course, Department of Electrical Engineering, Polytechnic of Malaysia.

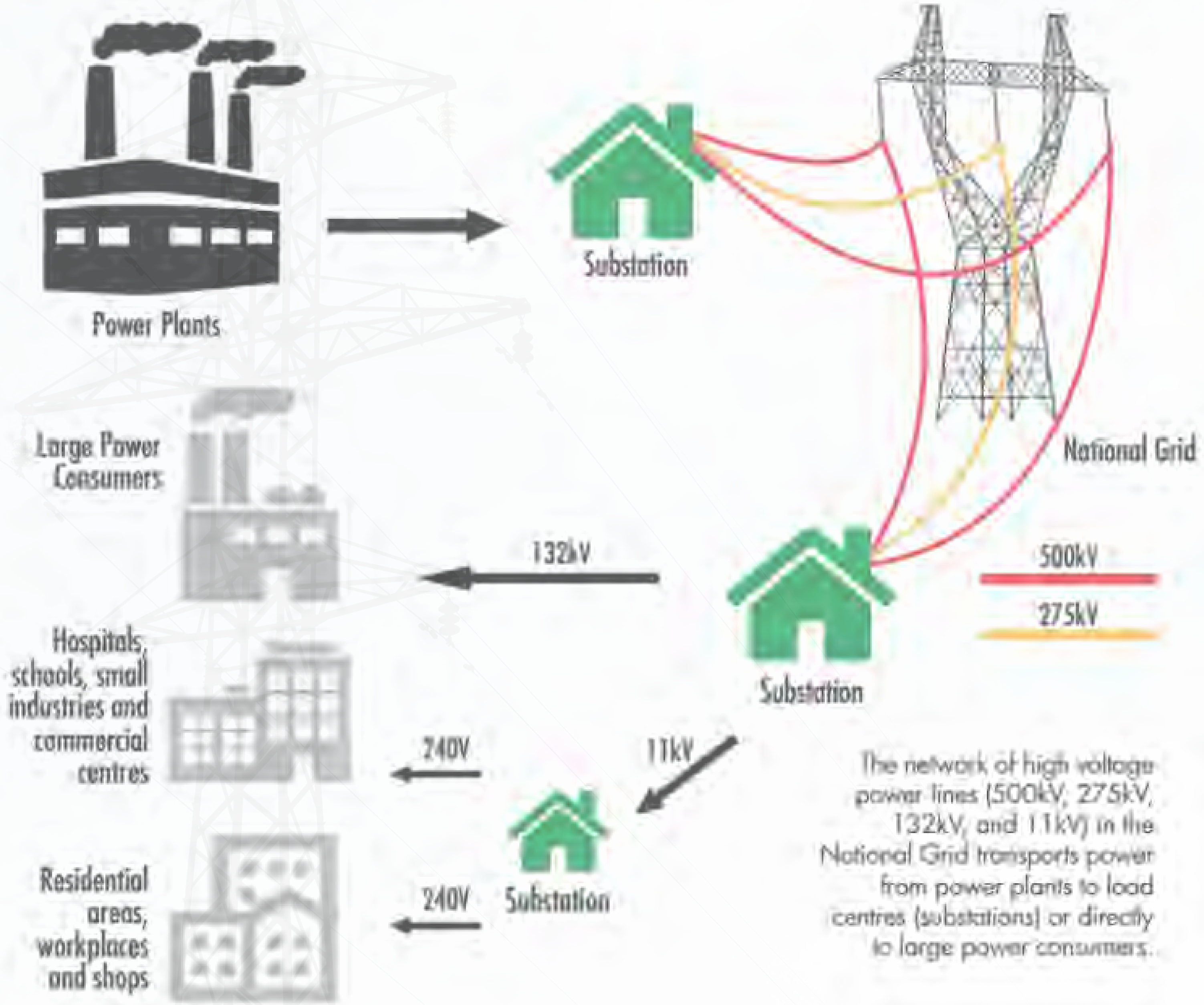
INTRODUCTION TO
TRANSMISSION LINES



An Overview

National Grid System

Source: Tenaga Nasional Berhad

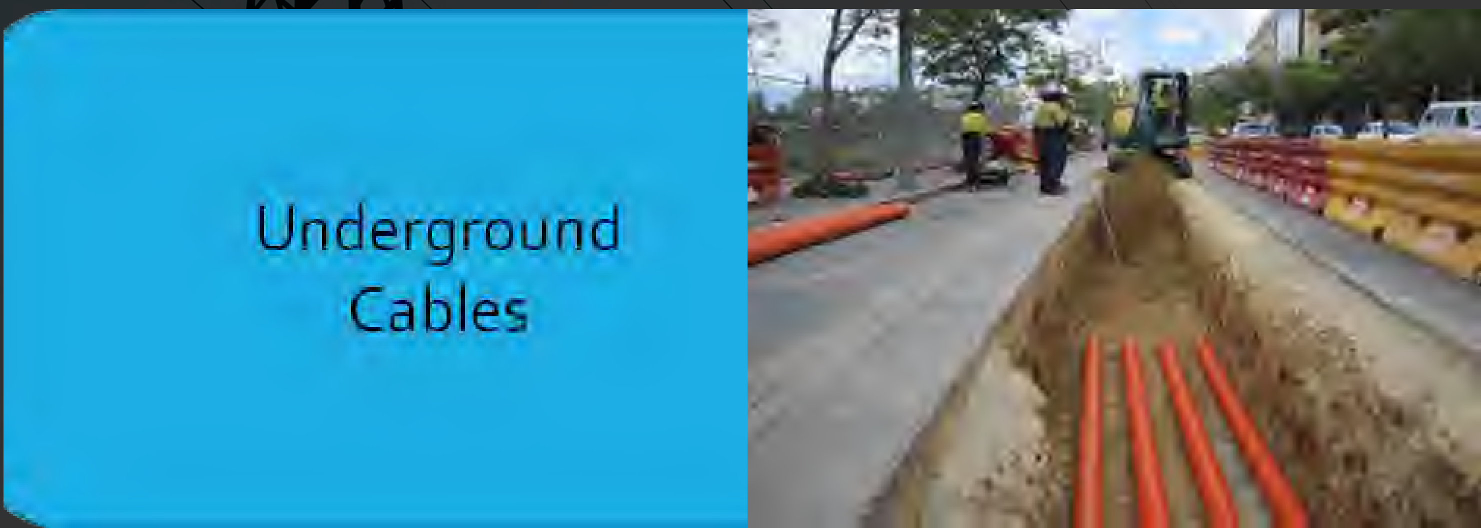


Source: Tenaga Nasional Berhad

FUNCTION OF TRANSMISSION LINES

A **TRANSMISSION LINES** is used for transmission of electrical power from generating substation to the various distribution units. It transmits the wave of voltage and current from one end to another. The transmission line is made up of conductor having a uniform cross-section along the line. Air act as an insulating or dielectric medium between the conductors.

TYPES OF TRANSMISSION LINES



Short Transmission Line

Medium Transmission Line

Long Transmission Line

Short Transmission Line

- Length of an overhead transmission line up to about **80km** and line voltage comparatively low **(<20kV)**
- The **capacitance effects** are small and can be **neglected**
- Only **resistance** and **inductance** of the line are **taken into account**

Medium Transmission Line

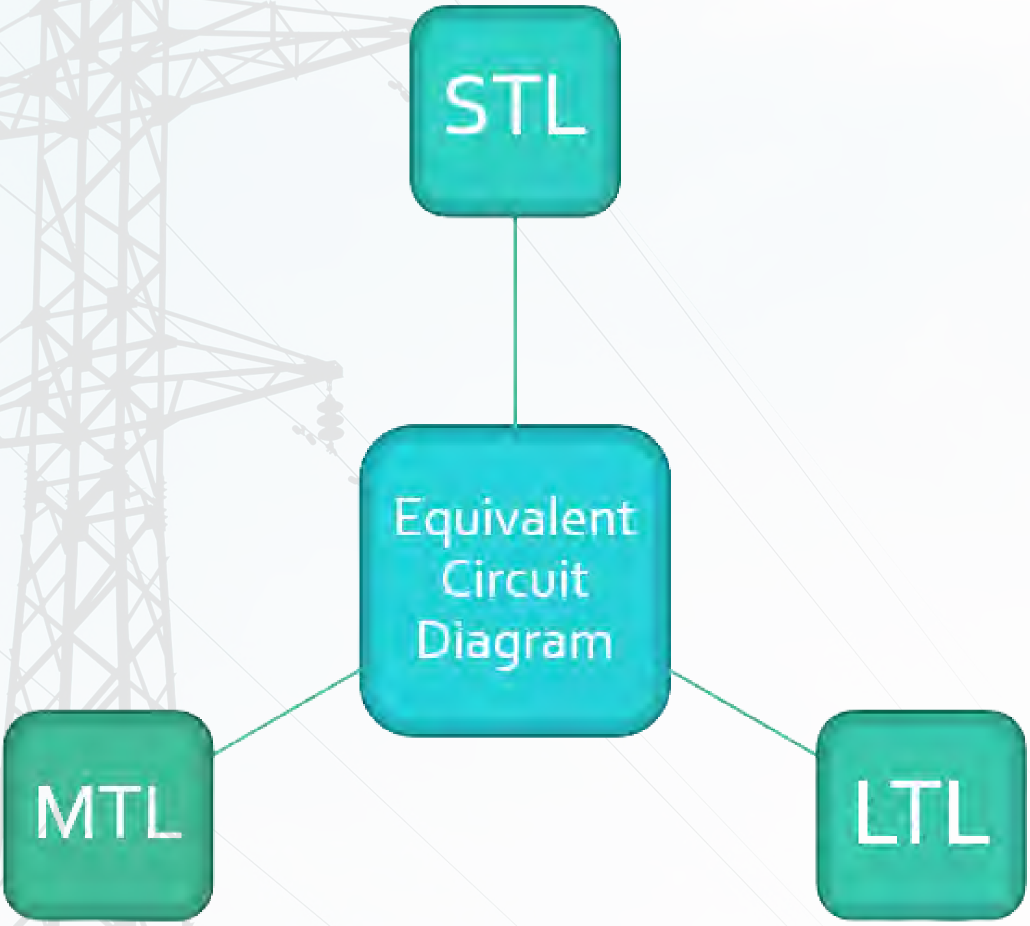
- Length of an overhead transmission line is about **80 – 240km** and the line voltage is moderately high **(>20kV < 100kV)**
- The **capacitance effect** are **taken into account**

Long Transmission Line

- Length of overhead transmission line is **> 240km** and line voltage is very high **(> 100kV)**
- For the treatment of such a line, the **line constants are considered uniformly distributed over the whole length** of the line and rigorous methods are employed for solution

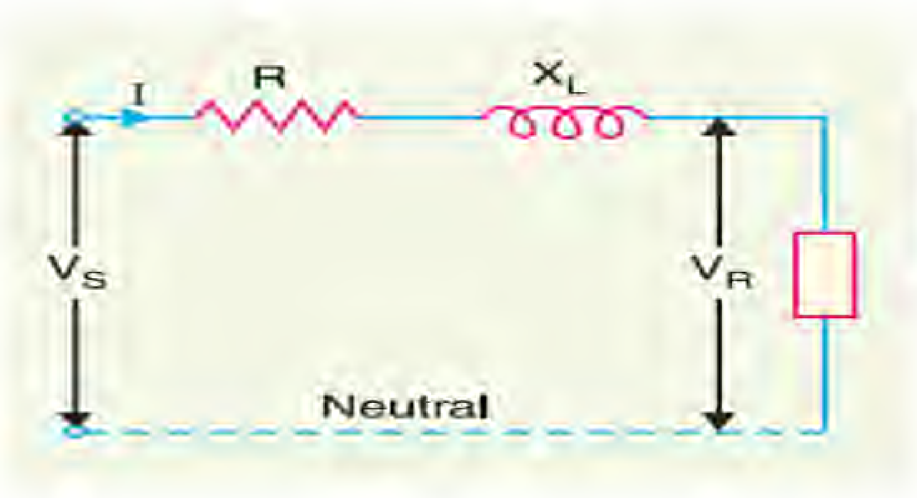
	Short Transmission Line	Medium Transmission Line	Long Transmission Line
Length	<80km	81km – 240km	>240km
Operating voltage	<20kV	21kV – 100kV	>100kV
Element Effected	Resistance Inductance	Resistance Inductance Capacitance	Resistance Inductance Capacitance Conductance

Equivalent Circuit Diagram for Transmission Lines



Equivalent Circuit Diagram for Short Transmission Line

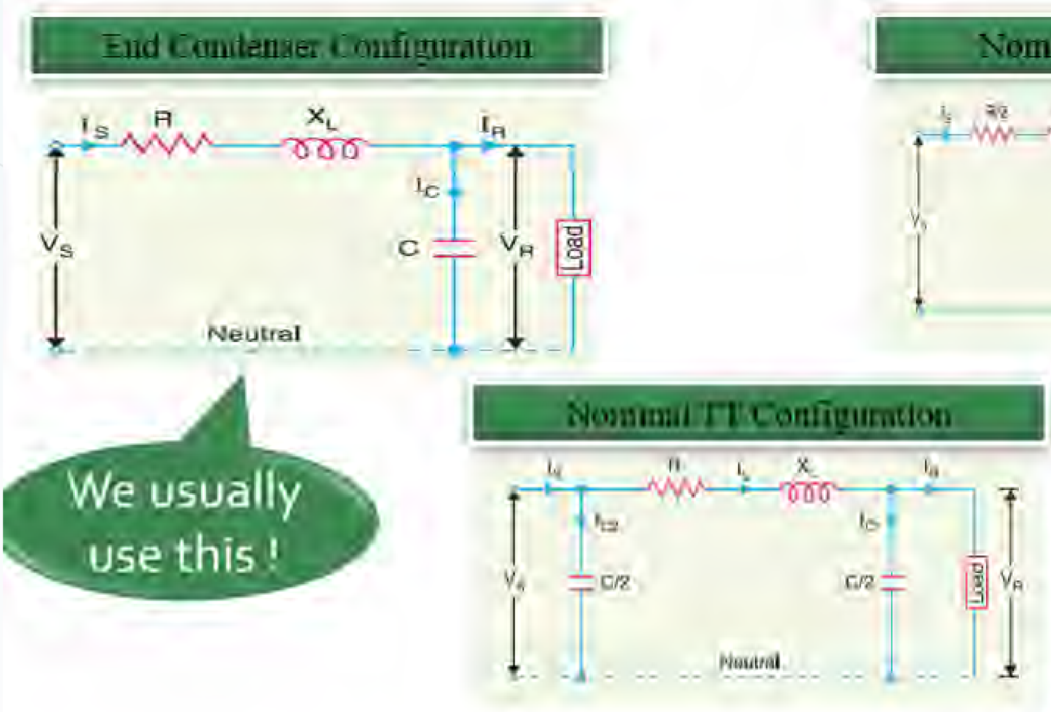
The resistance and inductance are lumped together, the capacitance of the line is ignored so the admittance is ignored.



R = resistance
XL = inductive reactance
Vs = phase voltage
VR = phase voltage at load

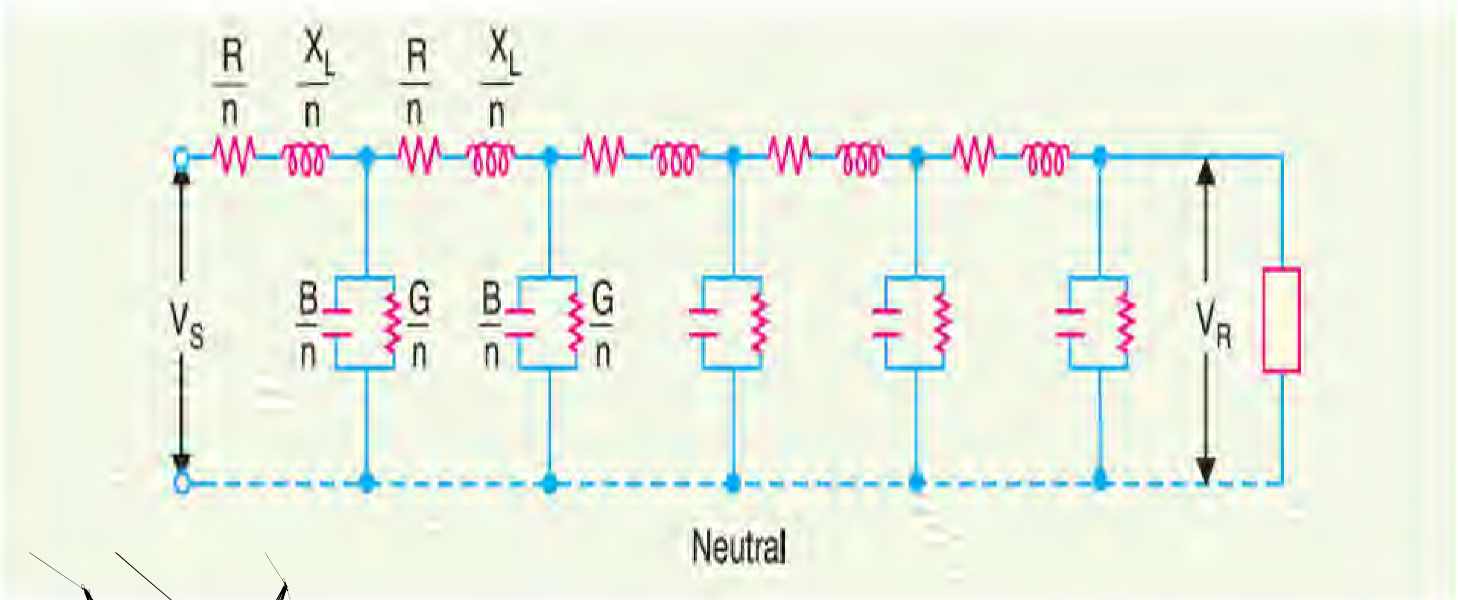
Equivalent Circuit Diagram for Medium Transmission Line

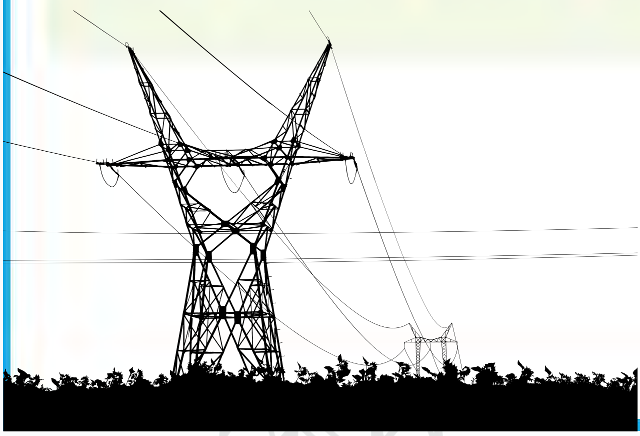
- The medium length lines can be model in three configuration.



R = resistance
XL = inductive reactance
Vs = phase voltage
VR = phase voltage at load
C = capacitance

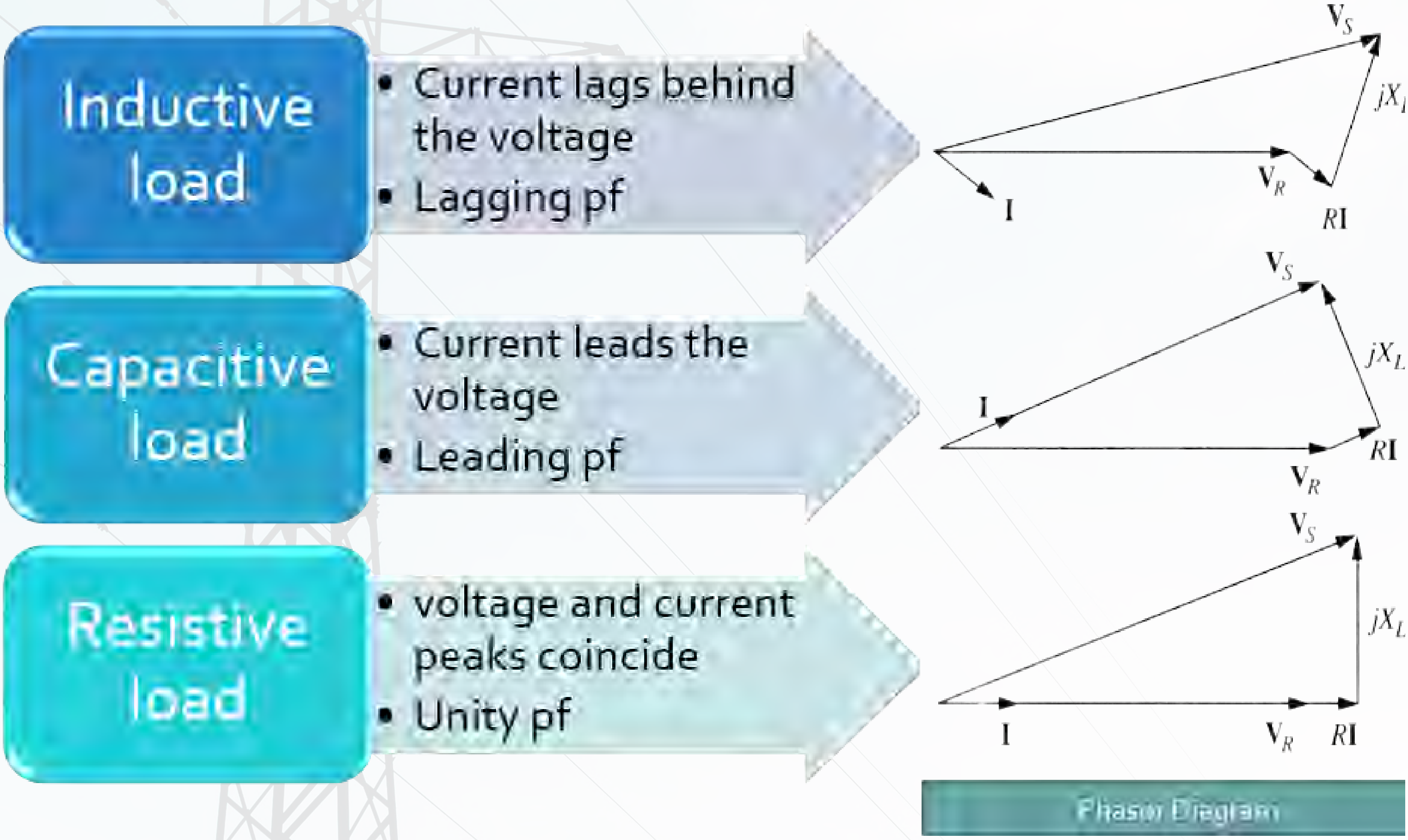
Equivalent Circuit Diagram for Long Transmission Line



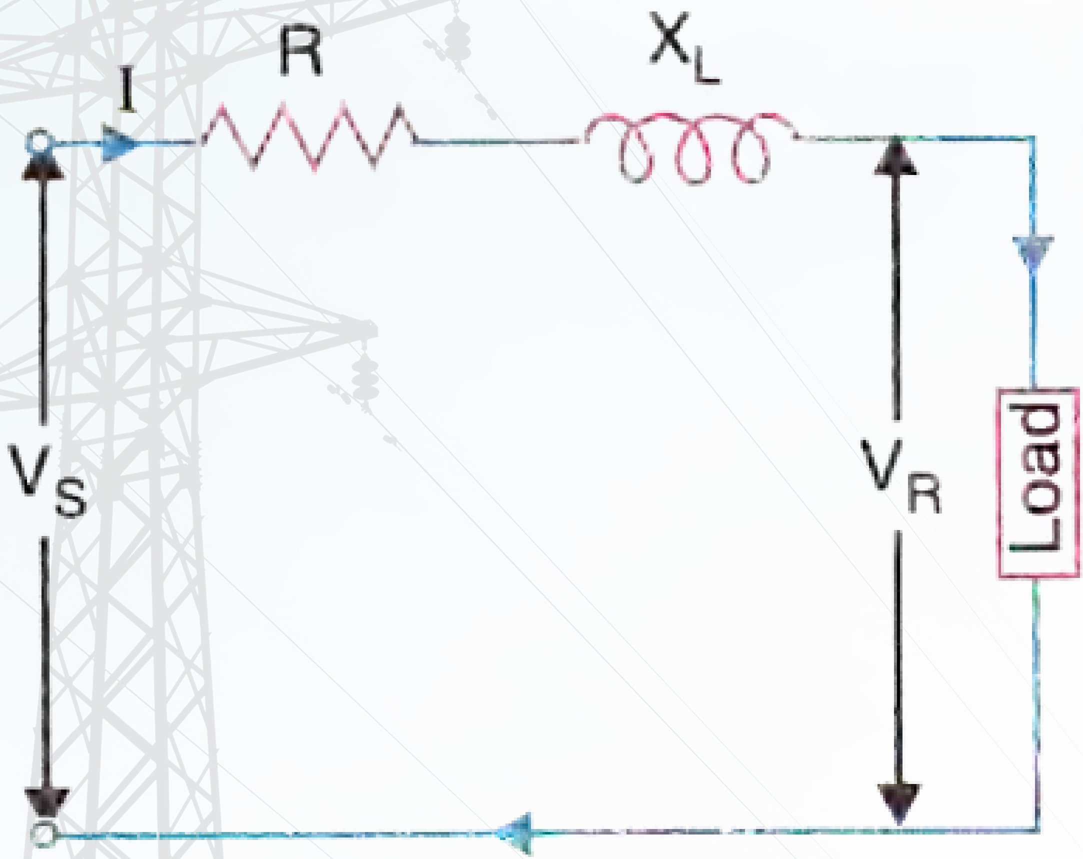


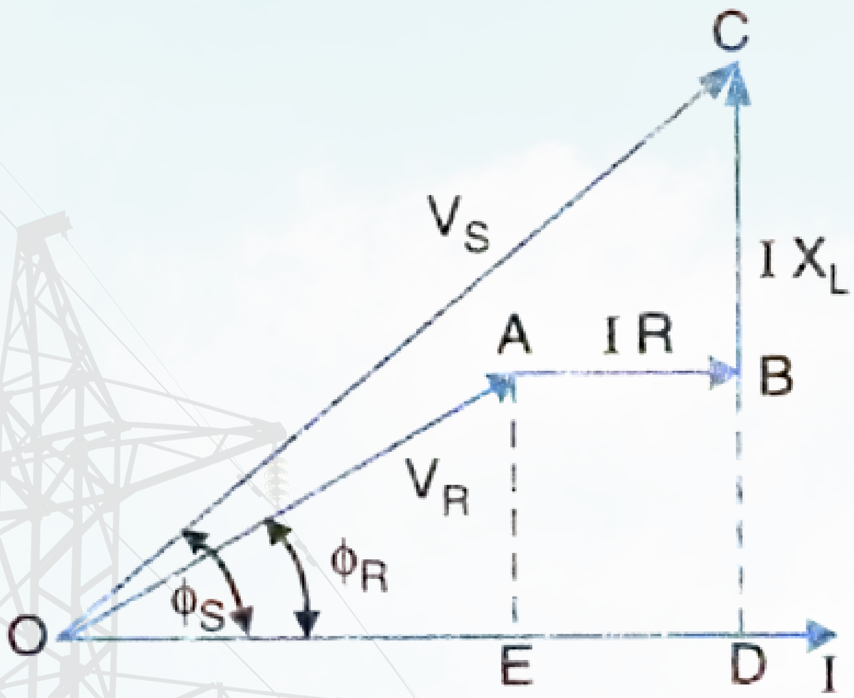
R = resistance
XL = inductive reactance
Vs = phase voltage
VR = phase voltage at load
C = capacitance
B = suspectance
G = conductance

Single Phase Phasor Diagram



Single Phase
Short Transmission Lines





- From the right angled triangle *ODC*, we get,

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

$$\text{or } V_S^2 = (OE + ED)^2 + (DB + BC)^2$$

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

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

$$\text{\% voltage regulation} = \frac{V_S - V_R}{V_R} \text{ X } 100$$

$$\text{ending end } p.f, \cos \Phi_S = \frac{OD}{OC} = \frac{V_R COS\, \emptyset_R + IR}{V_S}$$

$$\text{Power delivered} = V_R I_R \cos \Phi_R$$

$$\textit{Line Losses} = I^2 R$$

$$\text{Power sent out} = V_R I_R \cos \Phi_R + I^2 R$$

$$\text{\% Transmission efficiency} = \frac{\textit{Power delivered}}{\textit{Power sent out}} \text{ X } 100$$

$$= \frac{V_R I_R \cos \Phi_R}{V_R I_R \cos \Phi_R + I^2 R} \text{ X } 100$$

I = load current

R = loop resistance *i.e.*, resistance of both conductors

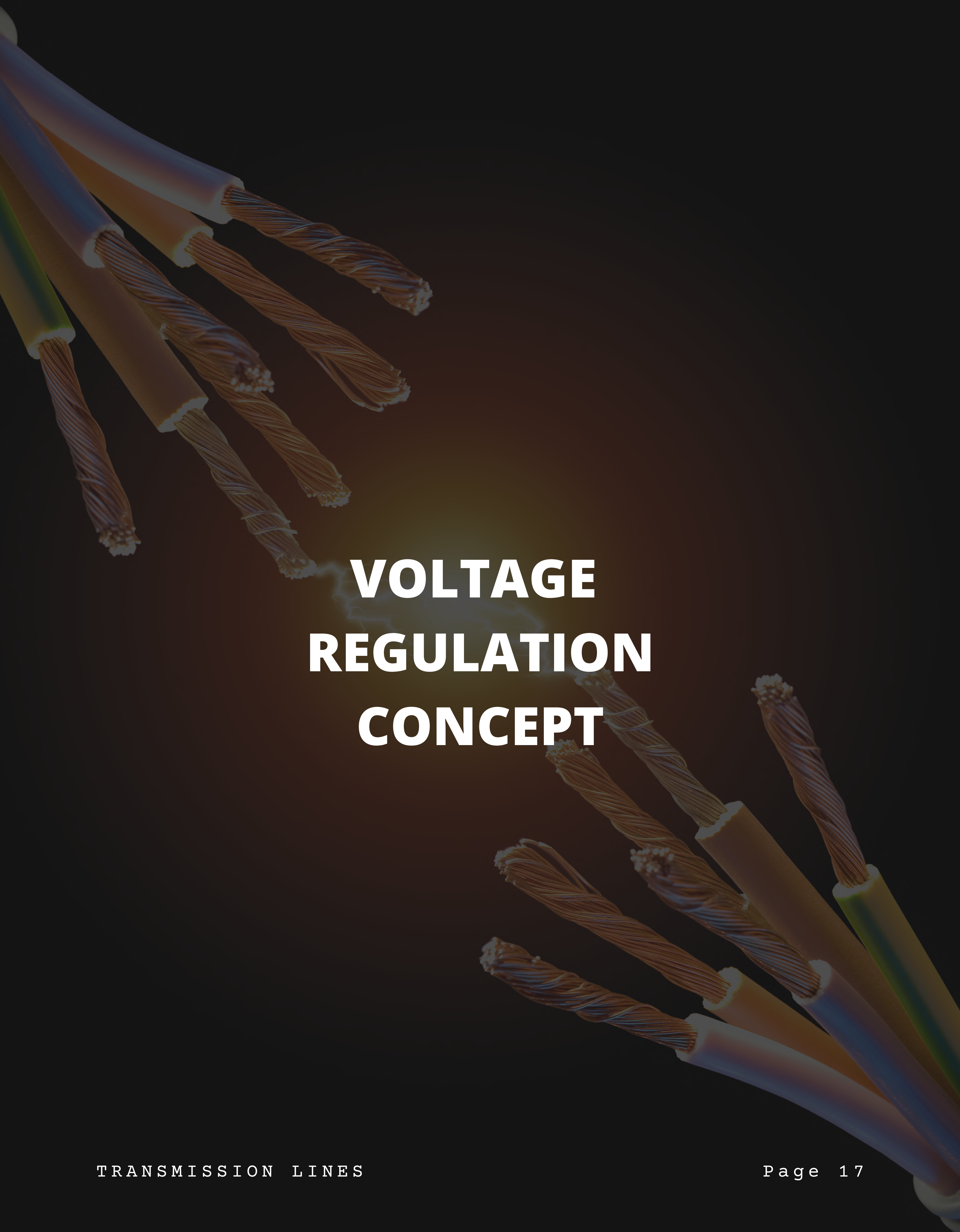
X_L = loop reactance

V_R = receiving end voltage

$\cos \varphi_R$ = receiving end power factor (lagging)

V_S = sending end voltage

$\cos \varphi_S$ = sending end power factor



VOLTAGE REGULATION CONCEPT

Regulation
&
Per Unit Regulation

When a transmission line is carrying current, there is a voltage drop in the line due to resistance and inductance of the line.

The result is that receiving end voltage (VR) of the line is generally less than the sending end voltage (VS).

This **voltage drop** (VS – VR) in the line is expressed as a **percentage of receiving end voltage VR** and is called **voltage regulation.**

$$\text{Percentage of voltage regulation} = \frac{|V_S| - |V_R|}{|V_R|} \times 100$$

Transmission Effiency

The power obtained at the receiving end of a transmission line is generally less than the sending end power due to losses in the line resistance.

The ratio of receiving end power to the sending end power of a transmission line is known as the **transmission efficiency** of the line;

$$\% \text{ transmission efficiency} = \frac{\textit{Receiving end power}}{\textit{Sending end Power}} \text{ X } 100$$

$$= \frac{V_R I_R \cos \Phi_R}{V_S I_S \cos \Phi_S} \text{ X } 100 \quad @$$

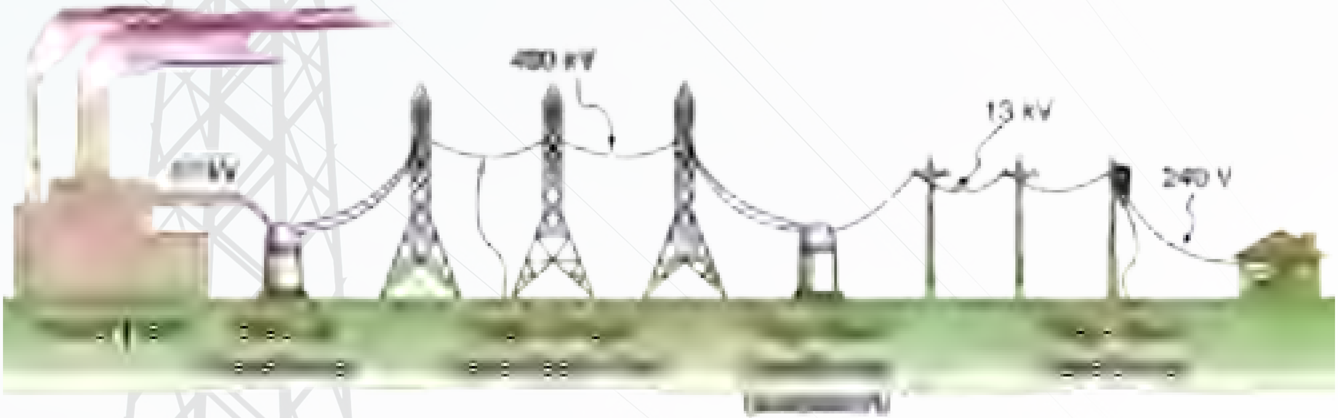
$$= \frac{\textit{Power delivered}}{\textit{Power sent out}} \text{ X } 100$$

$$= \frac{V_R I_R \cos \Phi_R}{V_R I_R \cos \Phi_R + I^2 R} \text{ X } 100$$

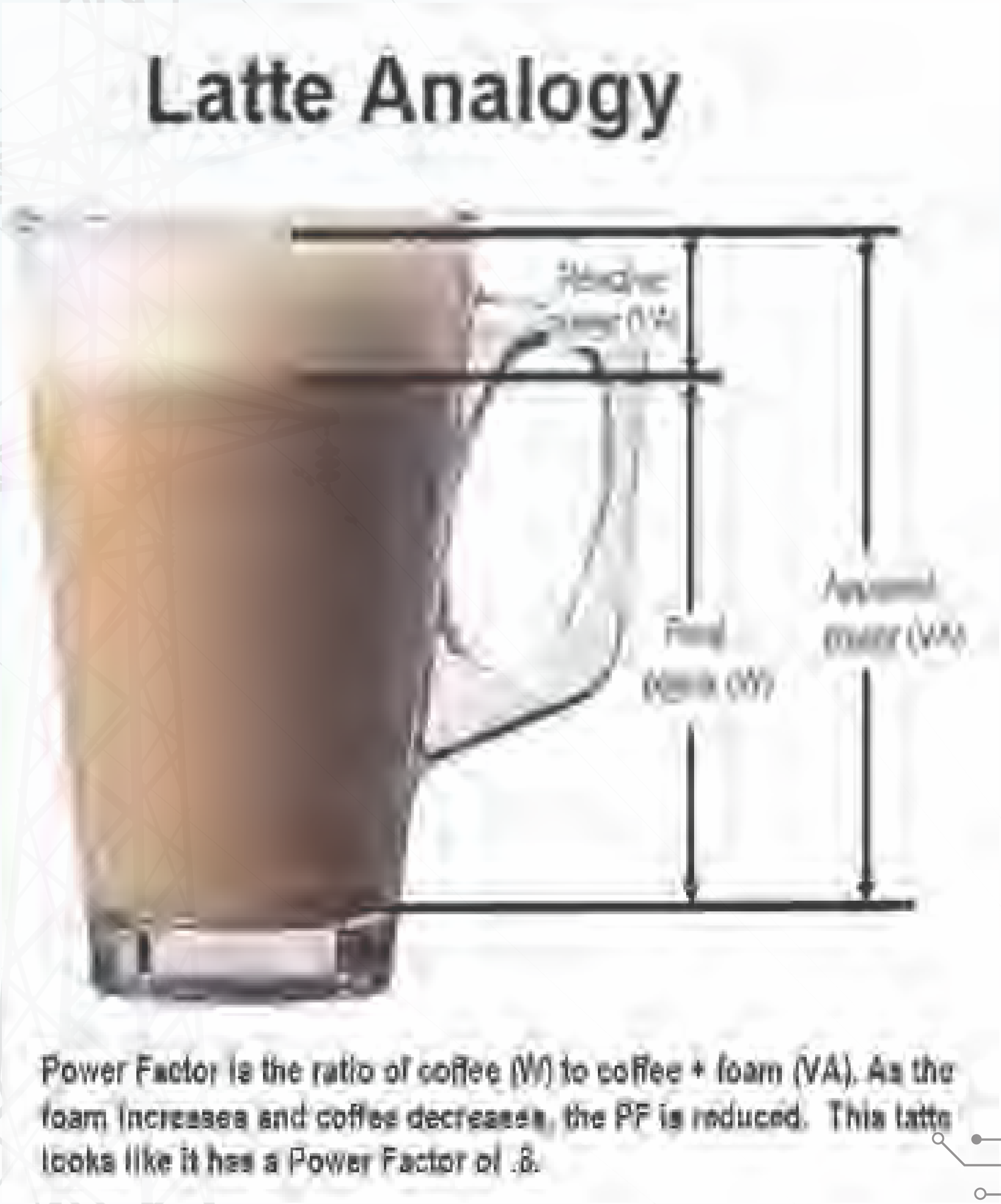
The Effect of High & Low Voltage on Transmission Efficiency

The **main advantages** of transmitting power over transmission lines on high voltage are :

- Cost of conductor is reduced for given power.
- Voltage drop in lines is reduced.
- Efficiency of transmission line is increased.

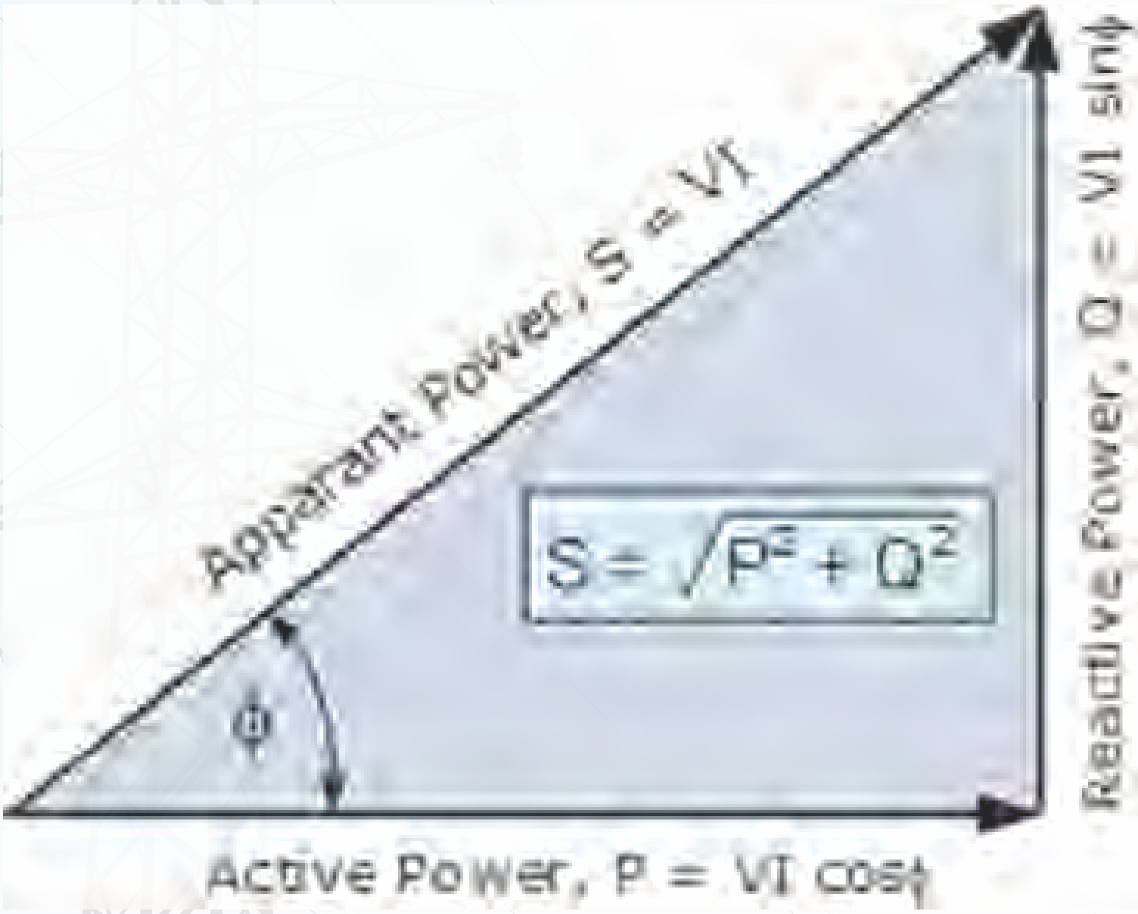


Calculate The Current Based on Apparent Power & Real Power



Calculate The Current Based on Apparent Power & Real Power

Calculate The Current Based on Apparent Power & Real Power



$$\cos\theta = \frac{P}{VI}$$

$$\text{power factor} = \cos\theta$$

$$= \frac{kW}{kVA} = \frac{active@real\ power}{Apparent\ power}$$

$$I = \frac{P}{V_R COS\emptyset_R}$$

$$I = \frac{Q}{V_R Sin\emptyset_R}$$

$$I = \frac{S}{V_R}$$

Example:

A single phase transmission line transfer 1100kW power to the factory with the voltage, 11kV and lagging power factor 0.8. This line have 2Ω resistance and 3Ω reactance. Calculate:

i) Voltage at the end of transmission
ii) Percentage of voltage regulation
iii) Transmission Efficiency

- Given;
  - Lines Resistance, R = 2Ω
  - Lines Reactance, X = 3Ω
  - Transmission Power, P = 1100kW
  - Power Factor, pf = 0.8 (lagging)
  - Receiving End Voltage, VR = 11000V

Load Current, $I = \frac{P \times 1000}{V_R \, COS \, \emptyset_R}$

$$I = \frac{1100 \times 1000}{11000 \times 0.8}$$

$$I = 125 \text{ A}$$

i) Voltage at the end of transmission

$\cos \Phi_R = 0.8$

$\sin \Phi_R = 0.6$

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

$$V_S = \sqrt{(11000 \times 0.8 + 125 \times 8)^2 + (11000 \times 0.6 + 125 \times 3)^2}$$

$$= 11426\text{V}$$

ii) % voltage regulation

Vs = 11426V

VR = 11000V

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

$$= \frac{11426 - 11000}{11000} \times 100$$

$$= 3.873\%$$

iii) Transmission Efficiency

losses in lines $= I^2 R$

$$= (125)^2 \times 2$$

$$= 31.25\text{kW}$$

% transmission efficiency $= \frac{Power\ delivered}{Power\ sent\ out} \times 100$

$$= \frac{1100k}{1100k + 31.25k} \times 100$$

$$= 97.24\%$$

Exercise 1

A single phase overhead transmission line delivers 1100kW at 33 kV at 0.8 p.f lagging. The total resistance and inductive reactance of the line are 10 Ω and 15 Ω respectively. Determine :

(i)sending end voltage
(ii)sending end power factor
(iii) transmission efficiency

(Ans: 33709.31V, 0.795, 98.44%)

Exercise 2

A single-phase overhead transmission line delivers 4000kW at 11 kV at 0.8 p.f lagging. If resistance and reactance per conductor are 0.15 Ω and 0.02 Ω respectively. Calculate :

.

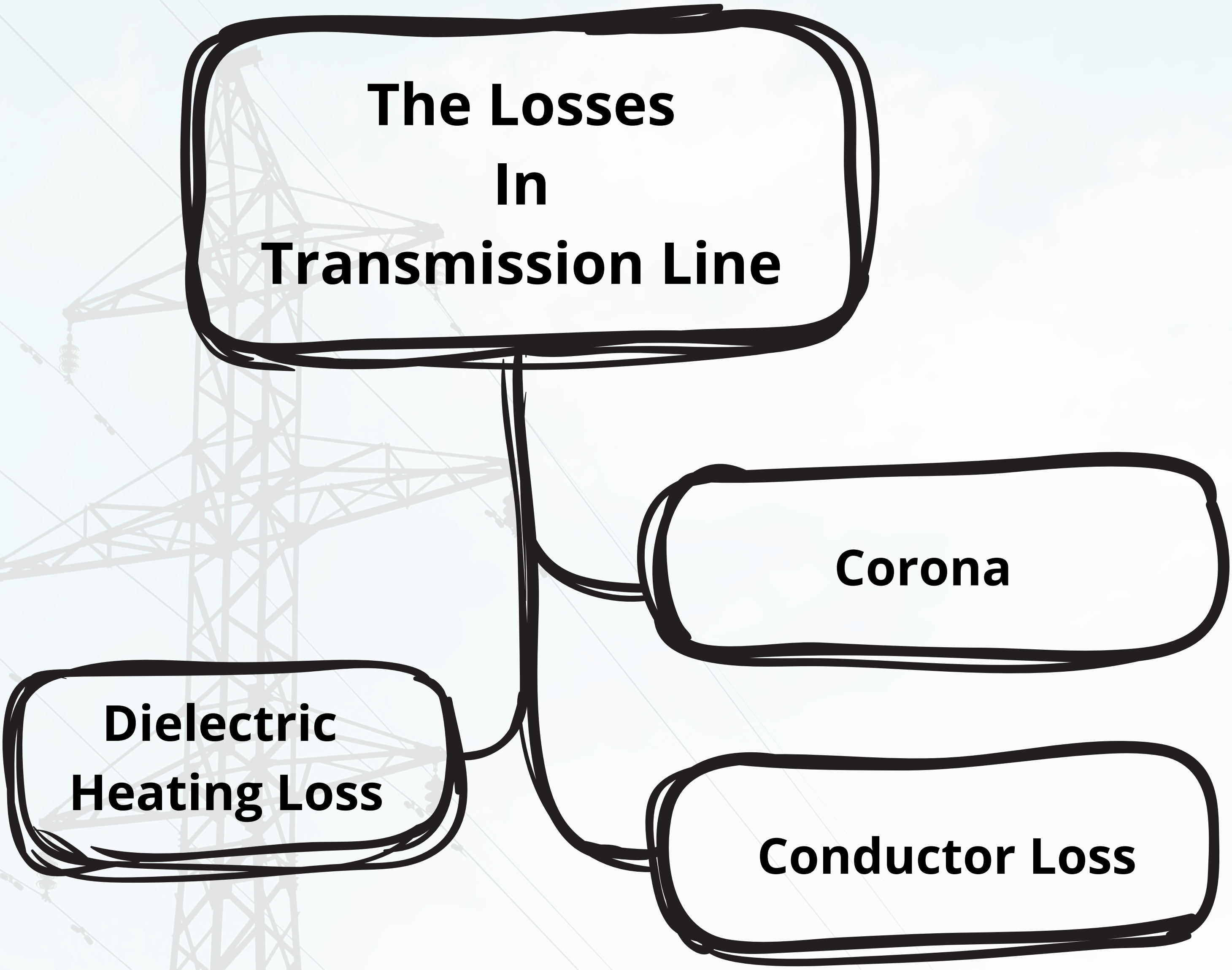
(i)percentage voltage regulation
(ii)sending end power factor
(iii) line losses

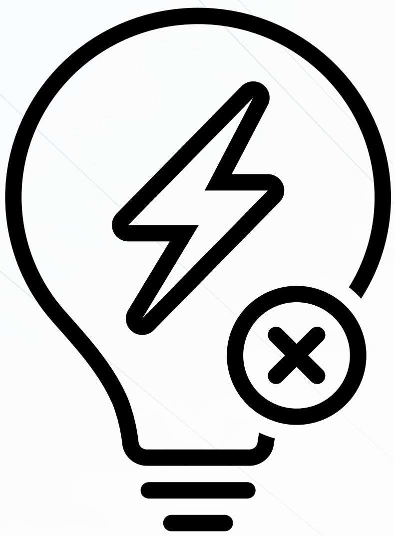
(Ans: 0.545%, 0.8, 30.992kW)

Exercise 3

A single-phase 11 kV line with a length of 15km is to transmit 500 kVA. The inductive reactance of the line is 0.5 Ω/km and the resistance is 0.3 Ω/km. **Calculate the efficiency and regulation of the line for 0.8 lagging power factor.**

(Ans: 97.729%, 3.355%)


The Losses
In
Transmission Line
Corona
Dielectric
Heating Loss
Conductor Loss



Corona

•***Corona*** was electrical discharge emerge around overhead line conductor, due to air flow where would disturb radio waves and creating lost power. When a *normal ac voltage* is applied across two conductors with *enough spacing between them*, there is no change in the atmospheric conditions surrounding the conductors. But if the *voltage exceeds a particular limiting value*, then the air surrounding the conductors will gets ionized and *luminous glow (weak purple color) will rise with hissing sound.*

This phenomena is called *corona.*

Corona

The corona discharge around a high voltage coil.

Large corona discharge (white) around conductors energized by a 1.5 million volt transformer in a laboratory.

Corona Effects

- Power loss
- The 3rd harmonic components makes the current non-sinusoidal and this increase the corona loss.
- The ozone gas formed chemically reacts with the conductor and can cause corrosion.
- Light (faint violet glow).
- Audible noise (hissing or cracking).
- Insulation damage.
- Radio, television and computer interference.

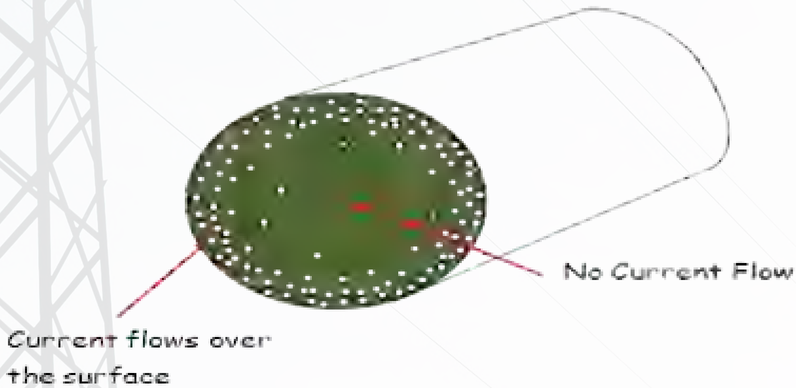
Conductor Loss

•Current flows through a transmission line and a line has a finite resistance there is an un-avoidable power loss

•This is sometimes called conductor heating

•To reduce conductor loss simply shorten the transmission line or use a larger diameter wire

•Conductor loss cause a phenomenon called ***skin effect***



Dielectric Heating Loss

•Potential difference between 2 conductors of a metallic transmission line causing dielectric heating.

•Heat is form of energy and must be taken from the energy propagating down the line.

•For air dielectric transmission line, the heating loss is negligible.

•For solid core transmission line, dielectric heating loss increase with frequency.

Transmission Insulators

- The insulators **provide necessary insulation between line conductors and supports** and thus **prevent any leakage current from conductors to earth**.

- A true insulator is a material that does not respond to an electric field and completely resists the flow of electric charge.

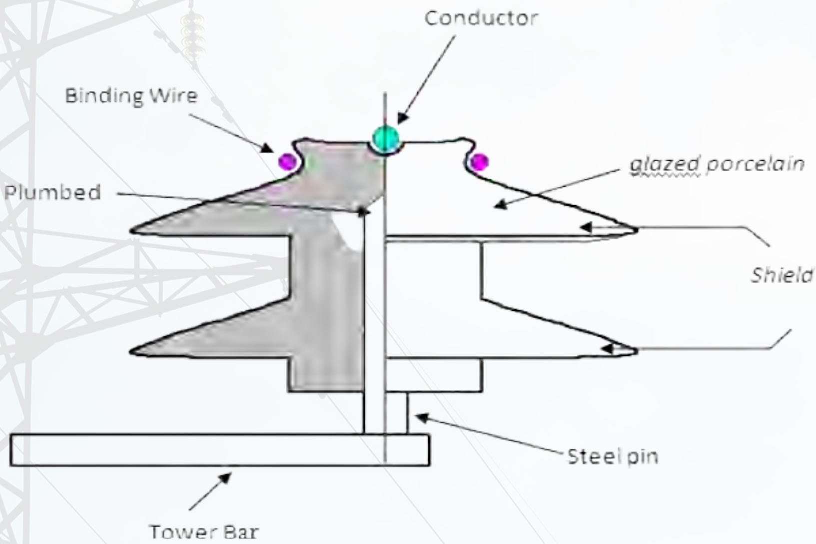
- But, a perfect insulator does not exist, because even insulators contain small numbers of mobile charges (charge carriers) which can carry current.

Pin Insulator

Suspension Insulator

Tension/Strain Insulator

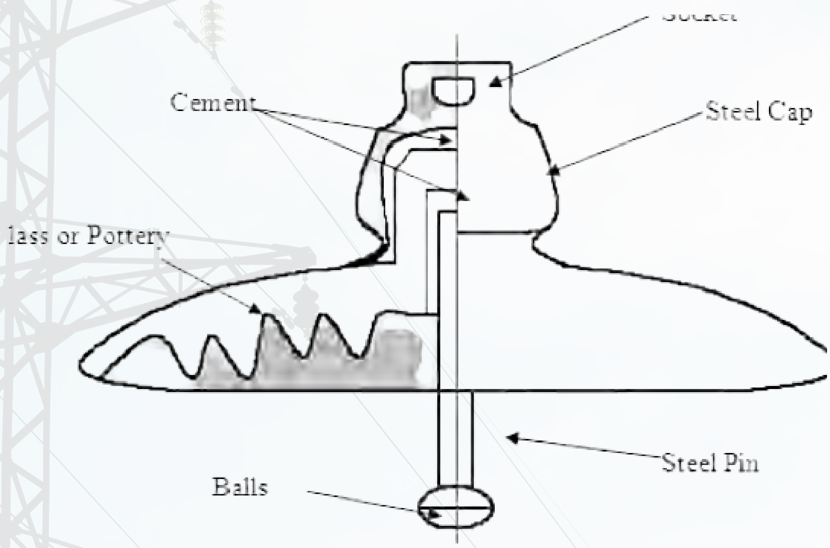
Transmission Insulators



Pin Insulator

- Small, simple in construction and cheap.
- Used for transmission and distribution of electrical power up to 33kV.
- For lower voltage up to 11kV – one piece is used.
- For higher voltage – two or more pieces are used.
- It becomes more heavy and costly for higher voltages.
- Mounted on the cross-arm of the pole.
- The line conductor is placed in the groove at the top of insulator and is tied down with binding wire of the same material as the conductor.

Transmission Insulators



Suspension Insulator

•Used for voltages above 33kV.

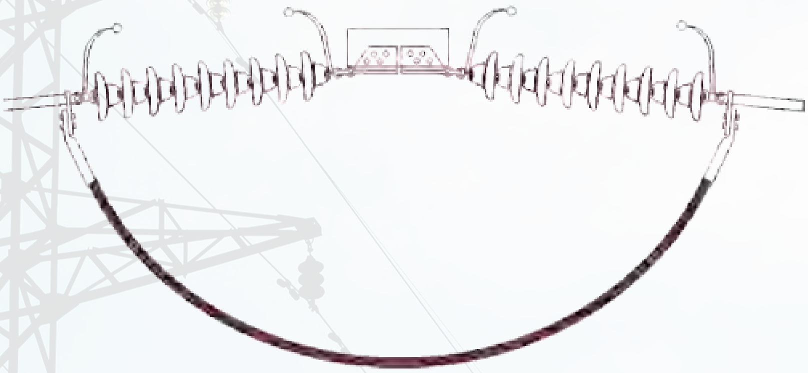
•Have no. of porcelain disc units which are connected to one another in series by using metal links to form a string of porcelain discs.

•The top of insulator is connected to the cross-arm of the tower while the lowest insulator holds the line conductor.

•Each unit is designed for the low voltage about 11kV.

•No. of units depend on the operating voltage i.e. if operating voltage is 132kV , the no. of units required is 12.

Transmission Insulators



Tension@Strain Insulator

•Used for handling the mechanical stresses at angle positions of the line :
- corner/ sharp curve
- end of lines
- intermediate anchor towers
- long river-crossings

•Low-tension (LT) line – shackle insulators are used

•High-tension (HT) line - assembly of the suspension insulators is used as ‘strain insulator’ arranged on a horizontal plane.

•On extra long spans (river crossings) two or more strings of strain insulators are used in parallel.

Transmission Insulators

The Advantage & Disadvantages of Pin Insulator

	Advantages	Disadvantages
Pin-type	Widely used on high voltage distribution lines	The voltage rating is only up to 36kv
	Having a better anti-fog performance	Should use with the spindles
	Easily handle and manufacture	The insulator pin may damage the porcelain thread holes
	Can be mounted as necessary, vertically or horizontally	Only can be used on distribution lines

Transmission Insulators

The Advantage & Disadvantages of Suspension Insulator

	Advantages	Disadvantages
Suspension-type	Each suspension disc is designed for normal [illegible] rating 11KV(Higher [illegible] rating 15KV), so by using different numbers of discs, a suspension string can be made suitable for any [illegible] level.	Suspension insulator string costlier than pin and post type insulator.
	If any one of the disc insulators in a suspension string is damaged, it can be replaced much easily	Suspension string requires more height of supporting structure than that for pin or post insulator to maintain same ground clearance of current conductor.
	Mechanical stresses on the suspension insulator is less since the line hanged on a flexible suspension string.	The amplitude of free swing of conductors is larger in suspension insulator system, hence, more spacing between conductors should be provided

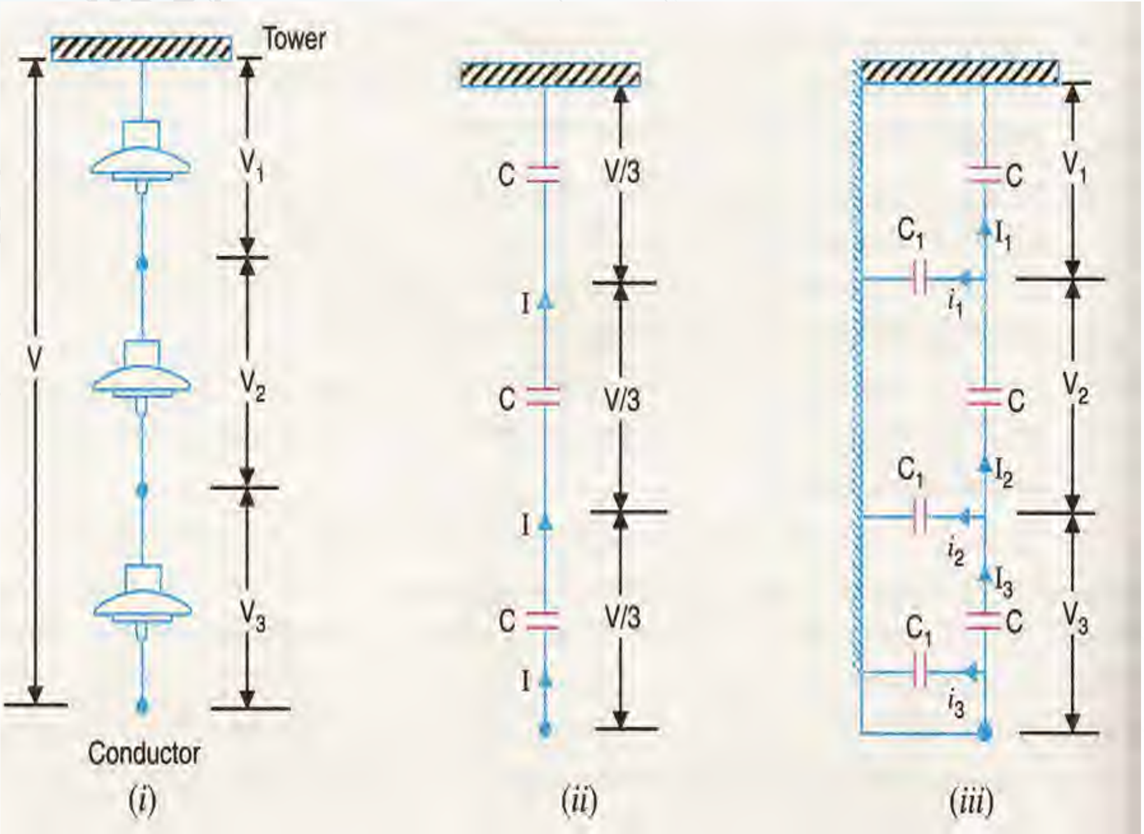
Transmission Insulators

The Advantage & Disadvantages of Tension@Strain Insulator

- The strain insulators are exactly identical in shape with the suspension insulators.
- These strings are placed in the horizontal plane rather than vertical. As is done in case of suspension insulators.
- These are used to take the tension of the conductors at line terminals, at angle towers, at road crossings and at junctions of overhead lines with cables. These insulators are therefore known as tension or strain insulators.

Transmission Insulators

Voltage Across Insulator Network



Transmission Insulators

Voltage Across Insulator Network

C	: self capacitance; capacitor - porcelain disc lies in between two metal links
C_1	: shunt capacitance; air capacitance - present between metal links and the earthed tower
V_1	: voltage across 1st dics
V_2	: voltage across 2nd dics
V_3	: voltage across 3rd dics
V	: voltage across conductor to earth

Take $K = C_1/C$ or $C_1 = KC$

- Applying Kirchhoff's law $\boxed{C_1 = KC}$

$I_2 = I_1 + i_1$

$CV_2 = CV_1 + C_1V_1$

$CV_2 = CV_1 + KCV_1$

$CV_2 = C(V_1 + KV_1)$

$V_2 = (V_1 + KV_1)$

$V_2 = V_1(1 + K)$

$V_1 = V_2/ (1+ K)$

Transmission Insulators

Voltage Across Insulator Network

- Applying Kirchhoff's law to node B,

  $I_3 = I_2 + i_2$

  $CV_3 = CV_2 + C_1(V_1 + V_2)$

  $CV_3 = CV_2 + KC(V_1 + V_2)$

  $CV_3 = C[V_2 + K(V_1 + V_2)]$

  $V_3 = [V_2 + K(V_1 + V_2)]$

  $V_3 = [KV_1 + V_2(1 + K)]$

  $V_3 = [KV_1 + V_1(1 + K)(1 + K)]$

  $V_3 = V_1[K + (1 + K)(1 + K)]$

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

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

- Voltage between the conductor and the earthier tower is,

  $V = V_1 + V_2 + V_3$

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

  $V = V_1(3 + 4K + K_2)$

  Simplify

  $V_1 = V / (3 + 4K + K_2)$

Transmission Insulators

Example

A network of four insulators is used to hang a single 33kV, three -phase overhead line conductor. The air or bypass capacity between each lid and tower is 1/10 of the capacity of each unit. Calculate the voltage across each insulator.

Solution:

Given:

$$E = 33kV$$
$$K = C_1/C = 1/10 = 0.1$$

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

$$V_4 = V_1(1 + 6K + 5K^2 + K^3)$$

So:

$$V_2 = V_1(1 + K)$$
$$V_2 = V_1(1 + 0.1)$$
$$V_2 = 1.1V_1$$

$$V_3 = V_1(1 + 3K + K^2)$$
$$V_3 = V_1(1 + 3(0.1) + (0.1)^2)$$
$$V_3 = 1.31V_1$$

$$V_4 = V_1(1 + 6K + 5K^2 + K^3)$$
$$V_4 = V_1(1 + 6(0.1) + 5(0.1)^2 + (0.1)^3)$$
$$V_4 = 1.651V_1$$

Transmission Insulators

$$E = V_1 + V_2 + V_3 + V_4$$
$$E = V_1 + 1.1V_1 + 1.31V_1 + 1.651V_1$$
$$E = 4.062V_1$$

$$E = \frac{33000}{\sqrt{3}} = 19050V$$

$$V_1 = E / 4.062$$
$$V_1 = 19050 / 4.062$$
$$V_1 = 4690V$$

So:

$$V_2 = 1.1V_1$$
$$V_2 = 1.1(4690)$$
$$V_2 = 5159V$$

$$V_3 = 1.31V_1$$
$$V_3 = 1.31(4690)$$
$$V_3 = 6144V$$

$$V_4 = 1.651V_1$$
$$V_4 = 1.651(4690)$$
$$V_4 = 7743V$$

Transmission Insulators

The Accessories Needed to Improve Insulator Network Efficiency

Cross Arm Method

Guard Ring Method

- The voltage across the unit nearer to the conductor is more than the voltage in the unit nearer to the tower.
- 100% efficiency means that the voltage across the disc will be exactly same.

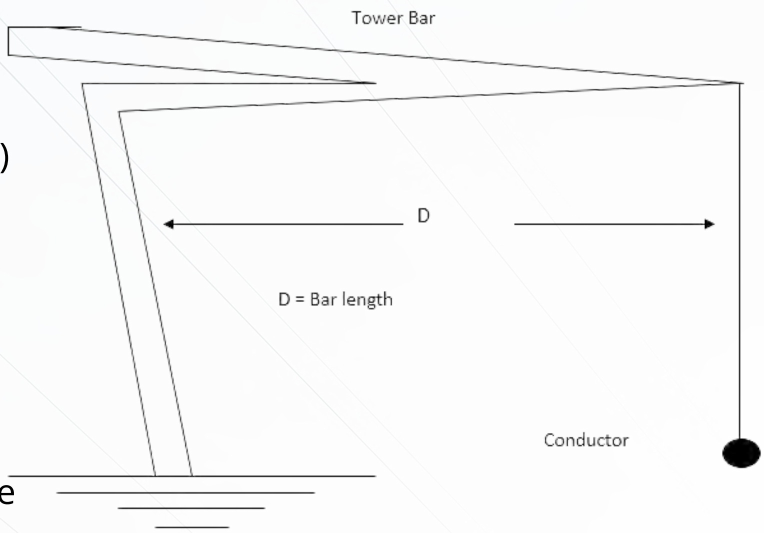
$$\text{Network efficiency} = \frac{\text{Voltage across the string}}{n \times \text{Voltage across the insulator near to the line conductor}} = \frac{E}{nVT}$$

Transmission Insulators

The Accessories Needed to Improve Insulator Network Efficiency

Cross Arm Method

- Increase the length of cross-arms by increasing the distance between insulator and tower.
- The ratio of shunt capacitance to mutual capacitance (k=C1/C) will reduce to 0.1.
- The network efficiency increases and the voltage distribution is more uniform.
- Only suitable for high and large tower post to support long bar weight and network insulator.

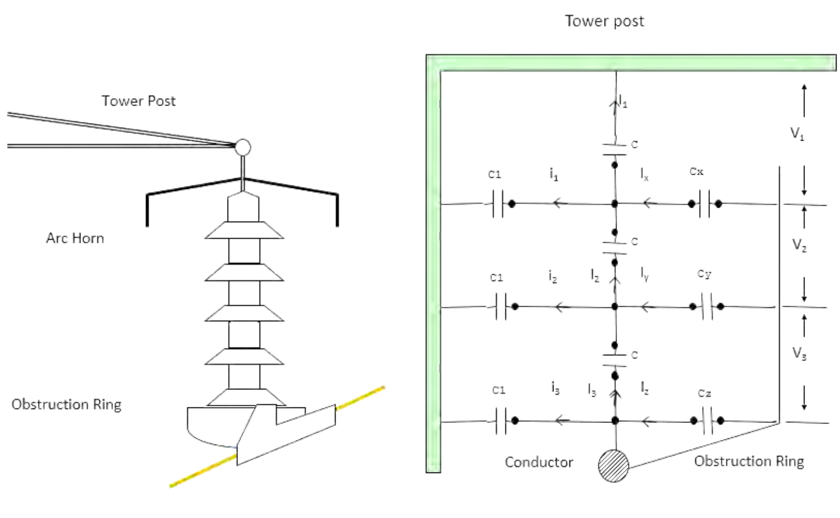


Transmission Insulators

The Accessories Needed to Improve Insulator Network Efficiency

Guard Ring Method

- Ring way obstruction can be done with use *static shield*.
- This static shield assembled on end lower part insulator unit connected by using joining of metal in suspension insulator and then connects to line conductor.
- Reduce the earth capacitance and create capacitance between insulator line and cap.
- Higher capacitance in nearby unit with guard ring and this will reduce voltage fall in the insulator.
- The same voltage in per unit is impossible to obtain practically



(a) Construction (b) Equivalent circuit

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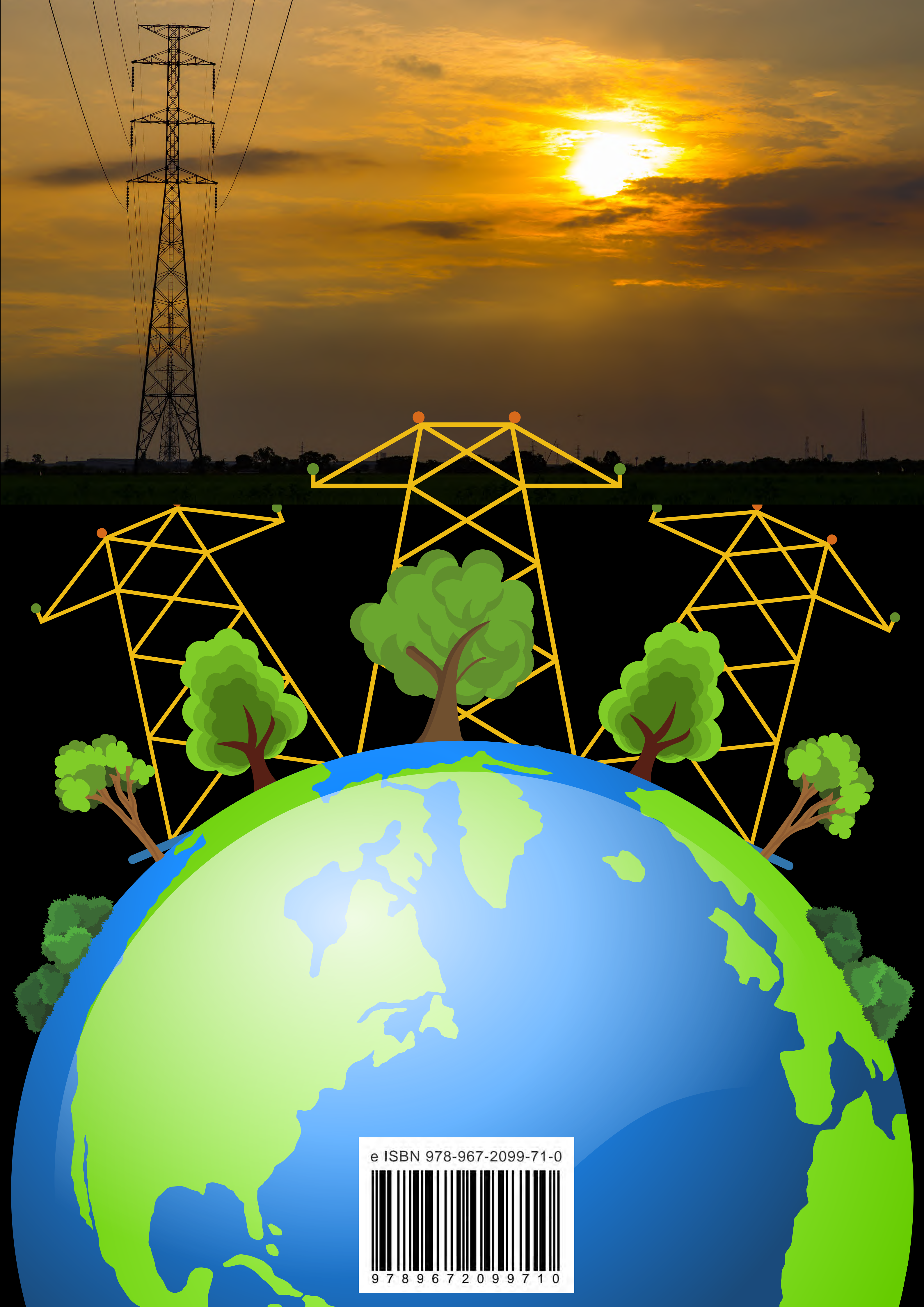

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