LECTURE HANDOUTS **L1**

DEPT: EEE **III / V**

Course Name with Code : **19EEC12 & TRANSMISSION & DISTRIBUTION**

Course Teacher : **Mrs.M.Selvakumari**

Unit : **I – STRUCTURE OF POWER SYSTEM**

Date of Lecture:

Topic of Lecture: Introduction of transmission and distribution

Introduction :

- Generation of electricity is a major factor, but how this electricity is transmitted from the power stations to the substations and finally to the consumers and this process is done by transmission and distribution lines.
- Transmission and distribution refers to the different stages of carrying electricity over poles and wires from generators to a home or an industry. The primary distinction between the two is the voltage level at which electricity moves in each stage.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

Energy is available in various forms from different natural sources such as pressure head of water, chemical energy of fuels, nuclear energy of radioactive substances etc. All these forms of energy can be converted into electrical energy by the use of suitable arrangements.

History of Electricity

- In 1882 the World's first power station was established by Thomas Alva Edison in Pearl Street of US.
- In 1897, the first hydroelectric power station was established in India near a Tea estate at Sidrapong in Darjeeling.

Electricity Generation

The device converts mechanical energy to electrical energy is called a generator. Synchronous machines can produce high power reliably with high efficiency, and therefore, are widely used as generators in power systems.

Conventional Energy Sources (CES)

- Hydroelectric power generation
- Thermal power generation
- Atomic power generation

Non – Conventional Energy Sources (NCES)

- Solar power generation
- Wind power generation
- Bio-Mass / Co-Generation
- Pumped Storage Hydro Power Generation

PER CAPITA CONSUMPTION
Avg World

Country	kWh
World Average	3104
USA	12988
Australia	10134
Japan	7836
Germany	7019
Italy	5159
Brazil	2529
China	3762
India	1100

ELECTRICITY GENERATION CAPACITY IN INDIA 3,49,288 MW (as on 31.01.2019)

Conventional Energy Sources: (80 %) : 2,75,206 MW

- Hydroelectric power generation (13.2 %) : 45,399 MW
- Thermal power generation (64.7 %) : 2,23,027 MW
- Atomic power generation (1.97 %) : 6,780 MW

Non–Conventional energy sources (20%): 74,082 MW

- Solar power generation : 25,212 MW
- Wind power generation : 35,138 MW
- Bio-Mass / Co-Generation : 9,213 MW
- Small Hydro : 4,519 MW
- Total Installed Capacity (Appx) : 3,49,288 MW

ELECTRICITY GENERATION CAPACITY IN TAMILNADU 30,446 MW (As on 31.01.2019)

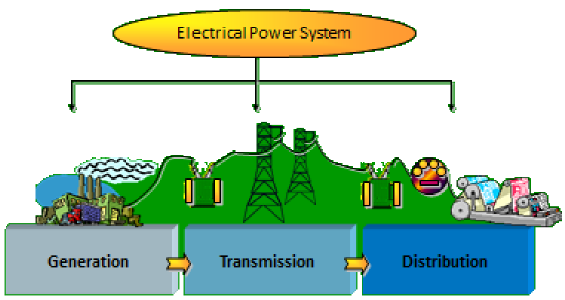
Conventional Energy Sources (61%): 18,512 MW

- Hydroelectric power generation : 2,178 MW
- Thermal power generation (49%) : 14,886 MW
- Atomic power generation : 1,448 MW

Non–Conventional energy sources(39%): 11,934 MW

- Solar power generation : 2,278 MW
- Wind power generation : 8,322 MW
- Bio-Mass / Co-Generation : 890 MW
- Pumped Storage Hydro Power Generation : 444 MW
- Total Installed Capacity (Appx) : 30,446 MW

Electric Power System Network



- Generation - Generating and/or sources of electrical energy.

- Transmission - Transporting electrical energy from its sources to load centers with high voltages to reduce losses.
- Distribution - Distributing electrical energy from substations to end users/customers.

Course Overview

Objective

- To understand the basic structure of power systems
- To develop expressions for the computation of transmission line parameters.
- To obtain the equivalent circuits for the transmission lines
- To analyses the voltage distribution in insulator strings, cables and methods to improve the same.
- To understand the operation of the different distribution schemes

Outcomes

- Ability to understand the basic structure of power systems
- Ability to understand the computation of transmission line parameters.
- Ability to draw the equivalent circuits for the transmission lines
- Ability to understand the voltage distribution in insulator strings and cables
- Ability to understand the operation of the different distribution schemes

Video Content / Details of website for further learning (if any):

1. https://pdhonline.com/courses/e104a/e104a_new.htm
2. https://www.youtube.com/watch?v=-bX0k5Dlwek

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 1)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 15 to 17)

Course Faculty

LECTURE HANDOUTS | **L2**

DEPT: EEE | **III / V**

Course Name with Code :19EEC12 & TRANSMISSION & DISTRIBUTION

Course Teacher : Mrs.M.Selvakumari

Unit : I – STRUCTURE OF POWER SYSTEM

Date of Lecture:

Topic of Lecture: Structure of Electric Power System: Generation, Transmission and Distribution

Introduction :

- Generation, transmission and distribution of electric power in our country are carried out as 3-phase system at 50 Hz.
- Three most important conventional methods of power generation in our country are: coal based thermal plants, Hydel plants and nuclear plants.
- Load centers (where the power will be actually consumed) are in general situated far away from the generating station. So to transmit the large amount of power (hundreds of MW) efficiently and economically over long distance, high transmission voltage (such as 400 kV, 220 kV) is used.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

Structure of Electric Power System: Generation, Transmission and Distribution

Electrical power produced at the power stations such as hydro, thermal and nuclear stations which are located at favorable places generally away from the consumers. It is transmitted over long distance to load centers with the help of conductors as transmission lines. Transmission and distribution system can be sub-divided into two transmission and secondary transmission, Primary distribution and secondary distribution.

Generating Station

6.6, 11 or 33 KV. Most usual generating voltage adopted is 11KV. Stepped up to 13KV.

Types of Transmission

Primary and Secondary transmission

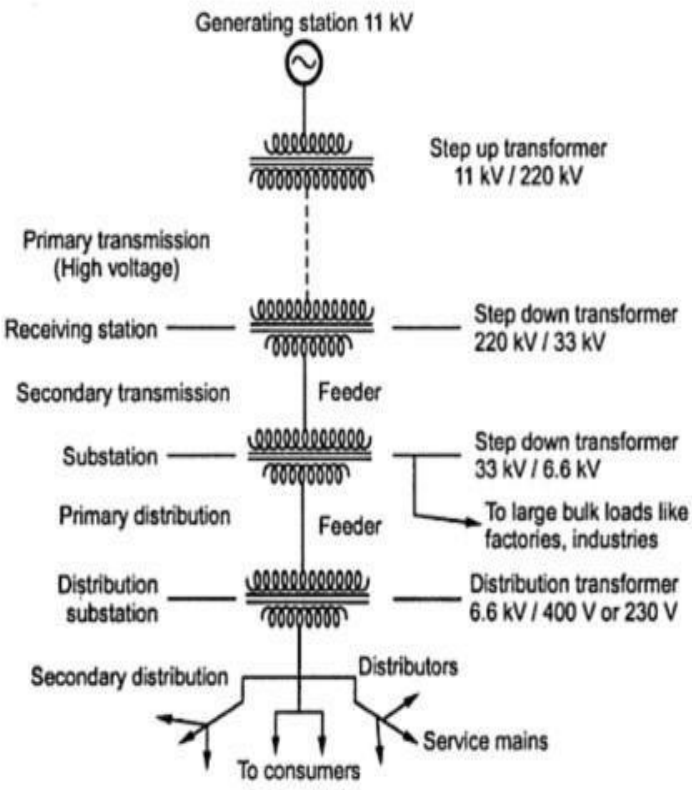
Primary Transmission:

220KV is transmitted by a 3ϕ 3 wire overhead system.

Secondary Transmission:

220KV reduced to 33KV by step down transformer.

33KV by a 3ϕ 3 wire systems to various (SS)



Structure of Electrical Power System

Distribution

Primary and secondary distribution

Primary Distribution

33KV to 11KV/6.6KV, 3ϕ, 3 wire. 11Kv line is laid along the road sides

Secondary Distribution

11kv/6.6Kv is step down the voltage to 400V, 3ϕ, 4 wires. The voltage between any two phases is 400V and between any phase and neutral is 230V.

Generation- 6.6KV, 11KV or 33KV

Primary transmission- 66KV, 132 KV, 220 KV, 225 KV, 330 KV,400 KV

Secondary transmission-- 11 KV or 33 KV

Distribution—6.6 KV, 11 KV or 33 KV

Classification of Electrical Power System

1. D.C or A.C system.
2. Underground or overhead systems.

3ϕ, 3 wires is universally adopted for generation and transmission.

Distribution-- 3ϕ, 4 wires ac system.

Underground system is expensive than overhead system. Overhead system is adopted for transmission and distribution.

Merits and Demerits

DC Transmission Merits

1. Requires only 2 conductors as compared to 3 for ac transmission.
2. There is no inductance, capacitance, phase displacement and surge problem.
3. Due to the absence of inductance, the voltage drop in a DC transmission is less.
4. No skin effect.
5. Less corona loss and radio interference with communication circuits
6. Same working voltage, the potential stress or the insulation is less
7. No stability problem and synchronizing difficulties.

DC Transmission Demerits

1. Electric power can't be generated at high DC voltage due to commutation problem.
2. A DC voltage can't be stepped up for transmission of power of high voltages.
3. DC switches and circuit breakers have their own limitations.

AC Transmission Merits

1. Power can be generated at high voltages.
2. Maintenance of AC substation is easy and cheaper.
3. AC voltage can be stepped up or stepped down by transformer.

Demerits

1. Construction is more complicated
2. Due to skin effect, the effective resistance of the line is increased.
3. AC line has capacitance and due to this there is a continuous loss of power

Video Content / Details of website for further learning (if any):

1. https://www.eepowerschool.com/energy/power-system-basic-structure-functioning/
2. https://www.youtube.com/watch?v=Yg6XsepGCKY

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 2)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 18 to 20)

Course Faculty

LECTURE HANDOUTS **L3**

DEPT: EEE **III / V**

Course Name with Code :**19EEC12 & TRANSMISSION & DISTRIBUTION**

Course Teacher : **Mrs.M.Selvakumari**

Unit : **I – STRUCTURE OF POWER SYSTEM**

Date of Lecture:

Topic of Lecture: AC and DC distributors

Introduction :

- Now-a-days electrical energy is generated, transmitted and distributed in the form of alternating current.
- One important reason for the widespread use of alternating current in preference to direct current is the fact that alternating voltage can be conveniently changed in magnitude by means of a transformer. Transformer has made it possible to transmit a.c. power at high voltage and utilize it at a safe potential.
- High transmission and distribution voltages have greatly reduced the current in the conductors and the resulting line losses.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

Types of Distributor's

There are two types of distribution viz.

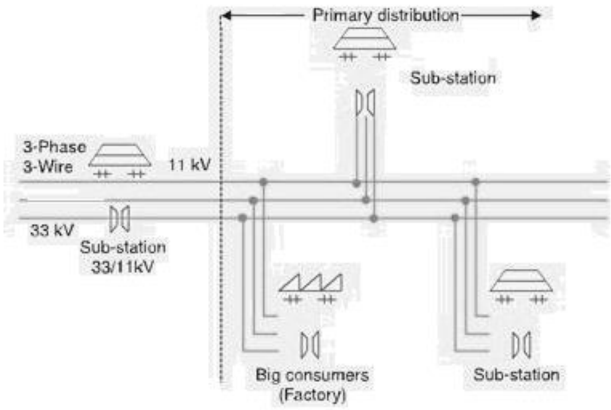
1. AC distribution
2. DC distribution

AC distribution

The a.c. distribution system is classified into ***(i)*** primary distribution system and ***(ii)*** secondary distribution system.

(*i*) Primary distribution system

It is that part of a.c. distribution system which operates at voltages somewhat higher than general utilization and handles large blocks of electrical energy than the average low-voltage consumer uses. The voltage used for primary distribution depends upon the amount of power to be conveyed and the distance of the substation required to be fed. The most commonly used primary distribution voltages are 11 kV, 6·6 kV and 3·3 kV. Due to economic considerations, primary distribution is carried out by 3-phase, 3-wire system.



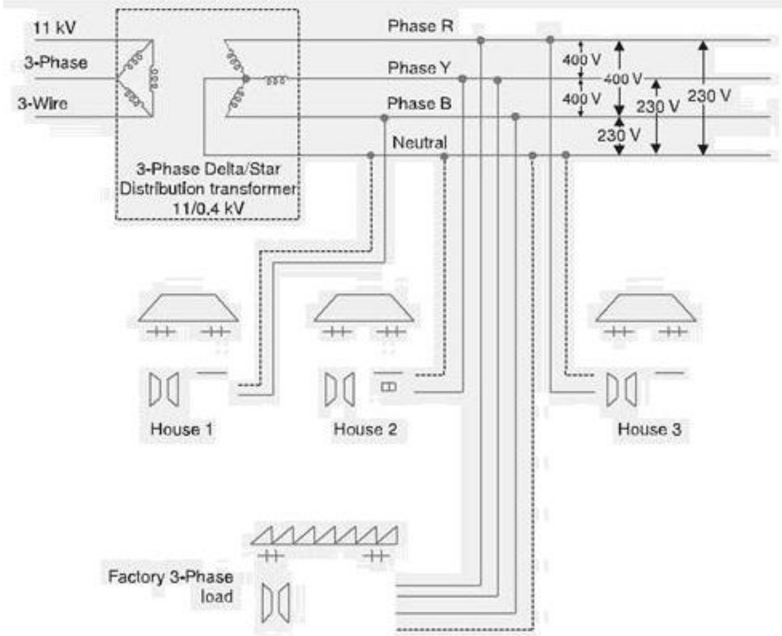
Typical Primary Distribution System

Fig. shows a typical primary distribution system Electric power from the generating station is transmitted at high voltage to the substation located in or near the city. At this substation, voltage is stepped down to 11 kV with the help of step-down transformer. Power is supplied to various substations for distribution or to big consumers at this voltage. This forms the high voltage distribution or primary distribution.

(*ii*) Secondary distribution system

It is that part of a.c. distribution system which includes the range of voltages at which the ultimate consumer utilizes the electrical energy delivered to him. The secondary distribution employs 400/230 V, 3-phase, 4-wire system.

Fig. shows a typical secondary distribution system. The primary distribution circuit delivers power to various substations, called distribution sub-stations. The substations are situated near the consumers' localities and contain step-down transformers. At each distribution substation, the voltage is stepped down to 400 V and power is delivered by 3-phase, 4-wire a.c. system. The voltage between any two phases is 400 V and between any phase and neutral is 230V. The single phase domestic loads are connected between any one phase and the neutral, whereas 3-phase 400 V motor loads are connected across 3-phase lines directly.



Typical Secondary Distribution System

Merits of AC Transmission System

Advantages:

- AC Circuit breakers is cheap than DC Circuit breakers.
- The repairing and maintenance of AC substation is easy and inexpensive than DC Substation.
- The Level of AC voltage may be increased or decreased step up and Step down transformers.

Demerits of AC Transmission System

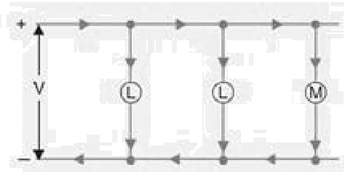
- In AC line, the size of conductor is greater than DC Line.
- The Cost of AC Transmission lines are greater than DC Transmission lines.
- Due to Skin effect, the losses in AC system are more.
- In AC Lines, there is Capacitance, so continuously power loss when no load on lines or Line is open.
- Other line losses are due to inductance.
- More insulation required in AC System
- Also corona Losses occur in AC System,
- There is telecommunication interference in AC System.
- There are stability and synchronizing problems in AC System.
- DC System is more efficient than AC System.

There are also re-active power controlling problems in AC System.

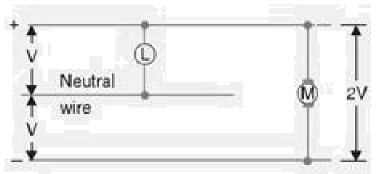
DC distribution

It is a common knowledge that electric power is almost exclusively generated, transmitted and distributed as a.c. However, for certain applications, d.c. supply is absolutely necessary. For instance, d.c. supply is required for the operation of variable speed machinery (*i.e.*, d.c. motors), for electro-chemical work and for congested areas where storage battery reserves are necessary. For this purpose, a.c. power is converted into d.c. power at the substation by using converting machinery e.g., mercury arc rectifiers, rotary converters and motor-generator sets. The d.c. supply from the substation may be obtained in the form of (*i*) 2-wire or (*ii*) 3-wire for distribution.

i) 2-wire d.c. system As the name implies, this system of distribution consists of two wires. One is the outgoing or positive wire and the other is the return or negative wire. The loads such as lamps, motors etc. are connected in parallel between the two wires as shown in Fig. This system is never used for transmission purposes due to low efficiency.



(***ii***) *3-wire d.c. system* It consists of two outers and a middle or neutral wire which is earthed at the substation. The voltage between the outers is twice the voltage between either outer or neutral wire as shown in Fig.



Advantages of DC Transmission

- There are two conductors used in DC transmission while three conductors required in AC transmission.
- There are no Inductance and Surges (High Voltage waves for very short time) in DC transmission.
- Due to absence of inductance, there are very low voltage drop in DC transmission lines comparing with AC (if both Load and sending end voltage is same)
- There is no concept of Skin effect in DC transmission. Therefore, small cross sectional area conductor required.
- A DC System has a less potential stress over AC system for same Voltage level. Therefore, a DC line requires less insulation.

- In DC System, There is no interference with communication system.
- In DC Line, Corona losses are very low.
- In High Voltage DC Transmission lines, there are no Dielectric losses.
- In DC Transmission system, there are no difficulties in synchronizing and stability problems.
- DC system is more efficient than AC, therefore, the rate of price of Towers, Poles, Insulators, and conductor are low so the system is economical.
- In DC System, the speed control range is greater than AC System.
- There is low insulation required in DC system (about 70%).
- The price of DC cables is low (Due to Low insulation)
- In DC Supply System, the Sheath losses in underground cables are low.
- DC system is suitable for High Power Transmission based on High Current transmission.
- In DC System, The Value of charging current is quite low, there fore, the length DC Transmission lines is greater than AC lines.

Disadvantages of Dc Transmission

- Due to commutation problem, Electric power can't be produce at High (DC) Voltage.
- For High Voltage transmission, we cannot step the level of DC Voltage (As Transformer cannot work on DC)
- There is a limit of DC Switches and Circuit breakers (and costly too)
- Motor generator set is used for step down the level of DC voltage and the efficiency of Motor-generator set is low than transformer.
- The system makes complex and costly.
- The level of DC Voltage cannot be change easily. So we cannot get desire voltage for Electrical and electronics appliances (such as 5 Volts, 9 Volts 15 Volts, 20 and 22 Volts etc) directly from Transmission system.

Video Content / Details of website for further learning (if any):

1. https://electrical-engineering-portal.com/electrical-distribution-systems
2. https://www.youtube.com/watch?v=_iz8ZkjD7z8

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 5)

2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 23 to 24)

Course Faculty

MUTHAYAMMAL ENGINEERING COLLEGE

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Estd. 2000

LECTURE HANDOUTS **L4**

DEPT: EEE **III / V**

Course Name with Code :**19EEC12 & TRANSMISSION & DISTRIBUTION**

Course Teacher : **Mrs.M.Selvakumari**

Unit : **I – STRUCTURE OF POWER SYSTEM**

Date of Lecture:

Topic of Lecture: Types of DC and AC Distributors

Introduction :

- 3 phase A.C distribution system requires 4 wires. D.C distribution system requires only one wire with the ground as a return path.
- Voltage drop is less in the dc distributor due to the absence of inductance voltage regulation is good.
- AC is easy and cheap to transform from one voltage to another using transformers.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

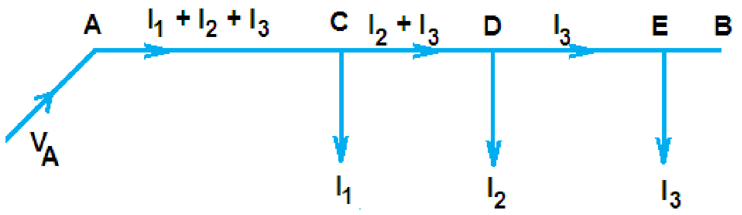
Types of Distributors (General)

The distributors of AC and DC distribution system are generally classified as per the way they are being fed by the feeders. The main distributor types in power distribution system are as under:

1. Distributor fed at one end
2. Distributor fed at both ends
3. Distribution fed at the centre
4. Ring distributor

Distributor fed at one end

The distributor is connected to the supply at one end and loads are taken at the different points along the length of distributor. DC distribution AB led at the end A and loads tapped points C, D and E respectively.



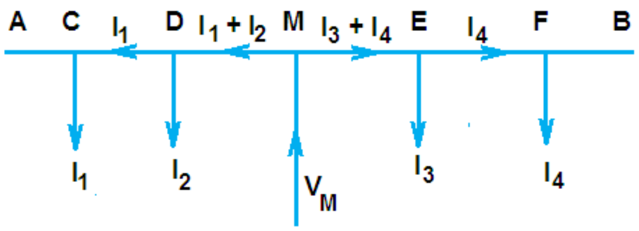
Distributor fed at one end

The following points are worth noting in this case:

- The current in the various sections of the distributor from the far end B goes on increasing as we approach the feeding point A. Thus, current in section CD is more than DE and current in section AC is more than CD.
- The voltage across the loads away from the feeding point goes on decreasing. The minimum voltage occurs at the farthest load point E.
- Whenever the load on the distributor is switched on, or off, there are heavy voltage fluctuations at the farthest load point E.
- If a fault occurs on any section of the distributor, the whole distributor will have to be disconnected from the supply mains for its repair. Therefore, continuity of supply is interrupted.

Distributor Fed at Both Ends

In this type, the distributor is connected to supply at both ends and loads are tapped at different points along the length of the distributor. The supply voltage at the two feeding points may or may not be equal. The single line diagram of a distributor fed at point A and B is shown in the figure. The various loads I_1, $I_2$and I_3 are tapped at point C, D and E respectively.



Distributor fed at the centre

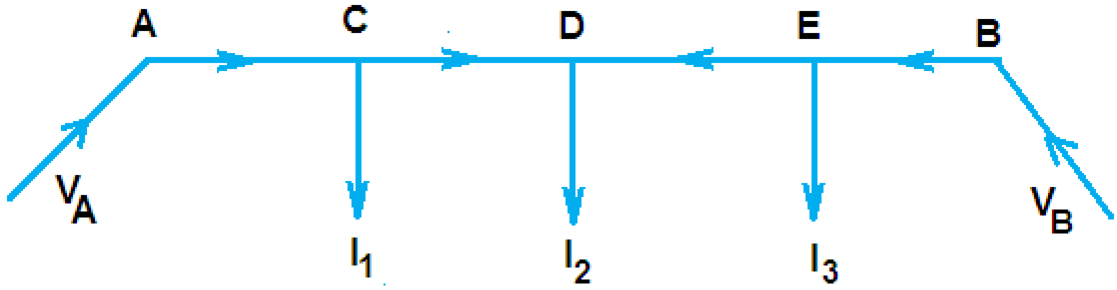
In this case, the voltage goes on decreasing as we move away from one feeding point (say A), reaches the minimum value and then again starts rising and attains the maximum value when reaches at the other feeding point (B). That load point obtains the minimum voltage which is fed from both sides i.e. point D in this case. However, the point of minimum potential is never fixed; it is shifted with the variation of load on the different sections of the distributor.

Advantages of Distributor Fed at both Ends

- If the supply of any feeding end fails, the continuity of power supply to the consumers is maintained from the other feeding end.
- In case, the fault occurs on any section of the distributor, the faulty section can be isolated and the supply is maintained to the remaining sections. This improves the reliability of supply.
- The area of cross-section required for a doubly fed distributor is much less than a single fed distributor. Hence, it is economical.

Distributor Fed at the Center

In this type of feeding, the distributor is connected to supply at the center and the loads are tapped on both the sides of the distributor along its length. The figure shows the single line diagram of distributor AB fed at the middle point M. The various loads I_1, I_2, I_3 and I_4 are tapped at points C, D, E and F respectively.



Distributor fed at both ends

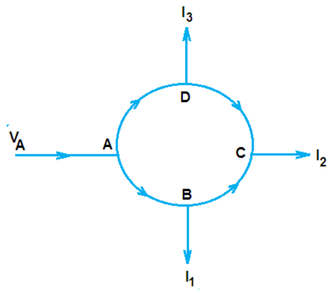
It is equivalent to two singly fed distributors (MA and MB), each one having a common feeding point and length equal to half of the total length. It is preferred over a distributor fed at one end because of the following advantages.

- The various sections of the distributor carry lesser current which reduces the voltage drop in the distributor.
- The voltage reaching the farther points (i.e. C and F) is more.
- There are fewer voltage fluctuations at the farther ends.
- The conductor size required for the distributor is less.

Ring Distributor or Ring Mains Distributor

In this type, the distributor is in the form of a ring (closed circuit) and is supplied at one or more than one points. When the distributor is fed at one point only, it is just a doubly fed distributor fed at equal voltages at both ends being brought together to form a closed ring.

The figure shows the single line diagram of a DC 2-wire ring distributor fed at point A The various loads I_1, I_2 and I_3, are tapped at point B, C and D respectively.



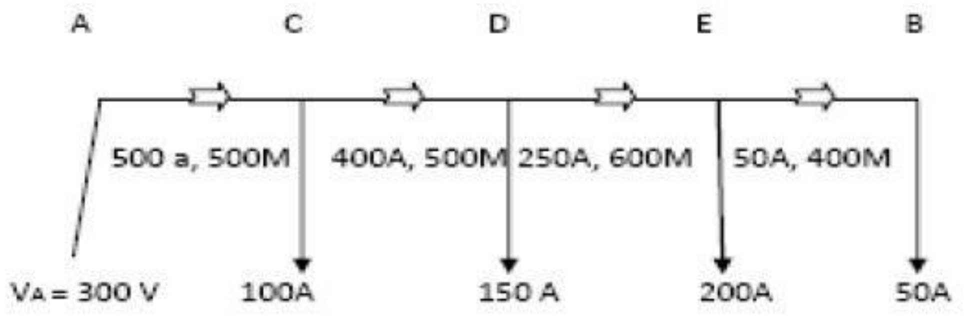
Ring distributor

It has all the advantages which have been mentioned for the doubly fed distributor. A ring main distributor may also be fed at more than one point. For the purpose of calculations, in that case, the distributor can be considered as a distributor consisting of a series of open distributors fed at both ends.

Problem: A 2 wire DC distribution cables A,B is 2 KM long and supplies load of 100A, 150A, 200A and 50A situated 500M, 1000M, 1600M and 2000M from the feeding point A. Each conductor has a resistance of 0.012/1000M. Calculate the potential at each load points if a potential difference of 300 V is maintained at point A.

Solution: Resistance /1000 of distributor

= 2*0.01 = 0.02 Voltage = 300V.



Resistance of section AC, RAC = 0.002*500/1000 = 0.01 Ω

Resistance of section CD, RCD = 0.002*500/1000 = 0.01 Ω

Resistance of section DE, RDE = 0.002*600/1000 = 0.012 Ω

Resistance of section EB, REB = 0.002*400/1000 = 0.008 Ω

Current from various sections.

IEB = 50A, IDE = 50+200 = 250 A, ICD =

50+200+150+600 A

IAC = 50 +200+150+100 = 500 A.

Potential difference at load point C = VC = voltage at A – voltage VA –IAC *RAC drop in ac. =

300 – 500 *0.01 = 295V Potential difference at load point D = VD =VC-ICD.RCD = 295-

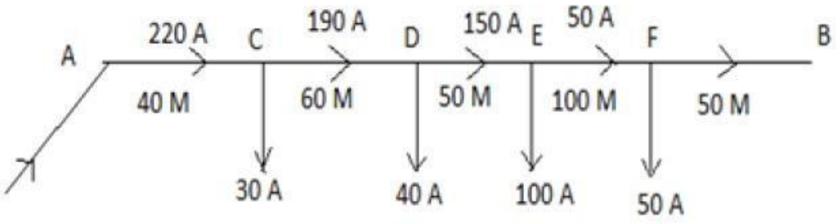
0.01*400 = 291V

Potential difference at load point E = VE = VD-VDE.RDE = 291-250*0.012 = 288V Potential difference at load point B = VB = VE=VEB.REB = 288-50*0.008 = 287.67V

2. A two wire dc distributor AB is 300 meter long. It is fed at point A. the various loads and their positions are given below.

At point	Distance from A(meters)	Concentrated load in mperes.
A	40	30
D	100	40
E	150	100
F	250	50

If the maximum permission voltage drop is not exceed 10v, find the cross sectional area of the distributor. Take e= 1.



Answer= 0.164 cm^2

Video Content / Details of website for further learning (if any):

1. https://www.yourelectricalguide.com/2018/01/distributor-types-power-distribution-system.html
2. https://www.youtube.com/watch?v=_iz8ZkjD7z8

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 10)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 26 to 28)

Course Faculty

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Estd. 2000

LECTURE HANDOUTS | **L5**

DEPT: EEE | **III / V**

Course Name with Code :19EEC12 & TRANSMISSION & DISTRIBUTION

Course Teacher : Mrs.M.Selvakumari

Unit : I – STRUCTURE OF POWER SYSTEM

Date of Lecture:

Topic of Lecture : DC and AC Distributors -Distributed and Concentrated loads

Introduction :

- A uniformly distributed load (UDL) is a load that is distributed or spread across the whole region of an element such as a beam or slab. In other words, the magnitude of the load remains uniform throughout the whole element.
- Concentrated loading is one where a load acting on a very small area of the structure's surface; the exact opposite of a distributed load.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

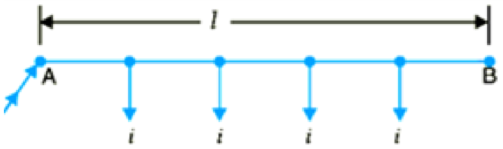
Detailed content of the Lecture:

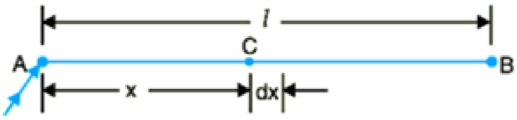
Uniform Loading

Loads are acts uniformly on all the points of distributor. Ideally no distribution load. E.g. Large number of loads of same voltage connected to the distributor at equal distance.

Uniformly Loaded Distributor Fed at One End

Fig shows the single line diagram of a 2-wire d.c. distributor *A B* fed at one end *A* and loaded uniformly with *i* amperes per metre length. It means that at every 1 m length of the distributor, the load tapped is *i* amperes. Let *l* metres be the length of the distributor and *r* ohm be the resistance per metre run.





Consider a point *C* on the distributor at a distance *x* metres from the feeding point *A* as shown in Fig. Then current at point *C* is

$= i\,l - i\,x$ amperes $= i\,(l - x)$ amperes

Now, consider a small length dx near point C. Its resistance is r dx and the voltage drop over length dx is $dv = i\,(l - x)\,r\,dx = i\,r\,(l - x)\,dx$ Total voltage drop in the distributor upto point C is

$$v = \int_0^x i\,r\,(l - x)\,dx = i\,r\left(l\,x - \frac{x^2}{2}\right)$$

The voltage drop upto point B (i.e. over the whole distributor) can be obtained by putting $x = l$ in the above expression.

∴ Voltage drop over the distributor AB

$$= i\,r\left(l \times l - \frac{l^2}{2}\right)$$

$$= \frac{1}{2}\,i\,r\,l^2 = \frac{1}{2}\,(i\,l)\,(r\,l)$$

$$= \frac{1}{2}\,I\,R$$

Uniformly Loaded Distributor Fed at Both Ends

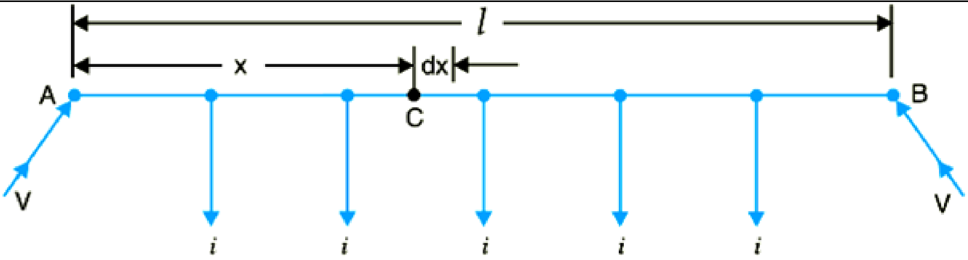
- Distributor fed at both ends with Equal voltages.
- Distributor fed at both ends with Unequal voltages

Distributor fed at both ends with Equal voltages

Consider a distributor *A B* of length *l* metres, having resistance *r* ohms per metre run and with uniform loading of *i* amperes per metre run as shown in Fig. 13.24. Let the distributor be fed at the feeding points *A* and *B* at equal voltages, say *V* volts. The total current supplied to the distributor is *i l*. As the two end voltages are equal, therefore, current supplied from each feeding point is *i l*/2 *i.e.*

Current supplied from each feeding point

$$= \frac{i\,l}{2}$$



Consider a point C at a distance x metres from the feeding point A. Then current at point C is $i\,l$

$$= \frac{i\,l}{2} - i\,x = i\left(\frac{l}{2} - x\right)$$

Now, consider a small length dx near point C. Its resistance is $r\,dx$ and the voltage drop over length dx is

$$dv = i\left(\frac{l}{2} - x\right) r\,dx = i\,r\left(\frac{l}{2} - x\right) dx$$

$$\therefore \quad \text{Voltage drop upto point } C = \int_0^x i\,r\left(\frac{l}{2} - x\right) dx = i\,r\left(\frac{l\,x}{2} - \frac{x^2}{2}\right)$$

$$= \frac{i\,r}{2}\left(l\,x - x^2\right)$$

Obviously, the point of minimum potential will be the mid-point. Therefore, maximum voltage drop will occur at mid-point *i.e.* where $x = l/2$.

$$\therefore \quad \text{Max. voltage drop} = \frac{i\,r}{2}\left(l\,x - x^2\right)$$

$$= \frac{i\,r}{2}\left(l \times \frac{l}{2} - \frac{l^2}{4}\right) \qquad \text{[Putting } x = l/2\text{]}$$

$$= \frac{1}{8}\,i\,r\,l^2 = \frac{1}{8}(i\,l)(r\,l) = \frac{1}{8}\,I\,R$$

where $i\,l = I$, the total current fed to the distributor from both ends

$r\,l = R$, the total resistance of the distributor

$$\text{Minimum voltage} = V - \frac{I\,R}{8} \text{ volts}$$

Distributor fed at both ends with Unequal voltages

Consider a distributor AB of length l metres having resistance r ohms per metre run and with a uniform loading of i amperes per metre run as shown in Fig. Let the distributor be fed from feeding points A and B at voltages V_A and V_B respectively. Suppose that the point of minimum potential C is situated at a distance x metres from the feeding point A. Then current supplied by the feeding point A will be i x.

$$\text{Voltage drop in section } AC = \frac{i\,r\,x^2}{2} \text{ volts}$$

$$\therefore \quad \text{Voltage drop in section } BC = \frac{i\,r\,(l-x)^2}{2} \text{ volts}$$

$$\text{Voltage at point } C,\ V_C = V_A - \text{Drop over } AC$$

$$= V_A - \frac{i\,r\,x^2}{2} \qquad \ldots(i)$$

$$\text{Also, voltage at point } C,\ V_C = V_B - \text{Drop over } BC$$

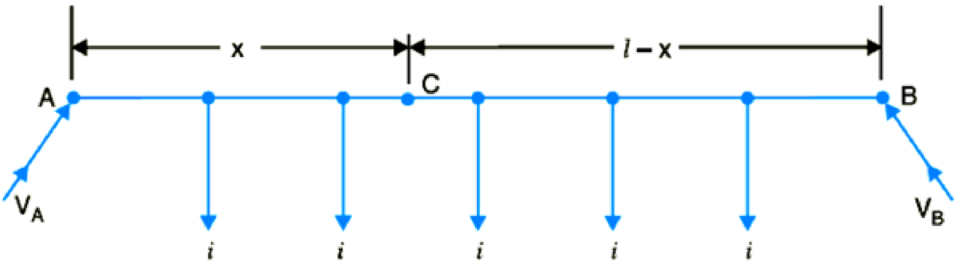
$$= V_B - \frac{i\,r\,(l-x)^2}{2} \qquad \ldots(ii)$$

From equations (*i*) and (*ii*), we get,

$$V_A - \frac{i\,r\,x^2}{2} = V_B - \frac{i\,r\,(l-x)^2}{2}$$

Solving the equation for x, we get,

$$x = \frac{V_A - V_B}{i\,r\,l} + \frac{l}{2}$$



As the distance of C from feeding point B is (l − x), therefore, current fed from B is i (l − x).

$$\therefore \quad \text{Voltage drop in section } BC = \frac{i\,r\,(l-x)^2}{2} \text{ volts}$$

$$\text{Voltage at point } C,\ V_C = V_A - \text{Drop over } AC$$

$$= V_A - \frac{i\,r\,x^2}{2} \qquad \ldots(i)$$

$$\text{Also, voltage at point } C,\ V_C = V_B - \text{Drop over } BC$$

$$= V_B - \frac{i\,r\,(l-x)^2}{2} \qquad \ldots(ii)$$

From equations (*i*) and (*ii*), we get,

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Solving the equation for x, we get,

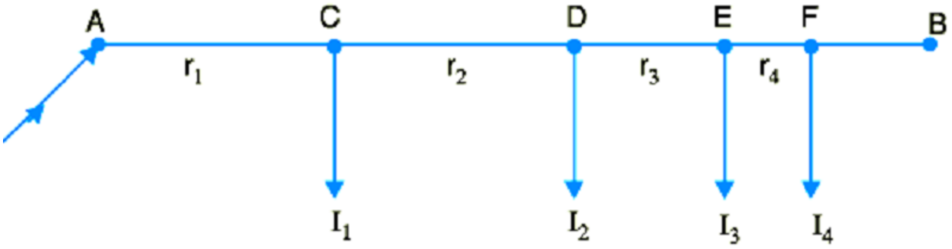
$$x = \frac{V_A - V_B}{i\,r\,l} + \frac{l}{2}$$

As all the quantities on the right hand side of the equation are known, therefore, the point on the distributor where minimum potential occurs can be calculated.

Concentrated Loading

Loads are acting on particular point. E.g. Tapped of for domestic use.

Fig. shows the single line diagram of a 2-wire d.c. distributor A B fed at one end A and having concentrated loads I_1 , I_2 , I_3 and I_4 tapped off at points C, D, E and F respectively. Let r_1 , r_2 , r_3 and r_4 be the resistances of both wires (go and return) of the sections A C, CD, DE and EF of the distributor respectively



Current fed from point A	$= I_1 + I_2 + I_3 + I_4$
Current in section AC	$= I_1 + I_2 + I_3 + I_4$
Current in section CD	$= I_2 + I_3 + I_4$
Current in section DE	$= I_3 + I_4$
Current in section EF	$= I_4$
Voltage drop in section AC	$= r_1 (I_1 + I_2 + I_3 + I_4)$
Voltage drop in section CD	$= r_2 (I_2 + I_3 + I_4)$
Voltage drop in section DE	$= r_3 (I_3 + I_4)$
Voltage drop in section EF	$= r_4 I_4$

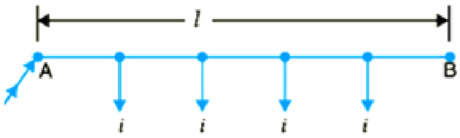
∴ Total voltage drop in the distributor

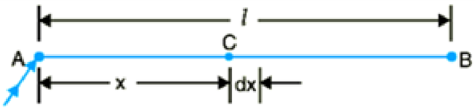
$$= r_1 (I_1 + I_2 + I_3 + I_4) + r_2 (I_2 + I_3 + I_4) + r_3 (I_3 + I_4) + r_4 I_4$$

It is easy to see that the minimum potential will occur at point F which is farthest from the feeding point A.

Concentrated Loading fed at one end-Concentrated Loading

Fig shows the single line diagram of a 2-wire d.c. distributor A B fed at one end A and loaded uniformly with i amperes per metre length. It means that at every 1 m length of the distributor, the load tapped is i amperes. Let l metres be the length of the distributor and r ohm be the resistance per metre run.





Consider a point C on the distributor at a distance x metres from the feeding point A as shown in Fig. Then current at point C is

$= i\,l - i\,x$ amperes $= i\,(l - x)$ amperes

Now, consider a small length dx near point C. Its resistance is r dx and the voltage drop over length dx is d v = $i\,(l - x)\,r\,dx = i\,r\,(l - x)$ dx Total voltage drop in the distributor upto point C is

$$v = \int_0^x i\,r\,(l - x)\,dx = i\,r\left(l\,x - \frac{x^2}{2}\right)$$

The voltage drop upto point B (i.e. over the whole distributor) can be obtained by putting $x = l$ in the above expression.

∴ Voltage drop over the distributor AB

$$= i\,r\left(l \times l - \frac{l^2}{2}\right)$$

$$= \tfrac{1}{2}\, i\,r\,l^2 = \tfrac{1}{2}\,(i\,l)\,(r\,l)$$

$$= \tfrac{1}{2}\, I\,R$$

Where,

$i\,l = I$, the total current entering at point A

$r\,l = R$, the total resistance of the distributor

Thus, in a uniformly loaded distributor fed at one end, the total voltage drop is equal to that produced by the whole of the load assumed to be concentrated at the middle point.

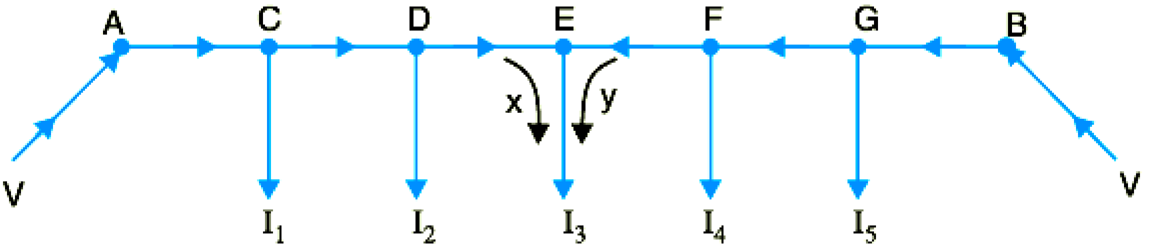
Concentrated Loading fed at both ends-Concentrated Loading

- Concentrated loading fed at both ends with Equal voltages
- Concentrated loading fed at both ends with Unequal voltages

Concentrated loading fed at both ends with Equal voltages

Consider a distributor A B fed at both ends with equal voltages V volts and having concentrated loads I_1, I_2, I_3, I_4 and I_5 at points C, D, E, F and G respectively as shown in Fig. As we move away from one of the feeding points, say A , p.d. goes on decreasing till it reaches the minimum value at some load point, say E, and then again starts rising and becomes V volts as we reach the other feeding point B.

All the currents tapped off between points A and E (minimum p.d. point) will be supplied from the feeding point A while those tapped off between B and E will be supplied from the feeding point B.



The current tapped off at point E itself will be partly supplied from A and partly from B. If these currents are x and y respectively, then,

$$I_3 = x + y$$

Therefore, we arrive at a very important conclusion that at the point of minimum potential, current comes from both ends of the distributor.

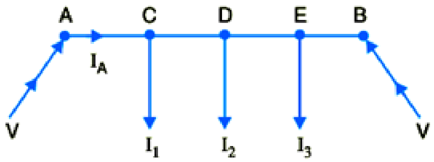
Point of minimum potential

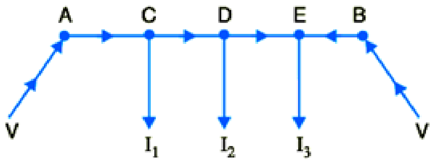
It is generally desired to locate the point of minimum potential. There is a simple method for it. Consider a distributor *A B* having three concentrated loads I_1, I_2 and I_3 at points *C*, *D* and *E* respectively. Suppose that current supplied by feeding end *A* is I_a . Then current distribution in the various sections of the distributor can be worked out as shown in Fig.

$$I_{AC} = I_A; \qquad I_{CD} = I_A - I_1$$

$$I_{AC} = I_A; \qquad I_{CD} = I_A - I_1$$

$$I_{DE} = I_A - I_1 - I_2; \qquad I_{EB} = I_A - I_1 - I_2 - I_3$$





Voltage drop between A and B = Voltage drop over A B

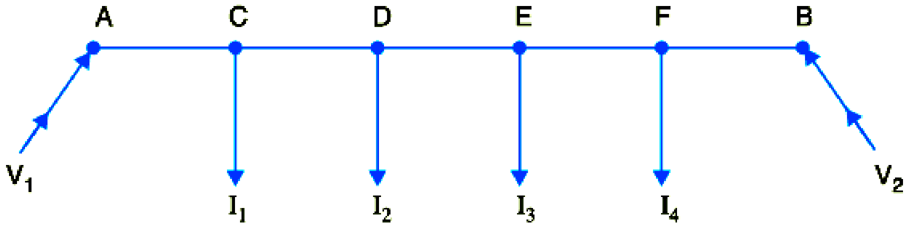
or $$V - V = I_A R_{AC} + (I_A - I_1) R_{CD} + (I_A - I_1 - I_2) R_{DE} + (I_A - I_1 - I_2 - I_3) R_{EB}$$

From this equation, the unknown I_A can be calculated as the values of other quantities are generally given. Suppose actual directions of currents in the various sections of the distributor are indicated as shown in Fig. The load point where the currents are coming from both sides of the distributor is the point of minimum potential i.e. point E in this case.

Concentrated loading fed at both ends with Unequal voltages

Fig. shows the distributor A B fed with unequal voltages end A being fed at V_1 volts and end B at V_2 volts. The point of minimum potential can be found by following the same procedure as discussed above. Thus in this case, Voltage drop between A and B = Voltage drop over A B

$V_1 - V_2$ = Voltage drop over A



Video Content / Details of website for further learning (if any):

1. https://www.allaboutcircuits.com/textbook/direct-current/chpt-10/mesh-current-method/
2. https://www.youtube.com/watch?v=k5Tlg27JDtc

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 12)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 29 to 33)

Course Faculty

LECTURE HANDOUTS | **L6**

DEPT: EEE | **III / V**

Course Name with Code : **19EEC12 & TRANSMISSION & DISTRIBUTION**

Course Teacher : **Mrs.M.Selvakumari**

Unit : **I – STRUCTURE OF POWER SYSTEM**

Date of Lecture:

Topic of Lecture Connection schemes, Interconnection and Requirements of Distribution System

Introduction :

- The distribution system is the electrical system between the substation fed by the transmission system and the consumer end. It generally consists of feeders, distributors.
- When a ring main feeder is energized by two or more substations or generating stations, it is called as an interconnected distribution system. This system ensures reliability in an event of transmission failure

Prerequisite knowledge for Complete understanding and learning of Topic:

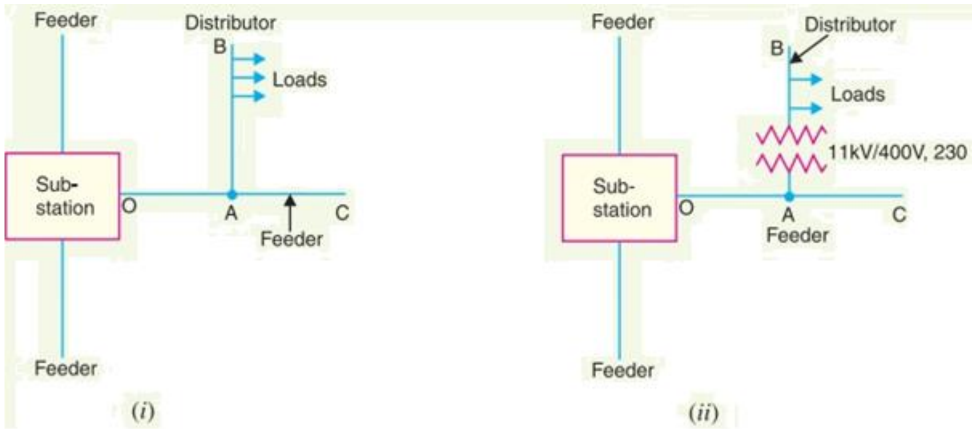
- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

All distribution of electrical energy is done by constant voltage system. In practice, the following distribution circuits are generally used :

Radial System

In this system, separate feeders radiate from a single substation and feed the distributors at one end only. Fig. (i) shows a single line diagram of a radial system for d.c. distribution where a feeder *OC* supplies a distributor *A B* at point *A*. Obviously, the distributor is fed at one end only *i.e.*, point *A* is this case. Fig. (*ii*) shows a single line diagram of radial system for a.c. distribution. The radial system is employed only when power is generated at low voltage and the substation is located at the centre of the load.



This is the simplest distribution circuit and has the lowest initial cost. However, it suffers from the following drawbacks :

(a) The end of the distributor nearest to the feeding point will be heavily loaded.

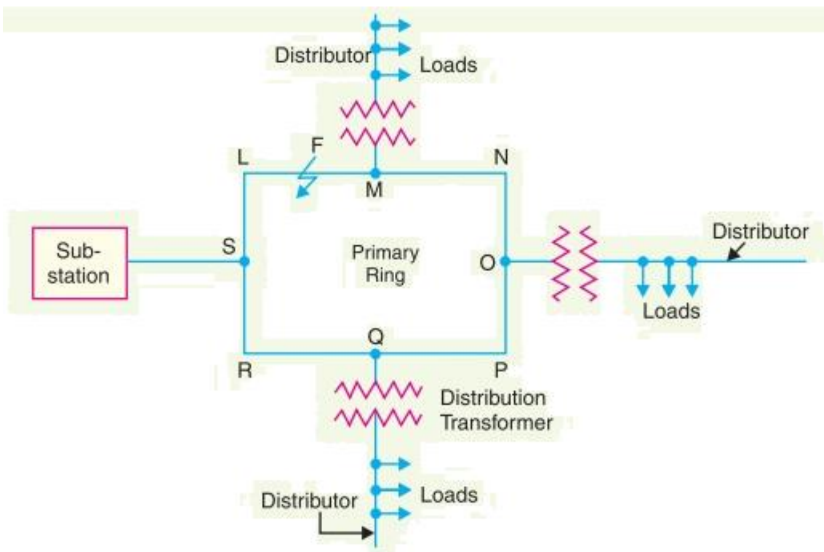
(b) The consumers are dependent on a single feeder and single distributor.

Therefore, any fault on the feeder or distributor cuts off supply to the consumers who are on the side of the fault away from the substation.

The consumers at the distant end of the distributor would be subjected to serious voltage fluctuations when the load on the distributor changes. Due to these limitations, this system is used for short distances only.

Ring main system

In this system, the primaries of distribution transformers form a loop. The loop circuit starts from the substation bus-bars, makes a loop through the area to be served, and returns to the substation. Fig. shows the single line diagram of ring main system for ac distribution where substation supplies to the closed feeder LMNOPQRS. The distributors are tapped from different points *M*, *O* and *Q* of the feeder through distribution transformers.

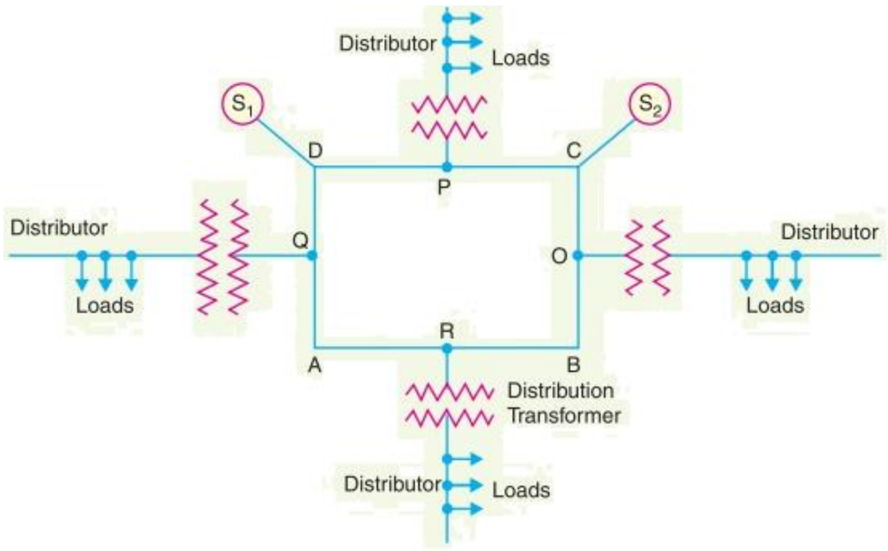


Interconnected system

When the feeder ring is energised by two or more than two generating stations or substations, it is called inter-connected system. Fig. shows the single line diagram of interconnected system where the closed feeder ring *ABCD* is supplied by two substations *S*1 and *S*2 at points *D* and *C* respectively. Distributors are connected to points *O*, *P*, *Q* and *R* of the feeder ring through distribution transformers. The interconnected system has the following advantages:

(a) It increases the service reliability.

(b) Any area fed from one generating station during peak load hours can be fed from the other generating station. This reduces reserve power capacity and increases efficiency of the system.



Requirements of a Distribution System

A considerable amount of effort is necessary to maintain an electric power supply within the requirements of various types of consumers. Some of the requirements of a good distribution system are : proper voltage, availability of power on demand and reliability.

(i) Proper voltage

One important requirement of a distribution system is that voltage variations at consumer's terminals should be as low as possible. The changes in voltage are generally caused due to the variation of load on the system. Low voltage causes loss of revenue, inefficient lighting and possible burning out of motors. High voltage causes lamps to burn out permanently and may cause failure of other appliances. Therefore, a good distribution system should ensure that the voltage variations at consumers terminals are within permissible limits. The statutory limit of voltage variations is ± 6% of the rated value at the consumer's terminals. Thus, if the declared voltage is 230 V, then the highest voltage of the consumer should not exceed 244 V while the lowest voltage of the consumer should not be less than 216 V.

(ii) Availability of power on demand

Power must be available to the consumers in any amount that they may require from time to time. For example, motors may be started or shut down, lights may be turned on or off, without advance warning to the electric supply company. As electrical energy cannot be stored, therefore, the distribution system must be capable of supplying load demands of the consumers. This necessitates that operating staff must continuously study load patterns to predict in advance those major load changes that follow the known schedules.

(iii) Reliability

Modern industry is almost dependent on electric power for its operation. Homes and office buildings are lighted, heated, cooled and ventilated by electric power. This calls for reliable service. Unfortunately, electric power, like everything else that is man-made, can never be absolutely reliable. However, the reliability can be improved to a considerable extent by (a) interconnected system (b) reliable automatic control system (c) providing additional reserve facilities.

Video Content / Details of website for further learning (if any):

1. https://electrical-engineering-portal.com/electrical-distribution-systems
2. https://www.youtube.com/watch?v=YVOwTIUrQCA

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 22)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 33 to 36)

Course Faculty

LECTURE HANDOUTS **L7**

DEPT: EEE **III / V**

Course Name with Code :19EEC12 & TRANSMISSION & DISTRIBUTION

Course Teacher : Mrs.M.Selvakumari

Unit : I – STRUCTURE OF POWER SYSTEM

Date of Lecture:

Topic of Lecture: Trends in Transmission-EHVAC and HVDC

Introduction:

- EHVAC Transmission line stands for Extra High Voltage Alternating Current transmission line. (EHV) transmission is defined as between 230kV and 765kV for AC. EHV lines are used to move large amounts of power across long distances. The higher the voltage, the lower the losses.
- HVDC stands for high voltage direct current, a well-proven technology used to transmit electricity over long distances by overhead transmission lines or submarine cables.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- AC Machines

Detailed content of the Lecture:

Types of Voltage and its range

Voltage Level	Type
Upto 1KV/1000 v	Low voltage
1K-35 KV	Medium voltage
35-230 KV	High voltage
230-765 KV	Extra high voltage
> 765KV	Ultra high voltage

With the increase in transmission voltage, for same amount of power to be transmitted current in the line decreases which reduces I^2R losses. This will lead to increase in transmission efficiency. With decrease in transmission current, size of conductor required reduces which decreases the volume of conductor. The transmission capacity is proportional to square of operating voltages. Thus the transmission capacity of line increases with increase in voltage.

Since the power plants are located far away from the load centres, there is need for transporting power over long distances economically only by using EHV lines of transmission.

Advantages & Disadvantages of EHVAC

Advantages

i. Reduces the volume of conductor material
ii. Reduction in current
iii. Transmission line losses decreases
iv. Increases transmission efficiency
v. Percentage line voltage drop decreases
vi. Saving of copper, hence more economical

Disadvantages

1. The cost for insulating the conductor increases.
2. Cost of transformers, switch gears and other equipments increases.
3. Electrostatic effects generated by high voltage are harmful to human beings and animals.

HVDC Transmission

AC is the main driving force in industries and residential areas but for long transmission line AC transmission is more expensive than DC. AC transmission has more complications because of frequency where in DC transmission frequency is absent.

History of HVDC

- First commercial HVDC transmission, Gotland 1 in Sweden 1954.
- In India, the first HVDC transmission was established between Rihand – Delhi project. HVDC was chosen to transmit bulk (thermal) power (1500MW) to Delhi, to ensure minimum losses and better stability and control.

Impact of HVDC

DC is **used** in extra high (EHV) and ultra high (UHV) power **transmission** (500,000V and up) for the following reasons: It is asynchronous. That is, becuase **DC** has no frequency, it can be used to connect two differnent systems without worrying about having to synchronize the systems.

Comparison between EVHVAC and HVDC

Sr.no	points	EHV A.C	H.V.D.C
1	Voltage level	220 KV,400 KV,765 KV	± 500
2	Amount of power delivered	There is limit due to power angle and inductance	No limit
3	Equivalent essential	Step-up transformer and step-down transformer	Step-up transformer, rectifier and inverter, step-down transformer
4	Economical viability	EHVAC is economical for bulk power is to be transmitted over a long distance. 500 KM and above	HVDC is economical to transmit bulk amount of power and above. Over a long distance(800 KM and above)

Video Content / Details of website for further learning (if any):

1. https://www.brainkart.com/article/EHVAC-and-HVDC-Transmission-System_12351/
2. https://www.facebook.com/101967737890599/videos/comparison-of-ehvac-and-hvdc/776971652743526/

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 28)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 38 to 41)

Course Faculty

MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)
Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

LECTURE HANDOUTS **L8**

DEPT: EEE **III / V**

Course Name with Code :**19EEC12 & TRANSMISSION & DISTRIBUTION**

Course Teacher : **Mrs.M.Selvakumari**

Unit : **I – STRUCTURE OF POWER SYSTEM**

Date of Lecture:

Topic of Lecture : HVDC Transmission

Introduction

- High voltage direct current (HVDC) power systems use D.C. for transmission of bulk power over long distances. For long-distance power transmission, HVDC lines are less expensive, and losses are less as compared to AC transmission.
- DC transmission requires fewer conductors than AC transmission - 2 conductors per DC circuit whereas three conductors per 3 phase AC circuit. ... Skin effect is absent in DC. Also, corona losses are significantly lower in the case of DC. An HVDC line has considerably lower losses compared to HVAC over longer distances.
-

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

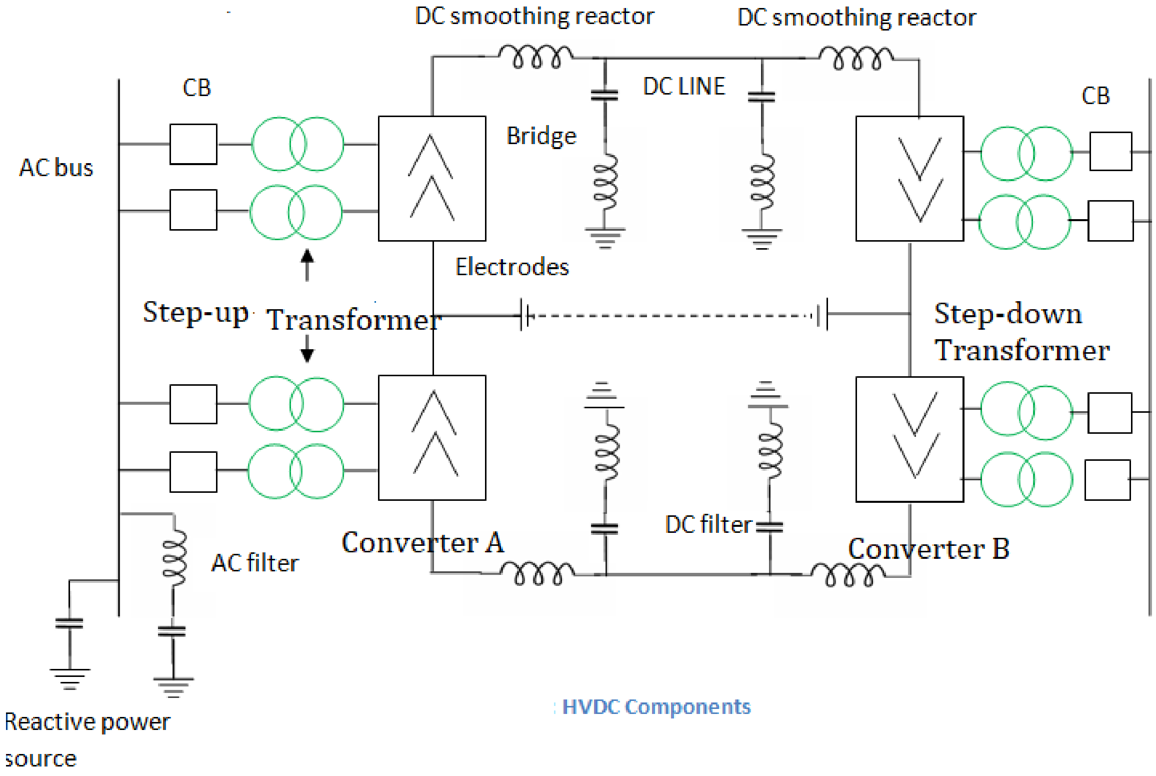
For large power transmission over long distances, the HVDC proves to be economical and efficient over High Voltage AC [HVAC] transmission system.

Component of an HVDC Transmission System

The HVDC system has the following main components:

- Converter Station
- Converter Unit
- Converter Transformers
- Filters
- Reactive Power Source
- Smoothing Reactor
- HVDC System Pole

The block diagram of HVDC transmission system is shown below.



HVDC Components

Converter Station

The terminal substations which convert an AC to DC are called rectifier terminal while the terminal substations which convert DC to AC are called inverter terminal. Every terminal is designed to work in both the rectifier and inverter mode. Therefore, each terminal is called converter terminal, or rectifier terminal. A two-terminal HVDC system has only two terminals and one HVDC line.

Converter Unit

The conversion from AC to DC and vice versa is done in HVDC converter stations by using three-phase bridge converters. This bridge circuit is also called Graetz circuit. In HVDC transmission a 12-pulse bridge converter is used. The converter obtains by connecting two or 6-pulse bridge in series.

Converter Transformer

The converter transformer converts the AC networks to DC networks or vice versa. They have two sets of three phase windings. The AC side winding is connected to the AC bus bar, and the valve side winding is connected to valve bridge. These windings are connected in star for one transformer and delta to another.

Filters

The AC and DC harmonics are generated in HVDC converters. The AC harmonics are injected into the AC system, and the DC harmonics are injected into DC lines.

Reactive Power Source

Reactive power is required for the operations of the converters. The AC harmonic filters provide reactive power partly. The additional supply may also be obtained from shunt capacitors synchronous phase modifiers and static var systems. The choice depends on the speed of control desired.

Smoothing Reactor

Smoothing reactor is an oil filled oil cooled reactor having a large inductance. It is connected in series with the converter before the DC filter. It can be located either on the line side or on the neutral side.

HVDC System Pole

The HVDC system pole is the part of an HVDC system consisting of all the equipment in the HVDC substation. It also interconnects the transmission lines which during normal operating condition exhibit a common direct polarity with respect to earth. Thus the word pole refers to the path of DC which has the same polarity with respect to earth. The total pole includes substation pole and transmission line pole.

HVDC Advantages, Disadvantages Over HVAC Transmission System

HVDC Advantages:

1. Cost of transmission is less, since only two conductors are used for transmission.
2. There is no reactive power. So transmission losses are reduced.
3. Due to high voltage transmission, for the same power current is less. So I2R loss is very less.
4. Because of DC transmission, there is no skin effect. So thin conductors can be used. In case of HVAC transmission, the thick conductors must be used to eliminate skin effect.

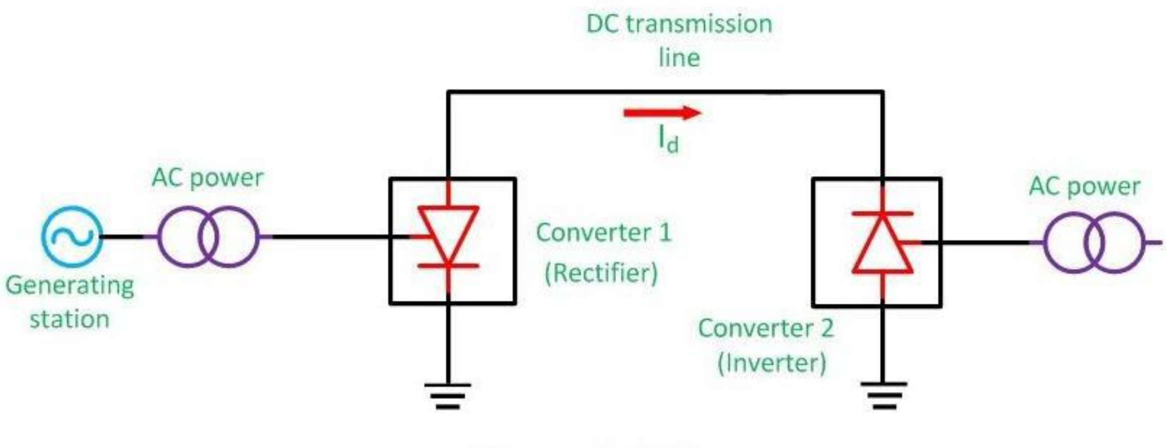
5. Two AC systems having different frequencies can be interconnected using HVDC transmission lines. This is not possible in HVAC transmission system.
6. Installation cost is less. Due to only two conductors and smaller towers required for HVDC.
7. HVDC uses electronic converters. So Protections, fault clearance can be implemented faster than HVAC. Therefore DC transmission system have improved transient stability.
8. In case of faults, power levels on HVDC system can be controlled electronically (i.e., very fast).
9. Since HVDC requires no charging current and the reactive power, it is preferred in power transmission through cables.
10. Unlike HVDC transmission system, HVAC induces body currents in the vicinity of the conductors.
11. HVDC transmission does not have any dielectric loss heating problems in the insulation of conductors.
12. HVDC has minimum audible noise as well as minimum radio, TV interference.
13. Due to bipolar transmission the voltage levels are balanced with respect to an earth.
14. DC cables used for transmission are cheaper than AC cables.
15. In HVDC, line charging and electric resonance do not present which leads to high-efficiency.

Disadvantages of HVDC Transmission

1. High cost converting and inverting equipments are required for HVDC transmission. So it is uneconomical for low power supply over short distances.
2. Converters control is quite complex.
3. Additional filters are required at various stages of HVDC transmission system. So its lead to high installation cost.

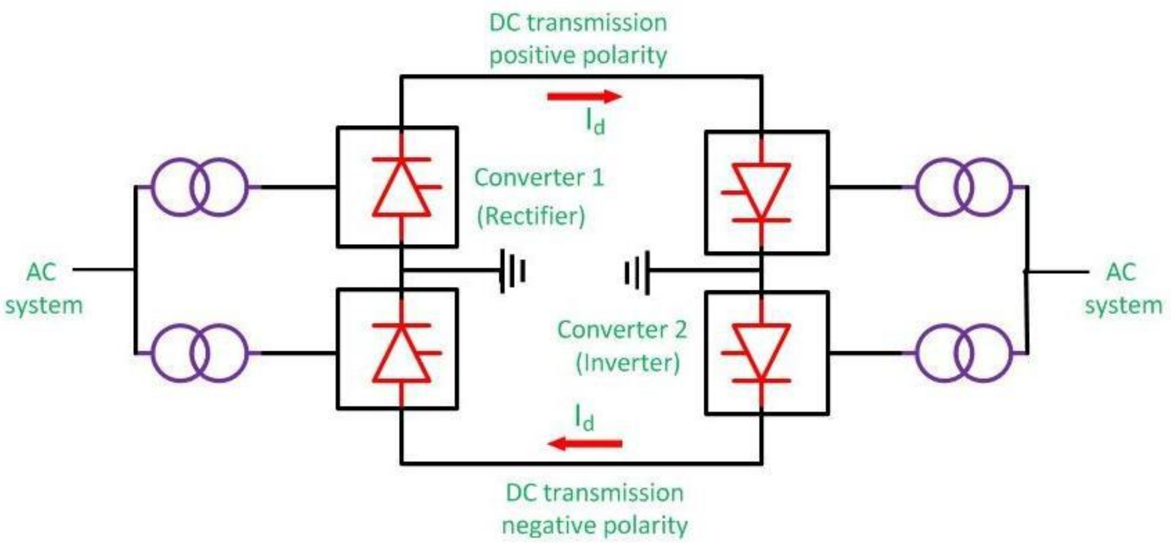
Types of HVDC Links

1.**Monopolar link** – It has a single conductor of negative polarity and uses earth or sea for the return path of current. Sometimes the metallic return is also used. In the Monopolar link, two converters are placed at the end of each pole. Earthing of poles is done by earth electrodes placed about 15 to 55 km away from the respective terminal stations. But this link has several disadvantages because it uses earth as a return path. The monopolar link is not much in use nowadays.



Monopolar link

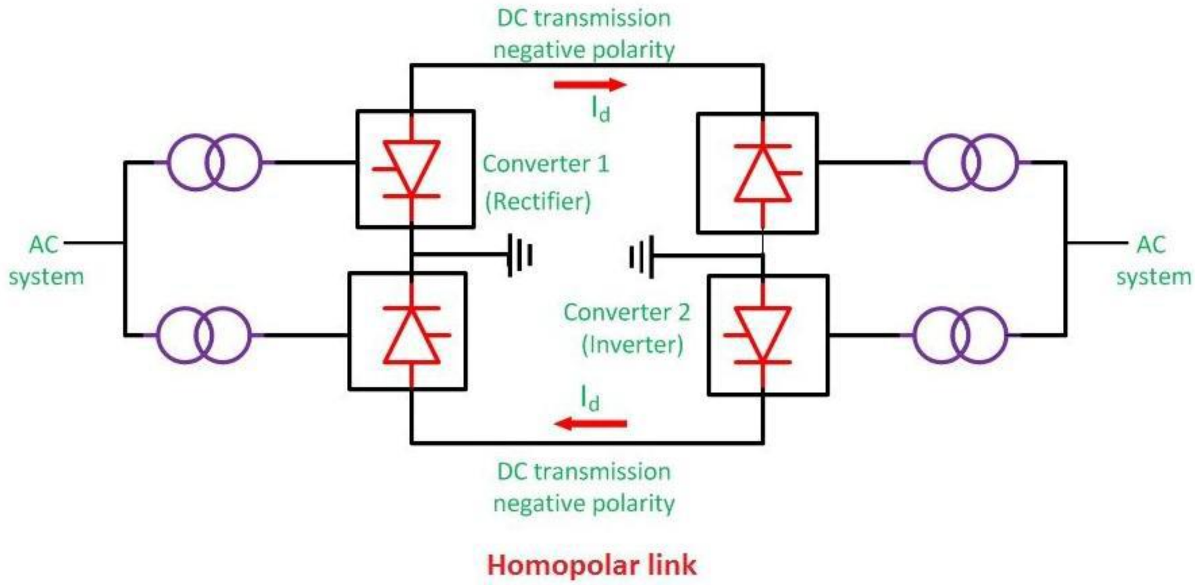
2.**Bipolar link** – The Bipolar link has two conductors one is positive, and the other one is negative to the earth. The link has converter station at each end. The midpoints of the converter stations are earthed through electrodes. The voltage of the earthed electrodes is just half the voltage of the conductor used for transmission the HVDC.



Bipolar link

The most significant advantage of the bipolar link is that if any of their links stop operating, the link is converted into Monopolar mode because of the ground return system. The half of the system continues supplies the power. Such types of links are commonly used in the HVDC systems.

3. Homopolar link– It has two conductors of the same polarity usually negative polarity, and always operates with earth or metallic return. In the homopolar link, poles are operated in parallel, which reduces the insulation cos



Video Content / Details of website for further learning (if any):

1. https://www.electrical4u.com/high-voltage-direct-current-transmission/
2. https://www.youtube.com/watch?v=CHQA5Hp1qbM

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 33)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 42 to 45)

Course Faculty

LECTURE HANDOUTS **L9**

DEPT: EEE **III / V**

Course Name with Code :**19EEC12 & TRANSMISSION & DISTRIBUTION**

Course Teacher : **Mrs.M.Selvakumari**

Unit : **I – STRUCTURE OF POWER SYSTEM**

Date of Lecture:

Topic of Lecture: FACTS- Flexible Alternating Current Transmission System

Introduction

- Flexible alternating current transmission systems (FACTS) devices are used for the dynamic control of voltage, impedance and phase angle of high voltage AC lines.
- FACTS devices facilitate economy and efficiency in power transmission systems in an environmentally optimal manner.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- AC Machines

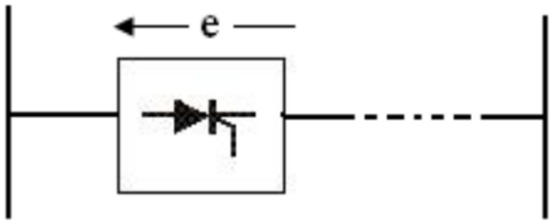
Detailed content of the Lecture:

A Flexible Alternating Current Transmission System (FACTS) is a system composed of static equipment used for the AC transmission of electrical energy and it is meant to enhance controllability and increase power transfer capability of the network and it is generally a power electronics-based system.

A FACTS is defined by the IEEE as “a power electronics based system other static equipment that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability”.

FACTS controllers are classified as

1. Series Controllers
2. Shunt Controllers
3. Combined Series-Series Controllers
4. Combined Series-Shunt Controllers

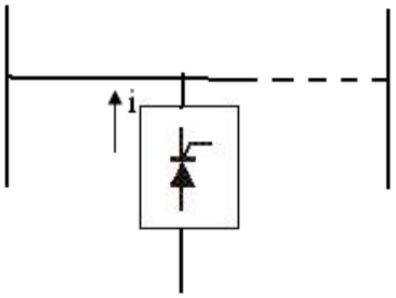


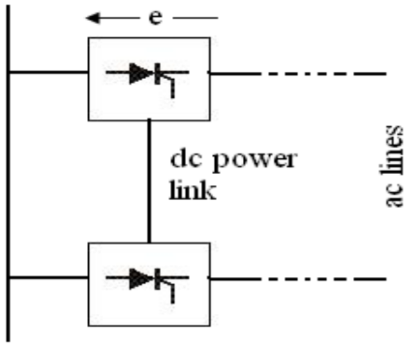
Series Controllers

- It could be variable impedance (capacitor, reactor, etc) or a power electronic based variable source of main frequency, subsynchonous and harmonic frequencies to serve the desired need.
- Inject a voltage in series with the line.
- If the voltage is in phase quadrature with the current, controller supplies or consumes reactive power.
- Any other phase, involves control of both active and reactive power.

Shunt Controllers

- It could be variable impedance (capacitor, reactor, etc) or a power electronic based variable source or combination of both.
- Inject a current in the system.
- If the current is in phase quadrature with the voltage, controller supplies or consumes reactive power.
- Any other phase, involves control of bothactive and reactive power.



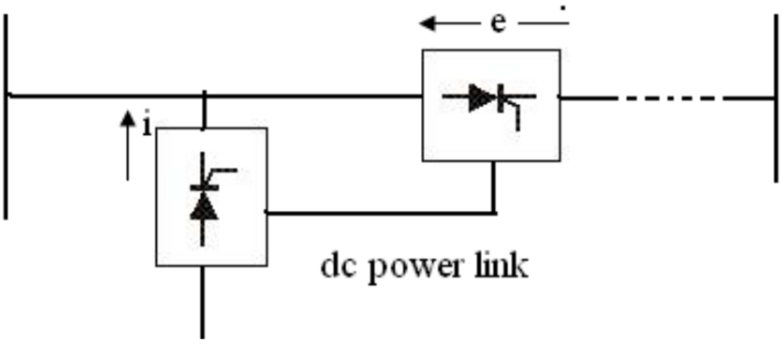


Combined Series-Series Controllers

- It could be a combination of separate series controllers or unified controller.
- Series controllers supply reactive power for each line and real power among lines via power link.
- Interline power flow controller balance real and reactive power flow in the lines.
- It could be a combination of separate series & shunt controllers or unified power flow controller.

Combined Series-Shunt Controllers

- It could be a combination of separate series & shunt controllers or unified power flow controller.
- Inject current into the system with the shunt controller and voltage in series with the line with series controller.
- When the controllers are unified, exchange real power between series and shunt controllers via power link.



Video Content / Details of website for further learning (if any):

1. https://www.electrical4u.com/facts-on-facts-theory-and-applications/
2. https://www.youtube.com/watch?v=ed0TznCliYw

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 35)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 45 to 47)

Course Faculty

MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)
Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

LECTURE HANDOUTS | **L10**

DEPT: EEE | **III / V**

Course Name with Code :19EEC12 & TRANSMISSION & DISTRIBUTION

Course Teacher : Mrs.M.Selvakumari

Unit : II – TRANSMISSION LINE PARAMETERS

Date of Lecture:

Topic of Lecture: Introduction to transmission line parameters

Introduction :

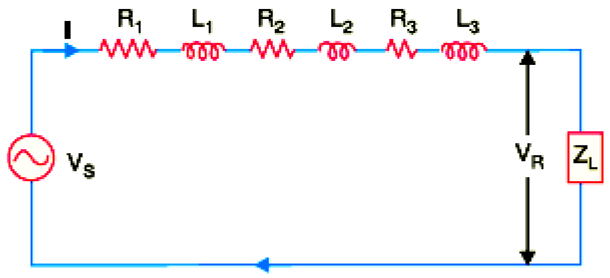
- The transmission line has mainly four parameters, resistance, inductance, capacitance and shunt conductance. These parameters are uniformly distributed along the line. Hence, it is also called the distributed parameter of the transmission line.
- The performance of transmission line depends on the parameters of the line.

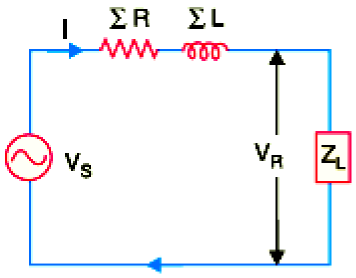
Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

A transmission line has resistance, inductance and capacitance uniformly distributed along the whole length of the line. Before we pass on to the methods of finding these constants for a transmission line, it is profitable to understand them thoroughly.





(*i*) Resistance. It is the opposition of line conductors to current flow. The resistance is distributed uniformly along the whole length of the line as shown in Fig. However, the performance of a transmission line can be analysed conveniently if distributed resistance is considered as lumped as shown in Fig.

(*ii*) Inductance. When an alternating current flows through a conductor, a changing flux is set up which links the conductor. Due to these flux linkages, the conductor possesses inductance. Mathematically, inductance is defined as the flux linkages per ampere *i.e.*,

$$\text{Inductance, } L = \frac{\psi}{I} \text{ henry}$$

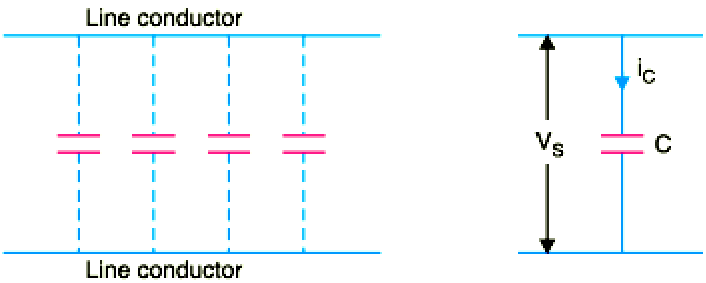
where ψ = flux linkages in weber-turns

I = current in amperes

The inductance is also uniformly distributed along the length of the * line as show in Fig. Again for the convenience of analysis, it can be taken to be lumped as shown in Fig

(*iii*) Capacitance. We know that any two conductors separated by an insulating material constitute a capacitor. As any two conductors of an overhead transmission line are separated by air which acts as an insulation, therefore, capacitance exists between any two overhead line conductors. The capacitance between the conductors is the charge per unit potential difference *i.e.*,

$$\text{Capacitance, } C = \frac{q}{v} \text{ farad}$$



where
q = charge on the line in coulomb
v = p.d. between the conductors in volts

The capacitance is uniformly distributed along the whole length of the line and may be regarded as a uniform series of capacitors connected between the conductors as shown in Fig. When an alternating voltage is impressed on a transmission line, the charge on the

conductors at any point increases and decreases with the increase and decrease of the instantaneous value of the voltage between conductors at that point. The result is that a current (known as *charging current*) flows between the conductors [See Fig.]. This charging current flows in the line even when it is open-circuited *i.e.*, supplying no load. It affects the voltage drop along the line as well as the efficiency and power factor of the line.

Resistance of a Transmission Line

The resistance of transmission line conductors is the most important cause of power loss in a transmission line. The resistance R of a line conductor having resistivity ρ, length l and area of cross-section a is given by ;

$$R = \rho\, l/a$$

The variation of resistance of metallic conductors with temperature is practically linear over the normal range of operation. Suppose $R1$ and $R2$ are the resistances of a conductor at $t1$ ºC and $t2$ ºC ($t2 > t1$) respectively. If α 1is the temperature coefficient at $t1$ °C, then,

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

where $\alpha_1 = \dfrac{\alpha_0}{1 + \alpha_0 \, t_1}$

α_0 = temperature coefficient at 0° C

Video Content / Details of website for further learning (if any):

1. https://circuitglobe.com/transmission-lines.html
2. https://www.youtube.com/watch?v=gyylPg2IhHc

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 1)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no ---to ---)

Course Faculty

MUTHAYAMMAL ENGINEERING COLLEGE

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Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

LECTURE HANDOUTS **L11**

DEPT: EEE **III / V**

Course Name with Code :**19EEC12 & TRANSMISSION & DISTRIBUTION**

Course Teacher : **Mrs.M.Selvakumari**

Unit : **II – TRANSMISSION LINE PARAMETERS**

Date of Lecture:

Topic of Lecture: Inductance of a transmission Line

Introduction :

- Flux linkages with any one conductor say A. There will be flux linkages with conductor A due to its own current. Also there will be flux linkages with this conductor due to mutual inductance effects.
- The inductance calculation of single-phase single circuit line, single-phase double circuit line, three-phase single circuit line and three-phase double circuit line will be considered.

Prerequisite knowledge for Complete understanding and learning of Topic:

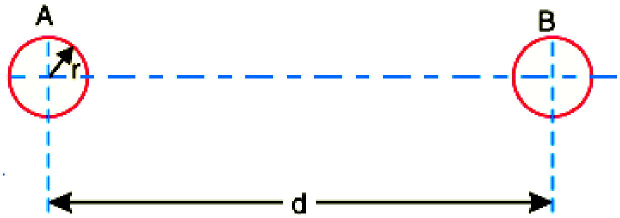
- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

Inductance of a Single Phase Two-Wire Line

A single phase line consists of two parallel conductors which form a rectangular loop of one turn. When an alternating current flows through such a loop, a changing magnetic flux is set up. The changing flux links the loop and hence the loop (or single phase line) possesses inductance. It may appear that inductance of a single phase line is negligible because it consists of a loop of one turn and the flux path is through air of high reluctance. But as the X –sectional area of the loop is very large, even for a small flux density, the total flux linking the loop is quite large and hence the line has appreciable inductance.

Consider a single phase overhead line consisting of two parallel conductors A and B spaced d metres apart as shown in Fig. Conductors A and B carry the same amount of current ($I_A = I_B$), but in the opposite direction because one forms the return circuit of the other. $I_A + I_B = 0$



$$= \frac{\mu_0 I_A}{2\pi}\left(\frac{1}{4} + \int_r^{\infty} \frac{dx}{x}\right)$$

In order to find the inductance of conductor A (or conductor B), we shall have to consider the flux linkages with it. There will be flux linkages with conductor A due to its own current I_A and also A due to the mutual inductance effect of current I_B in the conductor B

flux linkages with conductor A due to its own current

Flux linkages with conductor A due to current I_B

$$= \frac{\mu_0 I_B}{2\pi} \int_d^{\infty} \frac{dx}{x}$$

Total flux linkages with conductor A is

Now, $\quad I_A + I_B = 0 \quad \text{or} \quad -I_B = I_A$

$\therefore \quad -I_B \log_e d = I_A \log_e d$

$$\therefore \quad \psi_A = \frac{\mu_0}{2\pi}\left[\frac{I_A}{4} + I_A \log_e d - I_A \log_e r\right] \text{ wb-turns/m}$$

$$= \frac{\mu_0}{2\pi}\left[\frac{I_A}{4} + I_A \log_e \frac{d}{r}\right]$$

$$= \frac{\mu_0 I_A}{2\pi}\left[\frac{1}{4} + \log_e \frac{d}{r}\right] \text{ wb-turns/m}$$

$$\text{Inductance of conductor } A, L_A = \frac{\psi_A}{I_A}$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4} + \log_e \frac{d}{r}\right] \text{H/m} = \frac{4\pi \times 10^{-7}}{2\pi}\left[\frac{1}{4} + \log_e \frac{d}{r}\right] \text{H/m}$$

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

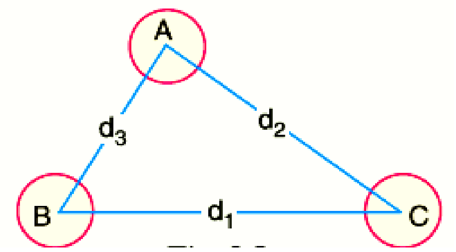
$$\text{Loop inductance} = 2\,L_A \text{ H/m} = 10^{-7}\left[1 + 4\log_e \frac{d}{r}\right] \text{H/m}$$

$$\text{Loop inductance} = 10^{-7}\left[1 + 4\log_e \frac{d}{r}\right] \text{H/m}$$

Note that eq. (ii) is the inductance of the two-wire line and is sometimes called loop inductance. However, inductance given by eq. (i) is the inductance per conductor and is equal to half the loop inductance.

Inductance of a 3-Phase Overhead Line

Fig. shows the three conductors A, B and C of a 3-phase line carrying currents I_A, I_B and I_C respectively. Let d_1, d_2 and d_3 be the spacings between the conductors as shown. Let us further assume that the loads are balanced i.e. $I_A + I_B + I_C = 0$. Consider the flux linkages with conductor There will be flux linkages with conductor A due to its own current and also due to the mutual inductance effects of I_B and I_C.



Flux linkages with conductor A due to current I_B

$$= \frac{\mu_0 I_A}{2\pi}\left(\frac{1}{4} + \int_r^{\infty}\frac{dx}{x}\right) \quad \ldots(i)$$

Flux linkages with conductor A due to current I_B

$$= \frac{\mu_0 I_B}{2\pi}\int_{d_3}^{\infty}\frac{dx}{x}$$

Flux linkages with conductor A due to current I_C

$$= \frac{\mu_0 I_C}{2\pi}\int_{d_2}^{\infty}\frac{dx}{x}$$

Total flux linkages with conductor A

$$
\begin{aligned}
\psi_A &= (i) + (ii) + (iii) \\
&= \frac{\mu_0\, I_A}{2\pi}\left(\frac{1}{4} + \int_r^{\infty} \frac{dx}{x}\right) + \frac{\mu_0\, I_B}{2\pi}\int_{d_3}^{\infty}\frac{dx}{x} + \frac{\mu_0\, I_C}{2\pi}\int_{d_2}^{\infty}\frac{dx}{x} \\
&= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} + \int_r^{\infty}\frac{dx}{x}\right) I_A + I_B\int_{d_3}^{\infty}\frac{dx}{x} + I_C\int_{d_2}^{\infty}\frac{dx}{x}\right] \\
&= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right) I_A - I_B \log_e d_3 - I_C \log_e d_2 + \log_e \infty\,(I_A + I_B + I_C)\right]
\end{aligned}
$$

As $\quad I_A + I_B + I_C = 0,$

$$
\therefore \quad \psi_A = \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right) I_A - I_B \log_e d_3 - I_C \log_e d_2\right]
$$

conductor A due to its own current

$$
= \frac{\mu_0\, I_A}{2\pi}\left(\frac{1}{4} + \int_r^{\infty}\frac{dx}{x}\right)
$$

Symmetrical Spacing

If the three conductors A, B and C are placed symmetrically at the corners of an equilateral triangle of side d, then, d1 = d2 = d3 = d. Under such conditions, the flux Derived in a similar way, the expressions for inductance are the same for conductors B and C.

$$
\begin{aligned}
\psi_A &= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right) I_A - I_B \log_e d - I_C \log_e d\right] \\
&= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right) I_A - (I_B + I_C)\log_e d\right] \\
&= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right) I_A + I_A \log_e d\right] \qquad (\because I_B + I_C = -I_A) \\
&= \frac{\mu_0\, I_A}{2\pi}\left[\frac{1}{4} + \log_e \frac{d}{r}\right] \text{ werber-turns/m} \\
L_A &= \frac{\psi_A}{I_A}\text{ H/m} = \frac{\mu_0}{2\pi}\left[\frac{1}{4} + \log_e \frac{d}{r}\right]\text{ H/m} \\
&= \frac{4\pi \times 10^{-7}}{2\pi}\left[\frac{1}{4} + \log_e \frac{d}{r}\right]\text{ H/m} \\
L_A &= 10^{-7}\left[0{\cdot}5 + 2\log_e \frac{d}{r}\right]\text{ H/m}
\end{aligned}
$$

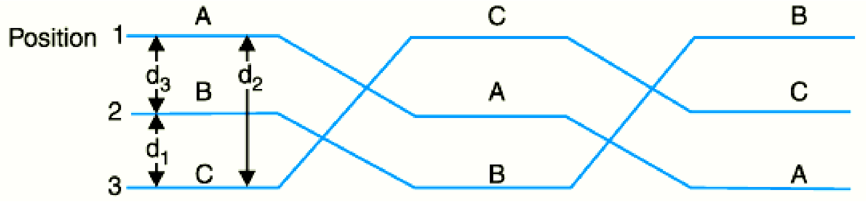
Unsymmetrical Spacing

When 3-phase line conductors are not equidistant from each other, the conductor pacing is said to be unsymmetrical. Under such conditions, the flux linkages and inductance of each phase are not the same. A different inductance in each phase results in unequal voltage drops in the three phases even if the currents in the conductors are balanced. Therefore, the voltage at the receiving end will not be the same for all phases. In order that voltage drops are equal in all conductors, we generally interchange the positions of the conductors at regular intervals along the line so that each conductor occupies the original position of every other conductor over an equal distance. Such an exchange of positions is known as transposition. Fig. shows the transposed line. The phase conductors are designated as A, B and C and the positions occupied are numbered 1, 2 and 3. The effect of transposition is that each conductor has the same average inductance.

Fig. shows a 3-phase transposed line having unsymmetrical spacing. Let us assume that each of the three sections is 1 m in length. Let us further assume balanced conditions i.e.,

$I_A + I_B + I_C = 0$

Let the line currents be :



$$I_A = I(1 + j\,0)$$
$$I_B = I(-0{\cdot}5 - j\,0{\cdot}866)$$
$$I_C = I(-0{\cdot}5 + j\,0{\cdot}866)$$

As proved above, the total flux linkages per metre length of conductor A is

$$\psi_A = \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right) I_A - I_B \log_e d_3 - I_C \log_e d_2\right]$$

Putting the values of I_A, I_B and I_C, we get,

$$\psi_A = \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right) I - I(-0{\cdot}5 - j\,0{\cdot}866)\log_e d_3 - I(-0{\cdot}5 + j\,0{\cdot}866)\log_e d_2\right]$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4}I - I\log_e r + 0{\cdot}5\,I\log_e d_3 + j\,0{\cdot}866\log_e d_3 + 0{\cdot}5\,I\log_e d_2 - j\,0{\cdot}866\,I\log_e d_2\right]$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4}I - I\log_e r + 0{\cdot}5\,I\left(\log_e d_3 + \log_e d_2\right) + j\,0{\cdot}866\,I\left(\log_e d_3 - \log_e d_2\right)\right]$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4}I - I\log_e r + I^{*}\log_e \sqrt{d_2 d_3} + j\,0{\cdot}866\,I\log_e \frac{d_3}{d_2}\right]$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4}I + I\log_e \frac{\sqrt{d_2\,d_3}}{r} + j\,0{\cdot}866\,I\log_e \frac{d_3}{d_2}\right]$$

$$= \frac{\mu_0\,I}{2\pi}\left[\frac{1}{4} + \log_e \frac{\sqrt{d_2 d_3}}{r} + j\,0{\cdot}866\log_e \frac{d_3}{d_2}\right]$$

$\therefore$ Inductance of conductor A is

$$L_A = \frac{\psi_A}{I_A} = \frac{\psi_A}{I}$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4} + \log_e \frac{\sqrt{d_2\,d_3}}{r} + j\,0{\cdot}866\log_e \frac{d_3}{d_2}\right]$$

$$= \frac{4\pi \times 10^{-7}}{2\pi}\left[\frac{1}{4} + \log_e \frac{\sqrt{d_2\, d_3}}{r} + j\, 0 \cdot 866 \log_e \frac{d_3}{d_2}\right] \text{ H/m}$$

$$= 10^{-7}\left[\frac{1}{2} + 2 \log_e \frac{\sqrt{d_2\, d_3}}{r} + j\, 1 \cdot 732 \log_e \frac{d_3}{d_2}\right] \text{ H/m}$$

Similarly inductance of conductors B and C will be :

$$L_B = 10^{-7}\left[\frac{1}{2} + 2 \log_e \frac{\sqrt{d_3\, d_1}}{r} + j\, 1 \cdot 732 \log_e \frac{d_1}{d_3}\right] \text{ H/m}$$

$$L_C = 10^{-7}\left[\frac{1}{2} + 2 \log_e \frac{\sqrt{d_1\, d_2}}{r} + j\, 1 \cdot 732 \log_e \frac{d_2}{d_1}\right] \text{ H/m}$$

Inductance of each line conductor

$$= \frac{1}{3}(L_A + L_B + L_C)$$

$$= {}^{*}\left[\frac{1}{2} + 2 \log_e \frac{\sqrt[3]{d_1\, d_2\, d_3}}{r}\right] \times 10^{-7} \text{ H/m}$$

$$= \left[0 \cdot 5 + 2 \log_e \frac{\sqrt[3]{d_1\, d_2\, d_3}}{r}\right] \times 10^{-7} \text{ H/m}$$

If we compare the formula of inductance of an un symmetrically spaced transposed line with that of symmetrically spaced line, we find that inductance of each line conductor in the two cases will be equal if

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

The distance d is known as equivalent equilateral spacing for un symmetrically transposed line.

Video Content / Details of website for further learning (if any):

1. https://electricalbaba.com/inductance-single-conductor-transmission-line/
2. https://www.youtube.com/watch?v=lU3Q6_DWnV4

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 39)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 49 to 53)

Course Faculty

MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)
Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

Estd. 2000

LECTURE HANDOUTS

L12

DEPT: EEE

III / V

Course Name with Code :**19EEC12 & TRANSMISSION & DISTRIBUTION**

Course Teacher : **Mrs.M.Selvakumari**

Unit : **II – TRANSMISSION LINE PARAMETERS**

Date of Lecture:

Topic of Lecture: Capacitance of single and double transmission lines

Introduction :

- Transmission line conductors constitute a capacitor between them. The conductors of the transmission line act as a parallel plate of the capacitor and the air is just like a dielectric medium between them.
- The capacitance of a line gives rise to the leading current between the conductors. It depends on the length of the conductor.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

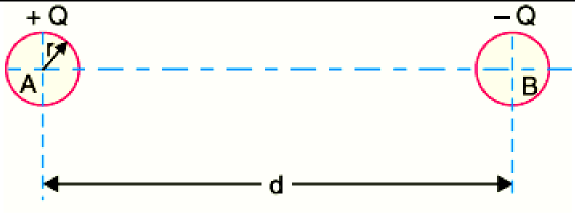
Detailed content of the Lecture:

Capacitance of a Single Phase Two-Wire Line

Consider a single phase overhead transmission line consisting of two parallel conductors A and B spaced d metres apart in air. Suppose that radius of each conductor is r metres. Let their respective charge be + Q and − Q coulombs per metre length. The total p.d. between conductor A and neutral “infinite” plane is

$$V_A = \int_r^{\infty} \frac{Q}{2\pi x \varepsilon_0} dx + \int_d^{\infty} \frac{-Q}{2\pi x \varepsilon_0} dx$$

$$= \frac{Q}{2\pi \varepsilon_0}\left[\log_e \frac{\infty}{r} - \log_e \frac{\infty}{d}\right] \text{volts} = \frac{Q}{2\pi \varepsilon_0} \log_e \frac{d}{r} \text{ volts}$$



Similarly, p.d. between conductor B and neutral "infinite" plane is

$$V_B = \int_r^{\infty} \frac{-Q}{2\pi x\,\varepsilon_0}\,dx + \int_d^{\infty} \frac{Q}{2\pi x\,\varepsilon_0}\,dx$$

$$= \frac{-Q}{2\pi\,\varepsilon_0}\left[\log_e \frac{\infty}{r} - \log_e \frac{\infty}{d}\right] = \frac{-Q}{2\pi\,\varepsilon_0}\log_e \frac{d}{r} \text{ volts}$$

Both these potentials are w.r.t. the same neutral plane. Since the unlike charges attract each other, the potential difference between the conductors is

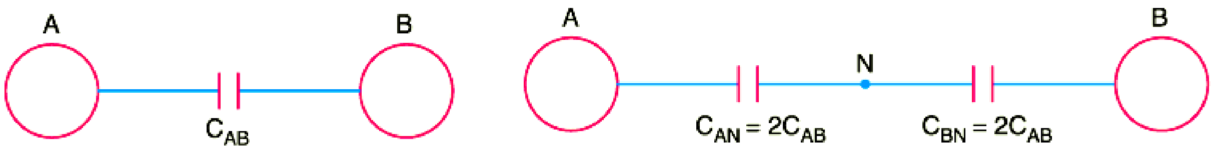
$$V_{AB} = 2V_A = \frac{2Q}{2\pi\,\varepsilon_0}\log_e \frac{d}{r} \text{ volts}$$

Capacitance, $$C_{AB} = Q/V_{AB} = \frac{Q}{\frac{2Q}{2\pi\,\varepsilon_0}\log_e \frac{d}{r}} \text{ F/m}$$

$$C_{AB} = \frac{\pi\,\varepsilon_0}{\log_e \frac{d}{r}} \text{ F/m}$$

Capacitance to neutral

Often it is desired to know the capacitance between one of the conductors and a neutral point between them. Since potential of the mid-point between the conductors is zero, the potential difference between each conductor and the ground or neutral is half the potential difference between the conductors. Thus the capacitance to ground or capacitance to neutral for the two-wire line is twice the line-to-line capacitance



Capacitance to neutral, $C_N = C_{AN} = C_{BN} = 2C_{AB}$

$$C_N = \frac{2\,\pi\,\varepsilon_0}{\log_e \frac{d}{r}} \text{ F/m}$$

Capacitance of a 3-Phase Overhead Line

In a 3-phase transmission line, the capacitance of each conductor is considered instead of capacitance from conductor to conductor. Here, again two cases arise viz., symmetrical spacing and unsymmetrical spacing.

i. Symmetrical Spacing:

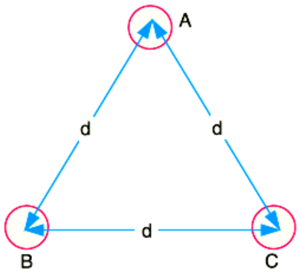


Fig shows the three conductors A, B and C of the 3-phase overhead transmission line having charges Q_A, Q_B and Q_C per meter length respectively. Let the conductors be equidistant (d meters) from each other. We shall find the capacitance from line conductor to neutral in this symmetrically spaced line.

Overall potential difference between conductor A and infinite neutral plane is given by

$$V_A = \int_r^\infty \frac{Q_A}{2\,\pi x \varepsilon_0}\,dx + \int_d^\infty \frac{Q_B}{2\,\pi x \varepsilon_0}\,dx + \int_d^\infty \frac{Q_C}{2\,\pi x \varepsilon_0}\,dx$$

$$= \frac{1}{2\pi\,\varepsilon_0}\left[Q_A \log_e \frac{1}{r} + Q_B \log_e \frac{1}{d} + Q_C \log_e \frac{1}{d}\right]$$

$$= \frac{1}{2\pi\,\varepsilon_0}\left[Q_A \log_e \frac{1}{r} + (Q_B + Q_C) \log_e \frac{1}{d}\right]$$

Assuming balanced supply, we have, $Q_A + Q_B + Q_C = 0$

$\therefore \quad Q_B + Q_C = -Q_A$

$\therefore \quad V_A = \frac{1}{2\pi\,\varepsilon_0}\left[Q_A \log_e \frac{1}{r} - Q_A \log_e \frac{1}{d}\right] = \frac{Q_A}{2\pi\varepsilon_0} \log_e \frac{d}{r}$ volts

Capacitance of a conductor w.r.t neutral is ,

$$C_A = \frac{Q_A}{V_A} = \frac{Q_A}{\frac{Q_A}{2\pi\,\varepsilon_0}\log_e \frac{d}{r}}\ \text{F/m} = \frac{2\pi\,\varepsilon_0}{\log_e \frac{d}{r}}\ \text{F/m}$$

$$C_A = \frac{2\pi\,\varepsilon_0}{\log_e \frac{d}{r}}\ \text{F/m}$$

Video Content / Details of website for further learning (if any):

1. https://electrical-engineering-portal.com/electrical-distribution-systems
2. https://www.youtube.com/watch?v=_iz8ZkjD7z8

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 41)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 53 to 55)

Course Faculty

LECTURE HANDOUTS **L13**

DEPT: EEE **III / V**

Course Name with Code :**19EEC12 & TRANSMISSION & DISTRIBUTION**

Course Teacher : **Mrs.M.Selvakumari**

Unit : **II – TRANSMISSION LINE PARAMETERS**

Date of Lecture:

Topic of Lecture: Application of self and mutual GMD

Introduction :

- **GMD -** Geometrical Mean Distance
- Self and mutual GMD simplifies the inductance calculations, particularly relating to the multi-conductor arrangement.
- Self GMD - It is the physical radius of a round solid conductor. Mutual GMD -The distance between one conductor to another conductor or the difference between the largest and smallest distance is known as mutual GMD.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

Application of Self-GMD and Mutual-GMD

The use of self-geometrical mean distance (abbreviated as self-GMD) and mutual geometrical mean distance (mutual-GMD) simplifies the inductance calculations, particularly relating to multi conductor arrangements. The symbols used for these are respectively Ds and Dm. We shall briefly discuss these terms.

(i) Self-GMD (Ds)

In order to have concept of Self-GMD (also sometimes called Geometrical mean radius; GMR), consider the expression for inductance per conductor per metre already derived in Art. Inductance/conductor/m.

$$= 2 \times 10^{-7}\left(\frac{1}{4} + \log_e \frac{d}{r}\right)$$

$$= 2 \times 10^{-7} \times \frac{1}{4} + 2 \times 10^{-7} \log_e \frac{d}{r}$$

In this expression, the term 2 × 10-7 × (1/4) is the inductance due to flux within the solid conductor.

For many purposes, it is desirable to eliminate this term by the introduction of a concept called self-GMD or GMR. If we replace the original solid conductor by an equivalent hollow cylinder with extremely thin walls, the current is confined to the conductor surface and internal conductor flux linkage would be almost zero. Consequently, inductance due to internal flux would be zero and the term 2 × 10-7 × (1/4) shall be eliminated. The radius of this equivalent hollow cylinder must be sufficiently smaller than the physical radius of the conductor to allow room for enough additional flux to compensate for the absence of internal flux linkage. It can be proved mathematically that for a solid round conductor of radius r, the self-GMD or GMR = 0·7788 r. Using self-GMD, the eq. (i) be:

Inductance/conductor/m = 2 × 10-7loge d/ Ds *

Where

Ds = GMR or self-GMD = 0·7788 r

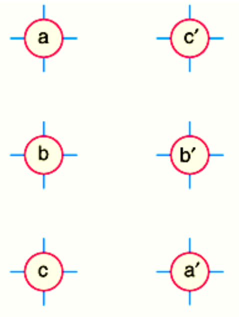
It may be noted that self-GMD of a conductor depends upon the size and shape of the conductor and is independent of the spacing between the conductors.

(ii) Mutual-GMD

The mutual-GMD is the geometrical mean of the distances form one conductor to the other and, therefore, must be between the largest and smallest such distance. In fact, mutual- GMD simply represents the equivalent geometrical spacing.

(a) The mutual-GMD between two conductors (assuming that spacing between conductors is large compared to the diameter of each conductor) is equal to the distance between their centres i.e. Dm = spacing between conductors = d

(b) For a single circuit 3-φ line, the mutual-GMD is equal to the equivalent equilateral spacing i.e., (d1 d2 d3)1/3.



Mutual GMD

c) The principle of geometrical mean distances can be most profitably employed to 3-φ double circuit lines. Consider the conductor arrangement of the double circuit shown in Fig. Suppose the radius of each conductor is r.

Self-GMD of conductor = 0·7788 r

Self-GMD of combination aa' is

$$D_{s1} = (**D_{aa} \times D_{aa'} \times D_{a'a'} \times D_{a'a})^{1/4}$$

Self-GMD of combination bb' is

$$D_{s2} = (D_{bb} \times D_{bb'} \times D_{b'b'} \times D_{b'b})^{1/4}$$

Self-GMD of combination cc' is

$$D_{s3} = (D_{cc} \times D_{cc'} \times D_{c'c'} \times D_{c'c})^{1/4}$$

Equivalent self-GMD of one phase

$$D_s = (D_{s1} \times D_{s2} \times D_{s3})^{1/3}$$

The value of Ds is the same for all the phases as each conductor has the same radius.

Mutual-GMD between phases A and B is

$$D_{AB} = (D_{ab} \times D_{ab'} \times D_{a'b} \times D_{a'b'})^{1/4}$$

Mutual-GMD between phases B and C is

$$D_{CA} = (D_{ca} \times D_{ca'} \times D_{c'a} \times D_{c'a'})^{1/4}$$

$$\text{Equivalent mutual-GMD, } D_m = (D_{AB} \times D_{BC} \times D_{CA})^{1/3}$$

It is worthwhile to note that mutual GMD depends only upon the spacing and is substantially independent of the exact size, shape and orientation of the conductor.

Inductance Relations in Terms of GMD

The inductance formulas developed in the previous articles can be conveniently expressed in terms of geometrical mean distances.

(*i*) *Single phase line*

$$\text{Inductance/conductor/m} = 2 \times 10^{-7} \log_e \frac{D_m}{D_s}$$

where $D_s = 0{\cdot}7788\, r$ and D_m = Spacing between conductors = d

(*ii*) *Single circuit 3-ϕ line*

$$\text{Inductance/phase/m} = 2 \times 10^{-7} \log_e \frac{D_m}{D_s}$$

where $D_s = 0{\cdot}7788\, r$ and $D_m = (d_1\, d_2\, d_3)^{1/3}$

(*iii*) *Double circuit 3-ϕ line*

$$\text{Inductance/phase/m} = 2 \times 10^{-7} \log_e \frac{D_m}{D_s}$$

where $D_s = (D_{s1}\, D_{s2}\, D_{s3})^{1/3}$ and $D_m = (D_{AB} \times D_{BC} \times D_{CA})^{1/3}$

Application:

1. Ships-Submarines
2. Railway engines
3. Road and other land vehicles-Trucks, Concepts, Production,-ready cars, Military Vehicles, Buses.

Video Content / Details of website for further learning (if any):

1. https://www.yourelectricalguide.com/2018/01/distributor-types-power-distribution-system.html
2. https://www.youtube.com/watch?v=_iz8ZkjD7z8

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 48)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 56 to 60)

Course Faculty

LECTURE HANDOUTS **L14**

DEPT: EEE **III / V**

Course Name with Code :19EEC12 & TRANSMISSION & DISTRIBUTION

Course Teacher : Mrs.M.Selvakumari

Unit : II – TRANSMISSION LINE PARAMETERS

Date of Lecture:

Topic of Lecture : Inductance of bundled conductors

Introduction :

- A bundle conductor is a conductor made up of two or more sub-conductors and is used as one phase conductor. For voltages greater than 220 kV it is preferable to use more than one conductor per phase which is known as Bundle conductor.
- Due to bundling of conductors the self GMD of the conductors is increased, so reactance of conductors decreases, so reduced voltage drop in conductors, hence voltage regulation improves.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

Commonly used conductor materials:

The most commonly used conductor materials for overhead lines are copper, aluminum, steel cored aluminum, galvanized steel and cadmium copper. The choice of a particular material will depend upon the cost, the required electrical and mechanical properties and the local conditions. All conductors used for overhead lines are preferably stranded in order to increase the flexibility. In stranded conductors, there is generally one central wire and round this, successive layers of wires containing 6, 12, 18, 24 ...... wires. Thus, if there are n layers, the total number of individual wires is $3n(n + 1) + 1$. In the manufacture of stranded conductors, the consecutive layers of wires are twisted or spiralled in opposite directions so that layers are bound together.

Types of Conductors

1. Copper

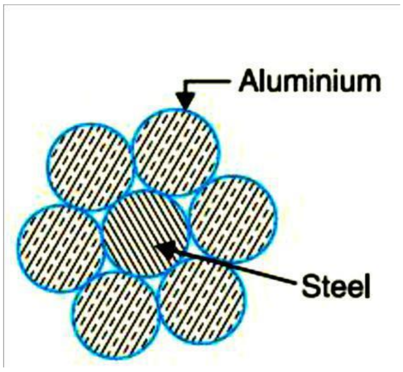
Copper is an ideal material for overhead lines owing to its high electrical conductivity and greater tensile strength. It is always used in the hard drawn form as stranded conductor. Although hard drawing decreases the electrical conductivity slightly yet it increases the tensile strength considerably. Copper has high current density *i.e.*, the current carrying capacity of copper per unit of Xsectional area is quite large. This leads to two advantages. Firstly, smaller X- sectional area of conductor is required and secondly, the area offered by the conductor to wind loads is reduced. Moreover, this metal is quite homogeneous, durable and has high scrap value. There is hardly any doubt that copper is an ideal material for transmission and distribution of electric power. However, due to its higher cost and non-availability, it is rarely used for these purposes. Now a days the trend is to use aluminium in place of copper.

2. Aluminium

Aluminium is cheap and light as compared to copper but it has much smaller conductivity and tensile strength.

3. **Steel cored aluminum**

Due to low tensile strength, aluminium conductors produce greater sag. This prohibits their use for large spans and makes them unsuitable for long distance transmission. In order to increase the tensile strength, the aluminium conductor is reinforced with a core of galvanised steel wires. The composite conductor thus obtained is known as *steel* cored aluminium and is abbreviated as A.C.S.R. (aluminium conductor steel reinforced).



4.Galvanized Steel

Steel has very high tensile strength. Therefore, galvanised steel conductors can be used for extremely long spans or for short line sections exposed to abnormally high stresses due to climatic conditions. They have been found very suitable in rural areas where cheapness is the main consideration. Due to poor conductivity and high resistance of steel, such conductors are not suitable for transmitting large power over a long distance. However, they can be used to advantage for transmitting a small power over a small distance where the size of the copper conductor desirable from economic considerations would be too small and thus unsuitable for use because of poor mechanical strength.

5. Stranded and Bundled Conductors

There are two types of transmission line conductors: overhead and underground. Overhead conductors, made of naked metal and suspended on insulators, are preferred over underground conductors because of the lower cost and easy maintenance. Also, overhead transmission lines use aluminum conductors, because of the lower cost and lighter weight compared to copper conductors, although more cross-section area is needed to conduct the same amount of current. There are different types of commercially available aluminum conductors: aluminum-conductor-steel-reinforced (ACSR), aluminum-conductor-alloy-reinforced (ACAR), all-aluminum-conductor (AAC), and all-aluminumalloy- conductor (AAAC).

Fig

6. ACSR(Aluminum Conductor Steel Reinforced)

ACSR is one of the most used conductors in transmission lines. It consists of alternate layers of stranded conductors, spiraled in opposite directions to hold the strands together, surrounding a core of steel strands. The proportion of steel and Aluminum in an ACSR conductor can be selected based on the mechanical strength and current carrying capacity demanded by each application.

ACSR conductors are recognized for their record of economy, dependability and favorable strength / weight ratio. ACSR conductors combine the light weight and good conductivity of Aluminum with the high tensile strength and ruggedness of steel. In line design, this can provide higher tensions, less sag, and longer span lengths than obtainable with most other types of overhead conductors.

Fig

Features

High Tensile strength Better sag properties Economic design

Best suited for transmission lines with long spans

7. ACAR (Aluminum Conductor Alloy Reinforced)

Aluminum Conductor Alloy Reinforced (ACAR) is formed by concentrically stranded wires of Aluminum 1350 on high strength Aluminum -Magnesium -Silicon (AlMgSi) alloy core. The number of wires of Aluminum1350 and AlMgSi alloy depends on the cable design. Though the general design comprises a stranded core of AlMgSi alloy strand, in certain cable constructions, the wires of AlMgSi alloy strands can be distributed in layers throughout the Aluminum 1350 strands. ACAR has got better mechanical and electrical properties as compared to an equivalent ACSR, AAC or AAAC. A very good balance between the mechanical and electrical properties therefore makes ACAR the best choice where the ampacity, strength and light weight are the main consideration of the line design. These conductors are extensively used in transmission and distribution lines.

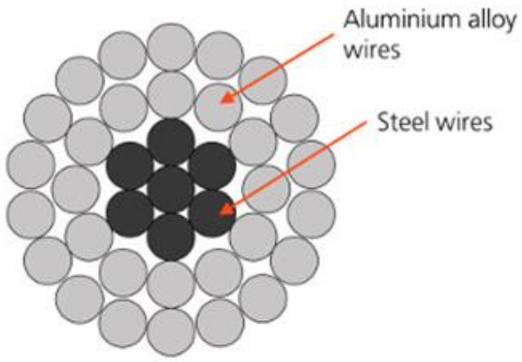
Features

Improved strength to weight ratio

Better mechanical properties

Improved electrical characteristics

Excellent resistance to corrosion



ACSR (Aluminium Conductors Steel Reinforced)

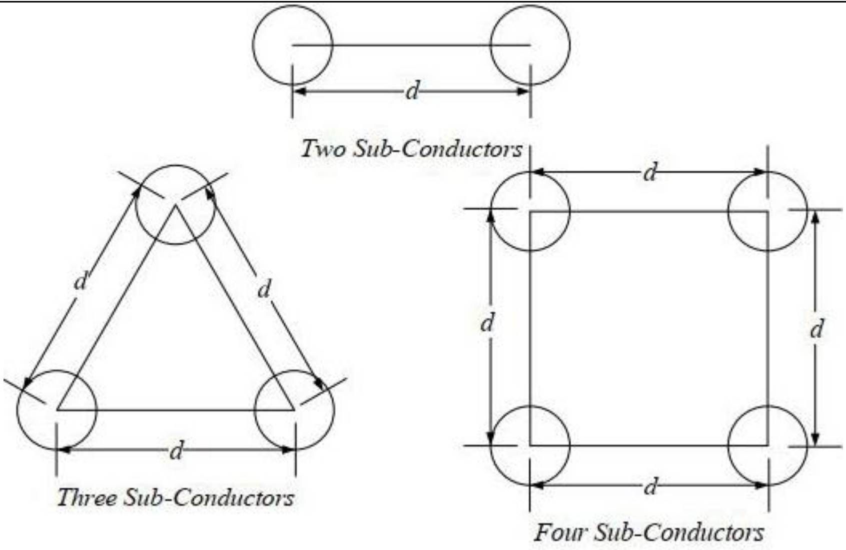
Bundled Conductors

Voltage above 230kv

Two or more conductor elements are coupled in parallel is called standard conductors.

Inductance of bundled conductors

In extra high voltage transmission line bundle conductors are used to reduce the effect of corona. The bundle conductors consist of two or more sub-conductors as shown in Fig.



Bundled Conductors

The inductance of bundle conductors can be calculated by determining its self GMD as follows.

For a bundle conductor having two sub-conductors the self GMD is given by

$$D_{s,bundle} = \sqrt[4]{(D_s X d)^2} = \sqrt{D_s d}$$

For a bundle conductor having three sub-conductors the self GMD is given by

$$D_{s,bundle} = \sqrt[9]{(D_s X d X d)^3} = \sqrt[3]{D_s d^2}$$

For a bundle conductor having four sub-conductors the self GMD is given by

$$D_{s,bundle} = \sqrt[16]{(D_s X d X d X \sqrt{2} d)^4} = 1.09\sqrt[4]{D_s d^3}$$

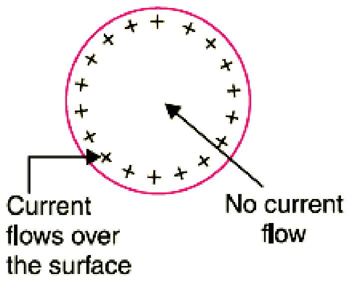
The bundle conductors have reduced reactance. Increasing the number of sub-conductors reduces the reactance because of increased GMR of the bundle.

Factors affecting transmission losses

- Losses due to the phenomena of corona.
- Copper losses in conductors.
- Skin effect.
- Proximity effect.

Skin Effect

The phenomena arising due to unequal distribution of electric current over the entire cross section of the conductor being used for long distance power transmission is referred as the **skin effect in transmission lines.** Such a phenomena does not have much role to play in case of a very short line, but with increase in the effective length of the conductors, **skin effect** increases considerably. So the modifications in line calculation need to be done accordingly. The distribution of electric current over the entire cross section of the conductor is quite uniform in case of a DC system. But what we are using in the present era of power system engineering is predominantly an alternating electric current system, where the electric current tends to flow with higher density through the surface of the conductors (i.e skin of the conductor), leaving the core deprived of necessary number of electrons.



Skin Effect

In fact there even arises a condition when absolutely no electric current flows through the core, and concentrating the entire amount on the surface region, thus resulting in an increase in the effective electrical resistance of the conductor. This particular trend of an AC transmission system to take the surface path for the flow of electric current depriving the core is referred to as the **skin effect in transmission lines**.

Factors affecting skin effect:

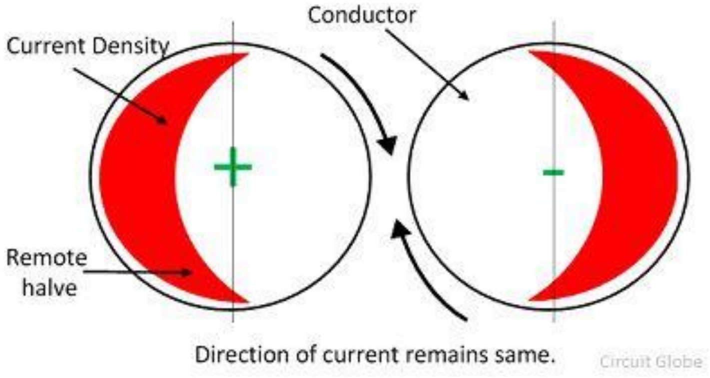
This crowding of current near the conductor surface is the skin effect. The skin effect depends upon the following factors :

a) Nature of material
b) Diameter of wire − increases with the diameter of wire.
c) Frequency − increases with the increase in frequency.
d) Shape of wire − less for stranded conductor than the solid conductor.

Proximity Effect

Proximity means nearness in space or time, so as the name suggests, **proximity effect in transmission lines** indicates the effect in one conductor for other neighbouring conductors. When the alternating current is flowing through a conductor, alternating magnetic flux is generated surrounding the conductor. This magnetic flux associates with the neighbouring wires and generates a circulating current (it can be termed as 'eddy current' also). This circulating current increases the resistance of the conductor and push away the flowing current through the conductor, which causes the crowding effect.

Apart from the skin effect the non-uniformity of current distribution is also caused by proximity effect. Consider a two wire line as shown in figure. Each line conductor can be divided into sections of equal cross sectional area (say three sections). Pairs aa`, bb` and cc` can form three loops in parallel. The flux linking aa` (and therefore its inductance) is the least and it increases somewhat for the loops bb` and cc`. Thus the density of AC flowing through the conductors is the highest at the inner edges (aa`) of the conductors and is the least at the outer edges (cc`). This type of non-uniform AC current distribution becomes more pronounced as the distance between the conductors is reduced. Like skin effect the non-uniformity current distribution also increases the effective conductor resistance. For normal spacing of overhead line this effect is negligible. However for underground cables where conductors are located close to each other, proximity effect always causes an appreciable increase in effective conductor resistance.



Proximity Effect

Factors affecting Proximity effect

- Frequency – The proximity effect increases with the increase in the frequency.
- Diameter – The proximity effect increases with the increase in the conductor diameter.
- Structure – This effect is more on the solid conductor as compared to the stranded conductor (i.e., ASCR).
- Material

Inductive Interference

It is a common practice to run communication line along the same route as the user of electronic communication system. The transmission line transmits power at relatively higher voltage. These lines give rises to electromagnetic & electrostatic fields, of sufficient which induce current and voltage in neighboring communication lines.

The effect of current and voltage on communication system include interference with communication service (e.g.) super position of extraneous currents on the true speech currents in the communication wires, hazards to peoples and damage to apparatus due to high voltages.

In extreme cases the effect of these fields makes it impossible to transmit any message faithfully and may raise the potential of the apparatus above the grounds to such an extent as to reduce the handling of the telephone receiver extremely dangerous.

The transmission line when running parallel with the communication lines give rise to electromagnetic and electrostatic field which induce current and voltages in the neighboring communication line which is called as inductive interference of transmission line.

Video Content / Details of website for further learning (if any):

1. https://www.allaboutcircuits.com/textbook/direct-current/chpt-10/mesh-current-method/
2. https://www.youtube.com/watch?v=k5Tlg27JDtc

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 51)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 61 to 63)

Course Faculty

LECTURE HANDOUTS **L15**

DEPT: EEE **III / V**

Course Name with Code :**19EEC12 & TRANSMISSION & DISTRIBUTION**

Course Teacher : **Mrs.M.Selvakumari**

Unit : **II – TRANSMISSION LINE PARAMETERS**

Date of Lecture:

Topic of Lecture Inductive interference with neighbouring communication circuits

Introduction :

- Usual practice to run telephone lines along the same route as the power lines
- In practice it is observed that the power lines and the communication lines run along the same path. Sometimes it can also be seen that both these lines run on same supports along the same route. The transmission lines transmit bulk power with relatively high voltage

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

It is usual practice to run telephone lines along the same route as the power lines. The transmission lines transmit bulk power at relatively high voltages and, therefore, these lines give rise to electro-magnetic and electrostatic fields of sufficient magnitude which induce are superposed on the true speech currents in the neighbouring telephone wires and set up distortion while the voltage so induced raise the potential of the communication circuit as a whole. In extreme cases the effect of these may make it impossible to transmit any message faithfully and may raise the potential of the telephone receiver above the ground to such an extent to render the handling of the telephone receiver extremely dangerous and in such cases elaborate precautions are required to be observed to avoid this danger.

In practice it is observed that the power lines and the communication lines run along the same path. Sometimes it can also be seen that both these lines run on same supports along the same route. The transmission lines transmit bulk power with relatively high voltage. Electromagnetic and electrostatic fields are produced by these lines having sufficient magnitude. Because of these fields, voltages and currents are induced in the neighbouring communication lines. Thus it gives rise to interference of power line with communication circuit.

Due to electromagnetic effect, currents are induced which is superimposed on speech current of the neighbouring communication line which results into distortion. The potential of the communication circuit as a whole is raised because of electrostatic effect and the communication apparatus and the equipments may get damaged due to extraneous voltages. In the worst situation, the faithful transmission of message becomes impossible due to effect of these fields. Also the potential of the apparatus is raised above the ground to such an extent that the handling of telephone receiver becomes extremely dangerous.

The electromagnetic and the electrostatic effects mainly depend on what is the distance between power and communication circuits and the length of the route over which they are parallel. Thus it can be noted that if the distortion effect and potential rise effect are within permissible limits then the communication will be proper. The unacceptable disturbance which is produced in the telephone communication because of power lines is called Telephone Interference.

There are various factors influencing the telephone interference. These factors are as follows
1) Because of harmonics in power circuit, their frequency range and magnitudes.
2) Electromagnetic coupling between power and telephone conductor.
The electric coupling is in the form of capacitive coupling between power and telephone conductor whereas the magnetic coupling is through space and is generally expressed in terms of mutual inductance at harmonic frequencies.
3) Due to unbalance in power circuits and in telephone circuits.
4) Type of return telephone circuit i.e. either metallic or ground return.
5) Screening effects.

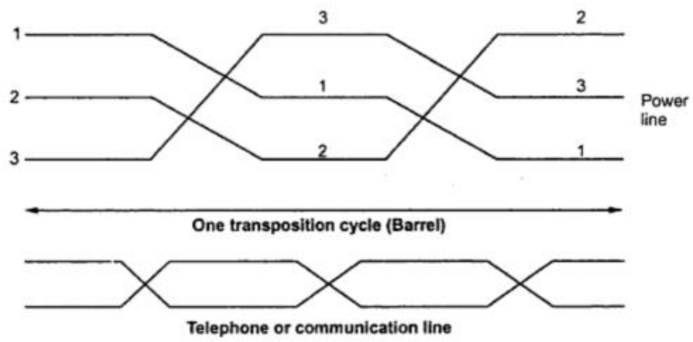
Steps for Reducing Telephone Interference

There are various ways that can reduce the telephone interference. Some of them are as listed below

i) The harmonics at the source can be reduced with the use of A.C. harmonic filters, D.C. harmonic filters and smoothing rectors.

ii) Use greater spacing between power and telephone lines. iii) The parallel run between telephone line and power line is avoided. iv) Instead of using overhead telephone wires, underground telephone cables may be used. v) If the telephone circuit is ground return then replace it with metallic return. vi) Use microwave or carrier communication instead of telephone communication.

vii) The balance of AC power line is improved by using transposition. Transposition of lines reduces the induced voltages to a considerable extent. The capacitance of the lines is balanced by transposition leading to balance in electrostatically induced voltages. Using transposition the fluxes due to positive and negative phase sequence currents cancel out so the electromagnetically induced e.m.f.s are diminished. For zero sequence currents the telephone lines are also transposed which is shown in the Fig.



Video Content / Details of website for further learning (if any):

1. https://electrical-engineering-portal.com/electrical-distribution-systems
2. https://www.youtube.com/watch?v=YVOwTIUrQCA

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 54)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 66 to 68)

Course Faculty

LECTURE HANDOUTS **L16**

DEPT: EEE **III / V**

Course Name with Code :**19EEC12 & TRANSMISSION & DISTRIBUTION**

Course Teacher : **Mrs.M.Selvakumari**

Unit : **II – TRANSMISSION LINE PARAMETERS**

Date of Lecture:

Topic of Lecture: Commonly used conductor materials

Introduction:

- The most commonly used conductor materials for over head lines are copper, aluminium, steel cored aluminium, galvanised steel and cadmium copper

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- AC Machines

Detailed content of the Lecture:

The choice of a particular material will depend upon the cost, the required electrical and mechanical properties and the local conditions. All conductors used for overhead lines are preferably stranded in order to increase the flexibility. In stranded conductors, there is generally one central wire and round this, successive layers of wires containing 6, 12, 18, 24 ...... wires. Thus, if there are n layers, the total number of individual wires is $3n(n + 1) + 1$. In the manufacture of stranded conductors, the consecutive layers of wires are twisted or spiralled in opposite directions so that layers are bound together.

TYPES OF CONDUCTOR

1.Copper

Copper is an ideal material for overhead lines owing to its high electrical conductivity and greater tensile strength. It is always used in the hard drawn form as stranded conductor. Although hard drawing decreases the electrical conductivity slightly yet it increases the tensile strength considerably. Copper has high current density *i.e.*, the current carrying capacity of copper per unit of Xsectional area is quite large. This leads to two advantages. Firstly, smaller X-sectional area of conductor is required and secondly, the area offered by the conductor to wind loads is reduced. Moreover, this metal is quite homogeneous, durable and has high scrap value. There is hardly any doubt that copper is an ideal material for transmission and distribution of electric power. However, due to its higher cost and non-availability, it is rarely used for these purposes. Now a days the trend is to use aluminium in place of copper.

2. Aluminium

Aluminium is cheap and light as compared to copper but it has much smaller conductivity and tensile strength. The relative comparison of the two materials is briefed below:

(*i*) The conductivity of aluminium is 60% that of copper. The smaller conductivity of aluminium means that for any particular transmission efficiency, the X-sectional area of conductor must be larger in aluminium than in copper. For the same resistance, the diameter of aluminium conductor is about 1·26 times the diameter of copper conductor. The increased X-section of aluminium exposes a greater surface to wind pressure and, therefore, supporting towers must be designed for greater transverse strength. This often requires the use of higher towers with consequence of greater sag.

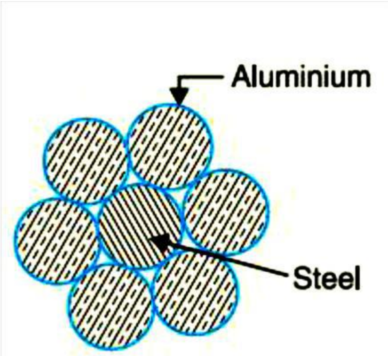
(*ii*) The specific gravity of aluminium (2·71 gm/cc) is lower than that of copper (8·9 gm/cc).Therefore, an aluminium conductor has almost one-half the weight of equivalent copper conductor. For this reason, the supporting structures for aluminium need not be made so strong as that of copper conductor.

(*iii*) Aluminium conductor being light, is liable to greater swings and hence larger cross-arms are required.

(*iv*) Due to lower tensile strength and higher co-efficient of linear expansion of aluminium, the sag is greater in aluminium conductors. Considering the combined properties of cost, conductivity, tensile strength, weight etc., aluminium has an edge over copper. Therefore, it is being widely used as a conductor material. It is particularly profitable to use aluminium for heavy-current transmission where the conductor size is large and its cost forms a major proportion of the total cost of complete installation.

3. Steel cored aluminium

Due to low tensile strength, aluminium conductors produce greater sag. This prohibits their use for larger spans and makes them unsuitable for long distance transmission. In order to increase the tensile strength, the aluminium conductor is reinforced with a core of galvanised steel wires. The composite conductor thus obtained is known as *steel cored aluminium* and is abbreviated as A.C.S.R. (aluminium conductor steel reinforced).



Steel-cored aluminium conductor consists of central core of galvanized steel wires surrounded by a number of aluminium strands. Usually, diameter of both steel and aluminium wires is the same. The X-section of the two metals are generally in the ratio of 1 : 6 but can be modified to 1 : 4 in order to get more tensile strength for the conductor. Fig. shows steel cored aluminium conductor having one steel wire surrounded by six wires of aluminium. The result of this composite conductor is that steel core takes greater percentage of mechanical strength while aluminium strands carry the bulk of current. The steel cored aluminium conductors have the following

Advantages:

(i) The reinforcement with steel increases the tensile strength but at the same time keeps the composite conductor light. Therefore, steel cored aluminium conductors will produce smaller sag and hence longer spans can be used.

(ii) Due to smaller sag with steel cored aluminium conductors, towers of smaller heights can be used.

4. **Galvanised steel**

Steel has very high tensile strength. Therefore, galvanised steel conductors can be used for extremely long spans or for short line sections exposed to abnormally high stresses due to climatic conditions. They have been found very suitable in rural areas where cheapness is the main consideration. Due to poor conductivity and high resistance of steel, such conductors are not suitable for transmitting large power over a long distance. However, they can be used to advantage for transmitting a small power over a small distance where the size of the copper conductor desirable from economic considerations would be too small and thus unsuitable for use because of poor mechanical strength.

5. Cadmium copper

The conductor material now being employed in certain cases is copper alloyed with cadmium. An addition of 1% or 2% cadmium to copper increases the tensile strength by about 50% and the conductivity is only reduced by 15% below that of pure copper. Therefore, cadmium copper conductor can be useful for exceptionally long spans. However, due to high cost of cadmium, such conductors will be economical only for lines of small X-section i.e., where the cost of conductor material is comparatively small compared with the cost of supports.

Video Content / Details of website for further learning (if any):

1. https://www.brainkart.com/article/EHVAC-and-HVDC-Transmission-System_12351/
2. https://www.facebook.com/101967737890599/videos/comparison-of-ehvac-and-hvdc/776971652743526/

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 56)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 70 to 73)

Course Faculty

LECTURE HANDOUTS **L17**

DEPT: EEE **III/ V**

Course Name with Code :**19EEC12 & TRANSMISSION & DISTRIBUTION**

Course Teacher : **Mrs.M.Selvakumari**

Unit : **II – TRANSMISSION LINE PARAMETERS**

Date of Lecture:

Topic of Lecture : Corona discharges

Introduction

- Corona Discharge is an electrical discharge caused by the ionization of a fluid such as air surrounding a conductor that is electrically charged. The corona effect will occur in high voltage systems unless sufficient care is taken to limit the strength of the surrounding electric field.
- Corona discharge can cause an audible hissing or cracking noise as it ionizes the air around the conductors. The corona effect can also produce a violet glow, production of ozone gas around the conductor, radio interference, and electrical power loss.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

Definition

When an alternating potential difference is applied across two conductors whose spacing is large as compared to their diameters, there is no apparent change in the condition of atmospheric air surrounding the wires if the applied voltage is low. However, when the applied voltage exceeds a certain value, called critical disruptive voltage, the conductors are surrounded by a faint violet glow called corona.

Theory of corona formation

Some ionisation is always present in air due to cosmic rays, ultraviolet radiations and radioactivity. Therefore, under normal conditions, the air around the conductors contains some ionised particles and neutral molecules. When p.d. is applied between the conductors, potential gradient is set up in the air which will have maximum value at the conductor surfaces. Under the influence of potential gradient, the existing free electrons acquire greater velocities. The greater the applied voltage, the greater the potential gradient and more is the velocity of free electrons. When the potential gradient at the conductor surface reaches about 30 kV per cm (max. value), the velocity acquired by the free electrons is sufficient to strike a neutral molecule with enough force to dislodge one or more electrons from it. This produces another ion and one or more free electrons, which inturn are accelerated until they collide with other neutral molecules, thus producing other ions. Thus, the process of ionisation is cumulative. The result of this ionisation is that either corona is formed or spark takes place between the conductors.

Factors Affecting Corona

The phenomenon of corona is affected by the physical state of the atmosphere as well as by the conditions of the line. The following are the factors upon which corona depends:

(i)Atmosphere

As corona is formed due to ionisation of air surrounding the conductors, therefore, it is affected by the physical state of atmosphere. In the stormy weather, the number of ions is more than normal and as such corona occurs at much less voltage as compared with fair weather.

(ii) Conductor size.

The corona effect depends upon the shape and conditions of the conductors. The rough and irregular surface will give rise to more corona because unevenness of the surface decreases the value of breakdown voltage. Thus a stranded conductor has irregular surface and hence gives rise to more corona that a solid conductor.

(iii) Spacing between conductors.

If the spacing between the conductors is made very large as compared to their diameters, there may not be any corona effect. It is because larger distance between conductors reduces the electro-static stresses at the conductor surface, thus avoiding corona formation.

(iv) Line voltage.

The line voltage greatly affects corona. If it is low, there is no change in the condition of air surrounding the conductors and hence no corona is formed. However, if the line voltage has such a value that electrostatic stresses developed at the conductor surface make the air around the conductor conducting, then corona is formed.

Methods of Reducing Corona Effect

(i) **By Increasing the Conductor Size :**

By increasing the conductor size the voltage at which occurs is raised and hence corona effects reduced. ACSR conductor having larger cross section is used for transmission line.

(ii) **By Increasing Conductor Spacing :**

By increasing the spacing between the conductors the voltage of which corona occurs is increased and hence corona effect is reduced.

(iii) Using bundled conductors: Bundled conductors increase the effective diameter of the conductor hence reducing the corona effect.

(iv) Using Carona rings: A corona ring is electrically connected to the high voltage conductor, encircling the points where the corona effect is most likely to occur. This encircling significantly reduces the sharpness of the surface of the conductor – distributing the charge across a wider area. This in turn reduces corona discharge.

Video Content / Details of website for further learning (if any):

1. https://www.electricaltechnology.org/2018/02/corona-effect-discharge-transmission-lines-power-system.html
2. https://www.youtube.com/watch?v=3X289DW33iU

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 66)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 75 to 78)

Course Faculty

LECTURE HANDOUTS | **L18**

DEPT: EEE | **III / V**

Course Name with Code :19EEC12 & TRANSMISSION & DISTRIBUTION

Course Teacher : Mrs.M.Selvakumari

Unit : II – TRANSMISSION LINE PARAMETERS

Date of Lecture:

Topic of Lecture: Skin and proximity effects.

Introduction :

- The phenomena arising due to unequal distribution of electric current over the entire cross section of the conductor being used for long distance power transmission is referred as the skin effect in transmission lines.
- The phenomena arising due to unequal distribution of electric current over the entire cross section of the conductor being used for long distance power transmission is referred as the skin effect in transmission lines. Such a phenomena does not have much role to play in case of a very short line, but with increase in the effective length of the conductors, skin effect increases considerably. So the modifications in line calculation needs to be done accordingly

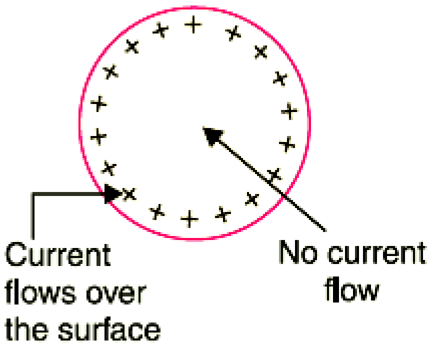
Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

SKIN EFFECT

The distribution of electric current over the entire cross section of the conductor is quite uniform in case of a DC system. But what we are using in the present era of power system engineering is predominantly an alternating electric current system, where the electric current tends to flow with higher density through the surface of the conductors (i.e skin of the conductor), leaving the core deprived of necessary number of electrons.



In fact there even arises a condition when absolutely no electric current flows through the core, and concentrating the entire amount on the surface region, thus resulting in an increase in the effective electrical resistance of the conductor. This particular trend of an AC transmission system to take the surface path for the flow of electric current depriving the core is referred to as the skin effect in transmission lines.

PROXIMITY EFFECT

Proximity means nearness in space or time, so as the name suggests, **proximity effect in transmission lines** indicates the effect in one conductor for other neighboring conductors. When the alternating current is flowing through a conductor, alternating magnetic flux is generated surrounding the conductor. This magnetic flux associates with the neighboring wires and generates a circulating current (it can be termed as 'eddy current' also). This circulating current increases the resistance of the conductor and push away the flowing current through the conductor, which causes the crowding effect.

Video Content / Details of website for further learning (if any):

1. https://circuitglobe.com/transmission-lines.html
2. https://www.youtube.com/watch?v=gyylPg2IhHc

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 68)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 79 to 83)

Course Faculty

LECTURE HANDOUTS **L19**

DEPT: EEE **III/ V**

Course Name with Code :**19EEC12 & TRANSMISSION & DISTRIBUTION**

Course Teacher : **Mrs.M.Selvakumari**

Unit : **III – MODELLING AND PERFORMANCE OF TRANSMISSION LINES**

Date of Lecture:

Topic of Lecture: Introduction to classification of transmission lines

Introduction :

- A Transmission line classification is based on its length are Short, Medium and Long lines. The length of line is calculated between the two substations of concern.
- The performance of the transmission line depends upon the total value of series impedance and shunt admittance.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory

Detailed content of the Lecture:

Classification of Transmission Lines:

A transmission line has *three constants *R*, *L* and *C* distributed uniformly along the whole length of the line. The resistance and inductance form the series impedance. The capacitance existing between conductors for 1-phase line or from a conductor to neutral for a 3- phase line forms a shunt path throughout the length of the line. Therefore, capacitance effects introduce complications in transmission line calculations. Depending upon the manner in which capacitance is taken into account, the overhead transmission lines are classified as:

i. Short Transmission Lines
ii. Medium Transmission Lines
iii. Long Transmission Lines

(i) Short transmission lines When the length of an overhead transmission line is upto about 50 km and the line voltage is comparatively low (< 20 kV), it is usually considered as a short transmission line. Due to smaller length and lower voltage, the capacitance effects are small and hence can be neglected.

Therefore, while studying the performance of a short transmission line, only resistance and inductance of the line are taken into account.

(ii) Medium transmission lines When the length of an overhead transmission line is about 50-150 km and the line voltage is moderatly high (>20 kV < 100 kV), it is considered as a medium transmission line. Due to sufficient length and voltage of the line, the capacitance effects are taken into account. For purposes of calculations, the distributed capacitance of the line.

(iii) Long transmission lines When the length of an overhead transmission line is more than 150 km and line voltage is very high (> 100 kV), it is considered as a long transmission line. 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.

It may be emphasised here that exact solution of any transmission line must consider the fact that the constants of the line are not lumped but are distributed uniformly throughout the length of the line.

Terminologies:

While studying the performance of a transmission line, it is desirable to determine its voltage regulation and transmission efficiency.

(i) Voltage 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 −V R) in the line is expressed as a percentage of receiving end voltage V and is called voltage regulation.

The difference in voltage at the receiving end of a transmission line between conditions of no load and full load is called **voltage regulation** and is expressed as a percentage of the receiving end voltage.

(ii) Transmission efficiency. 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.

(iii) Surge Impedance: The **characteristic impedance** or **surge impedance** (usually written Z0) of a uniform transmission line is the ratio of the amplitudes of voltage and current of a single wave propagating along the line; that is, a wave travelling in one direction in the absence of reflections in the other direction. Characteristic impedance is determined by the geometry and materials of the transmission line and, for a uniform line, is not dependent on its length. The SI unit of characteristic impedance is the ohm.

The characteristic impedance of a lossless transmission line is purely real, with no reactive component. Energy supplied by a source at one end of such a line is transmitted through the line without being dissipated in the line itself. A transmission line of finite length (lossless or lossy) that is terminated at one end with an impedance equal to the characteristic impedance appears to the source like an infinitely long transmission line and produces no reflections

Video Content / Details of website for further learning (if any):

1. https://www.youtube.com/watch?v=qjY31x0m3d8
2. https://www.youtube.com/watch?v=SsOTU4AO4_Q

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 70)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 84 to 86)

Course Faculty

LECTURE HANDOUTS **L20**

DEPT: EEE **III / V**

Course Name with Code :19EEC12 & TRANSMISSION & DISTRIBUTION

Course Teacher : Mrs.M.Selvakumari

Unit : III – MODELLING AND PERFORMANCE OF TRANSMISSION LINES

Date of Lecture:

Topic of Lecture: Short line, Medium line - Equivalent Circuits, Phasor diagram

Introduction :

- A transmission line having its length less than 50 km is considered as a short transmission line. In short transmission line capacitance is neglected because of small leakage current and other parameters (resistance and inductance) are lumped in the transmission line.
- **A** medium transmission line is defined as a transmission line with an effective length more than 50-150 km. Unlike a short transmission line, the line charging current of a medium transmission line is appreciable and hence the shunt capacitance must be considered.
-

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory

Detailed content of the Lecture:

Performance of Single Phase Short Transmission Lines

When the length of an overhead transmission line is upto about 50 km and the line voltage is comparatively low (< 20 kV), it is usually considered as a short transmission line. Due to smaller length and lower voltage, the capacitance effects are small and hence can be neglected. Therefore, while studying the performance of a short transmission line, only resistance and inductance of the line are taken into account.

The equivalent circuit of a single phase short transmission line is shown in Fig. Here, the total line resistance and inductance are shown as instead of being distributed. The circuit is a simple a.c. series circuit.

Let,

I = load current

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

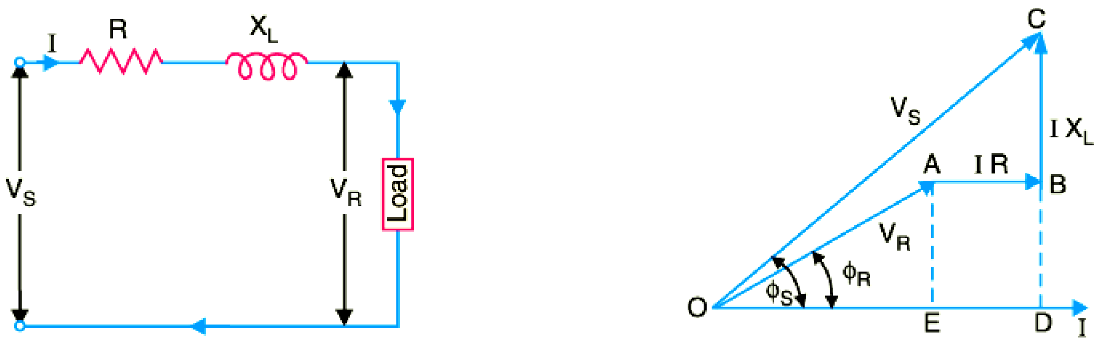
XL= loop reactance

VR = receiving end voltage

cos φR = receiving end power factor (lagging)

VS= sending end voltage

cos φS= sending end power factor



The *phasor diagram of the line for lagging load power factor is shown in Fig. From the right angled traingle ODC, we get,

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

or
$$V_S^2 = (OE + ED)^2 + (DB + BC)^2$$
$$= (V_R \cos \phi_R + IR)^2 + (V_R \sin \phi_R + IX_L)^2$$

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

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

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

(iii) $$\text{Power delivered} = V_R I_R \cos \phi_R$$
$$\text{Line losses} = I^2 R$$
$$\text{Power sent out} = V_R I_R \cos \phi_R + I^2 R$$
$$\text{\%age Transmission efficiency} = \frac{\text{Power delivered}}{\text{Power sent out}} \times 100$$
$$= \frac{V_R I_R \cos \phi_R}{V_R I_R \cos \phi_R + I^2 R} \times 100$$

An approximate expression for the sending end voltage Vs can be obtained as follows. Draw S perpendicular from B and C on OA produced as shown in Fig. Then OC is nearly equal to OF

OC = OF = OA + AF = OA + AG + GF

= OA + AG + BH

Vs= VR + IR cos φR + I XL sin φR

Performance of Single Phase Medium Transmission Lines

When the length of an overhead transmission line is about 50-150 km and the line voltage is moderatly high (>20 kV < 100 kV), it is considered as a medium transmission line. Due to sufficient length and voltage of the line, the capacitance effects are taken into account. For purposes of calculations, the distributed capacitance of the line.

However, as the length and voltage of the line increase, the capacitance gradually becomes of greater importance.

Since medium transmission lines have sufficient length (50-150 km) and usually operate at voltages greater than 20 kV, the effects of capacitance cannot be neglected. Therefore, in order to obtain reasonable accuracy in medium transmission line calculations, the line capacitance must be taken into consideration.

The capacitance is uniformly distributed over the entire length of the line. However, in order to make the calculations simple, the line capacitance is assumed to be lumped or concentrated in the form of capacitors shunted across the line at one or more points. Such a treatment of localising the line capacitance gives reasonably accurate results. The most commonly used methods (known as localised capacitance methods) for the solution of medium transmissions lines are :

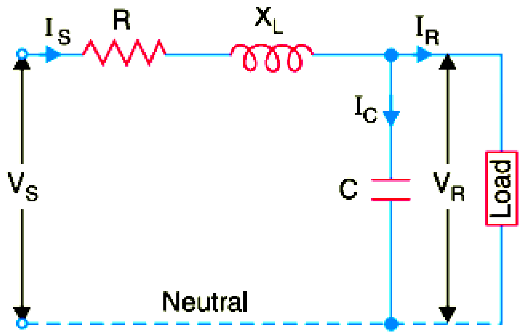
(i) End condenser method

(ii) Nominal T method

(iii) Nominal π method

i) End Condenser Method

In this method, the capacitance of the line is lumped or concentrated at the receiving or load end as shown in Fig.This method of localising the line capacitance at the load end overestimates the effects of capacitance. In Fig, one phase of the 3-phase transmission line is shown as it is more convenient to work in phase instead of line-to-line values.



Let

I R= load current per phase

R = resistance per phase

XL= inductive reactance per phase

C = capacitance per phase

cos φR= receiving end power factor (lagging) VS= sending end voltage per phase

The phasor diagram for the circuit is shown in Fig Taking the receiving end voltage VR as the reference phasor.

$$\text{we have, } \vec{V_R} = V_R + j\,0$$

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

$$\text{Capacitive current, } \vec{I_C} = j\,\vec{V_R}\,\omega C = j\,2\pi f C\,\vec{V_R}$$

The sending end current Is is the phasor sum of load current IR and capacitive current IC i.e. ,

$$\begin{aligned}\vec{I_S} &= \vec{I_R} + \vec{I_C} \\ &= I_R(\cos\phi_R - j\sin\phi_R) + j\,2\pi f C\,V_R \\ &= I_R\cos\phi_R + j(-I_R\sin\phi_R + 2\pi f C V_R) \\ &= \vec{I_S}\,\vec{Z} = \vec{I_S}(R + jX_L) \\ \vec{V_S} &= \vec{V_R} + \vec{I_S}\,\vec{Z} = \vec{V_R} + \vec{I_S}(R + jX_L)\end{aligned}$$

Thus, the magnitude of sending end voltage V_S can be calculated.

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

$$\%\ \text{Voltage transmission efficiency} = \frac{\text{Power delivered / phase}}{\text{Power delivered / phase} + \text{losses / phase}} \times 100 = \frac{V_R I_R \cos\phi_R}{V_R I_R \cos\phi_R + I_S^2 R} \times 100$$

Limitations

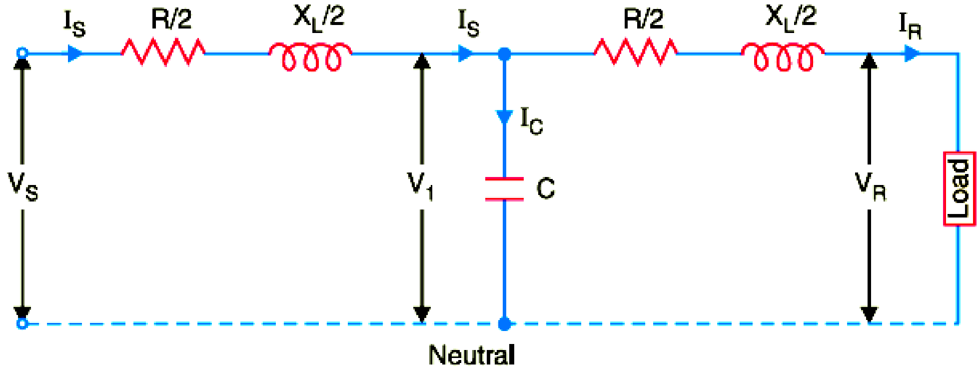
Although end condenser method for the solution of medium lines is simple to work out calculations, yet it has the following drawbacks :

(i) There is a considerable error (about 10%) in calculations because the distributed capacitance has been assumed to be lumped or concentrated.

(ii) This method overestimates the effects of line capacitance.

ii) Nominal T Method

In this 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 as shown in Fig. Therefore, in this arrangement, full charging current flows over half the line. In Fig. one phase of 3-phase transmission line is shown as it is advantageous to work in phase instead of line-to-line values.



Let

IR = load current per phase ;

R = resistance per phase

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

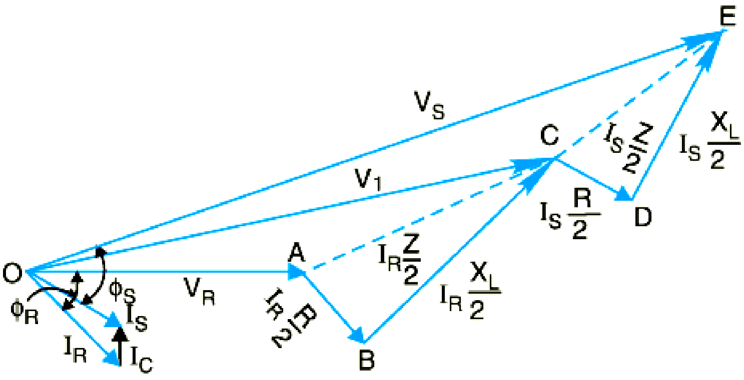
cos φR = receiving end power factor (lagging) ; VS= sending end voltage/phase

V1 = voltage across capacitor C

The *phasor diagram for the circuit is shown in Fig. Taking the receiving end voltage VR as the reference phasor, we have,

Receiving end voltage, $\vec{V_R} = V_R + j\,0$

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



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

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

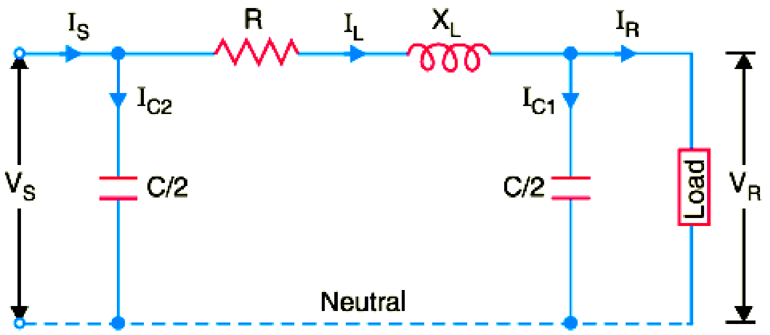
Capacitive current, $\vec{I_C} = j\,\omega\,C\,\vec{V_1} = j\,2\pi f\,C\,\vec{V_1}$

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

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

iii) Nominal π Method

In this method, capacitance of each conductor (i.e., line to neutral) is divided into two halves; one half being lumped at the sending end and the other half at the receiving end as shown in Fig. It is obvious that capacitance at the sending end has no effect on the line drop. However, its charging current must be added to line current in order to obtain the total sending end current.



Let

IR = load current per phase

R = resistance per phase

XL = inductive reactance per phase

C = capacitance per phase

cos φR = receiving end power factor (lagging) VS= sending end voltage per phase

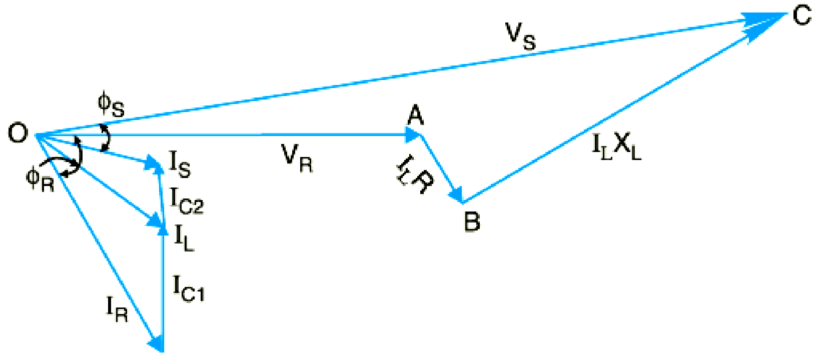
The phasor diagram for the circuit is shown in Fig. Taking the receiving end voltage as the reference phasor, we have,

$$\vec{V_R} = V_R + j\,0$$

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

Charging current at load end is

$$\vec{I_{C1}} = j\,\omega\,(C/2)\,\vec{V_R} = j\,\pi\,f\,C\,\vec{V_R}$$



Line current, $\vec{I_L} = \vec{I_R} + \vec{I_{C1}}$

Sending end voltage, $\vec{V_S} = \vec{V_R} + \vec{I_L}\,\vec{Z} = \vec{V_R} + \vec{I_L}\,(R + jX_L)$

Charging current at the sending end is

$$\vec{I_{C2}} = j\,\omega\,(C/2)\,\vec{V_S} = j\,\pi\,f\,C\,\vec{V_S}$$

∴ Sending end current, $\vec{I_S} = \vec{I_L} + \vec{I_{C2}}$

Video Content / Details of website for further learning (if any):
1. https://www.youtube.com/watch?v=vo3Oq5Rcbbw **2.** https://www.youtube.com/watch?v=1sHM8iKQguE
Important Books/Journals for further learning including the page nos.:
1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 82) 2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 91 to 101)

Course Faculty

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LECTURE HANDOUTS **L21**

DEPT: EEE **III / V**

Course Name with Code :19EEC12 & TRANSMISSION & DISTRIBUTION

Course Teacher : Mrs.M.Selvakumari

Unit : III – MODELLING AND PERFORMANCE OF TRANSMISSION LINES

Date of Lecture:

Topic of Lecture: Long line - Equivalent circuits, Phasor diagram

Introduction :

- Long Transmission Line Voltage, it is found that serious errors are introduced in the performance calculations. Therefore, in order to obtain fair degree of accuracy in the performance calculations of Long Transmission Line Voltage, the line constants are considered as uniformly distributed throughout the length of the line. Rigorous mathematical treatment is required for the solution of such lines.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory

Detailed content of the Lecture:

It is well known that line constants of the transmission line are uniformly distributed over the entire length of the line. However, reasonable accuracy can be obtained in line calculations for short and medium lines by considering these constants as lumped. Rigorous mathematical treatment is required for the solution of such lines.

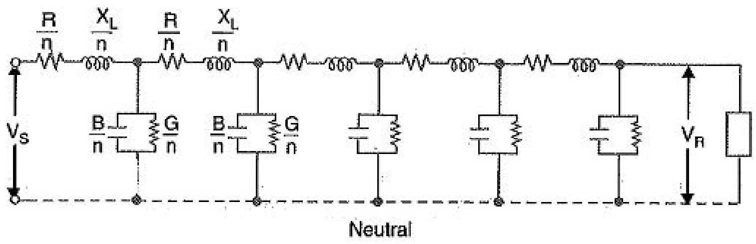

Figure shows the Equivalent circuit of a 3-phase Long Transmission Line Voltage on a phase-neutral

The whole line length is divided into n sections, each section having line constants 1/n th of those for the whole line.

The following points may by noted :

- The resistance and inductive reactance are the series elements.
- The leakage susceptance (B) and leakage conductance (G) are shunt elements. The leakage susceptance is due to the fact that capacitance exists between line and neutral.
- The leakage conductance takes into account the energy losses occurring through leakage over the insulators or due to corona effect between conductors. Admittance = $\sqrt{G^2 + B^2}$.
- The leakage current through shunt admittance is maximum at the sending end of the line and decreases continuously as the receiving end of the circuit is approached at which point its value is zero.

Analysis of Long Transmission Line Voltage (Rigorous method)

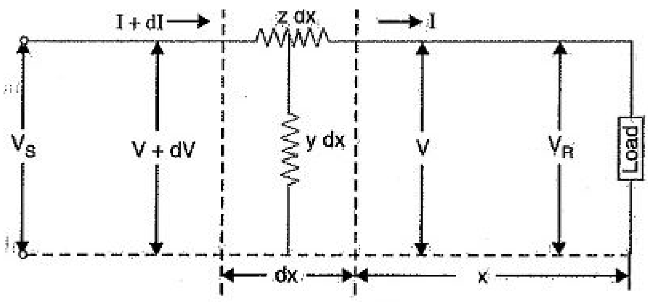

Figure shows one phase and neutral connection of a 3-phase with impedance and shunt admittance of the line uniformly distributed.

Let

z = series impedance of the line per unit length

y= shunt admittance of the line per unit length

V = voltage at the end of element towards receiving end

V+ dV = voltage at the end of element towards sending end

I + dI = current entering the element dx

I = current leaving the element dx

Then for the small element dx,

$$z\,dx = \text{series impedance}$$

$$y\,dx = \text{shunt admittance}$$

Obviously, $dV = I\,z\,dx$

$$\frac{dV}{dx} = I\,z \qquad \text{...}(i)$$

Now, the current entering the element is I + dl whereas the current leaving the element is I. The difference in the currents flows through shunt admittance of the element i.e.,

$$dI = \text{Current through shunt admittance of element} = V\,y\,dx$$

$$\frac{dI}{dx} = V\,y \qquad \text{...}(ii)$$

Differentiating eq. (i) w.r.t x, we get,

$$\frac{d^2V}{dx^2} = z\,\frac{dI}{dx} = z\,(V\,y) \qquad \left[\because \frac{dI}{dx} = V\;y \textit{ from } \exp\;(ii)\right]$$

$$\frac{d^2V}{dx^2} = y\,z\,V \qquad \text{...}\;(iii)$$

The solution of this differential equation is

$$V = k_1 \cosh\left(x\sqrt{y\,z}\right) + k_2 \sinh\left(x\sqrt{y\,z}\right) \qquad \text{...}(iv)$$

Differentiating exp. (iv) w.r.t. x, we have,

$$\frac{dV}{dx} = k_1\sqrt{y\,z}\,\sinh\,(x\sqrt{y\,z}) + k_2\sqrt{y\,z}\,\cosh\,(x\sqrt{y\,z})$$

$$\frac{dV}{dx} = I\,z \qquad [\text{from exp. } (i)]$$

$$I\,z = k_1\sqrt{y\,z}\,\sinh\,(x\sqrt{y\,z}) + k_2\sqrt{z\,y}\,\cosh\,(x\sqrt{y\,z})$$

$$I = \sqrt{\frac{y}{z}}\left[k_1 \sinh\,(x\sqrt{y\,z}) + k_2 \cosh\left(x\sqrt{y\,z}\right)\right] \qquad \text{...}(v)$$

Equations (iv) and (v) give the expressions for V and I in the form of unknown constants k_1 and k_2. The values of k_1 and k_2 can be found by applying end conditions as under :

$$\text{At} \quad x = 0, \quad V = V_R \text{ and } I = I_R$$

Putting these values in eq. (iv), we have,

$$V_R = k_1 \cosh 0 + k_2 \sinh 0 = k_1 + 0$$

$$V_R = k_1$$

Similarly, putting $x = 0$, $V = V_R$ and $I = I_R$ in eq. (v), we have,

$$I_R = \sqrt{\frac{y}{z}}\left[k_1 \sinh 0 + k_2 \cosh 0\right] = \sqrt{\frac{y}{z}}\left[0 + k_2\right]$$

$$k_2 = \sqrt{\frac{z}{y}}\, I_R$$

Substituting the values of k_1 and k_2 in eqs. (iv) and (v), we get,

$$V = V_R \cosh(x\sqrt{y\,z}) + \sqrt{\frac{z}{y}}\, I_R \sinh(x\sqrt{y\,z})$$

$$I = \sqrt{\frac{y}{z}} V_R \sinh(x\sqrt{y\,z}) + I_R \cosh(x\sqrt{y\,z})$$

The sending end voltage (V_S) and sending end current (I_S) are obtained by putting x = 1 in the above equations i.e.,

$$V_S = V_R \cosh(l\sqrt{y\,z}) + \sqrt{\frac{z}{y}} I_R \sinh(l\sqrt{y\,z})$$

$$I_S = \sqrt{\frac{y}{z}}\, V_R \sinh(l\sqrt{y\,z}) + I_R \cosh(l\sqrt{y\,z})$$

$$l\sqrt{y\,z} = \sqrt{l\,y \cdot l\,z} = \sqrt{Y\,Z}$$

$$\sqrt{\frac{y}{z}} = \sqrt{\frac{y\,l}{z\,l}} = \sqrt{\frac{Y}{Z}}$$

Y = total shunt admittance of the line

Z = total series impedance of the line

Therefore, expressions for V_S and I_S become

$$V_S = V_R \cosh\sqrt{YZ} + I_R \sqrt{\frac{Z}{Y}} \sinh\sqrt{YZ}$$

$$I_S = V_R \sqrt{\frac{Y}{Z}} \sinh\sqrt{YZ} + I_R \cosh\sqrt{YZ}$$

It is helpful to expand hyperbolic ine and cosine in terms of their power series.

$$\cosh\sqrt{Y\,Z} = \left(1 + \frac{Z\,Y}{2} + \frac{Z^2Y^2}{24} + \ldots\ldots\right)$$

$$\sinh\sqrt{Y\,Z} = \left(\sqrt{Y\,Z} + \frac{(Y\,Z)^{3/2}}{6} + \ldots\ldots\right)$$

Video Content / Details of website for further learning (if any):

1. https://www.youtube.com/watch?v=TXhkx13XNRw
2. https://www.youtube.com/watch?v=roqxNzFu4R0&t=31s

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 88)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 104 to 112)

Course Faculty

LECTURE HANDOUTS | **L22**

DEPT: EEE | **III / V**

Course Name with Code :19EEC12 & TRANSMISSION & DISTRIBUTION

Course Teacher : Mrs.M.Selvakumari

Unit : III – MODELLING AND PERFORMANCE OF TRANSMISSION LINES

Date of Lecture:

Topic of Lecture: Attenuation constant, phase constant, surge impedance

Introduction :

- It is a well-known fact that a long transmission lines (> 250 km) have distributed inductance and capacitance as its inherent property. When the line is charged, the capacitance component feeds reactive power to the line while the inductance component absorbs the reactive power. Hence, such impedance which renders the line as infinite line is known as surge impedance. It has a value of about 400 ohms and phase angle varying from 0 to –15 degree for overhead lines and around 40 ohms for underground cables.
- Surge Impedance Loading is a very essential parameter when it comes to the study of power systems as it is used in the prediction of maximum loading capacity of transmission lines.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory

Detailed content of the Lecture:

Propagation Constant

Electromagnetic waves propagate in a sinusoidal fashion. The measure of change in its amplitude and phase per unit distance is called the propagation constant. It is a complex quantity denoted by the Greek letter γ. It is used to describe the behavior of an electromagnetic wave along a transmission line. , which is given by,

$$\gamma = \alpha + j\beta$$
$$\gamma = \text{propagation constant}$$
$$\alpha = \text{attenuation constant}$$
$$\beta = \text{phase constant}$$

Attenuation Constant

The real part of the propagation constant is the attenuation constant and is denoted by Greek lowercase letter α (alpha). It causes a signal amplitude to decrease along a transmission line. The natural units of the attenuation constant are Nepers/meter.

Phase Constant

The phase constant is denoted by Greek lowercase letter β (beta) adds the imaginary component to the propagation constant. It determines the sinusoidal amplitude/phase of the signal along a transmission line, at a constant time. The phase constant's "natural" units are radians/meter.

Surge Impedance (Z_S)

Surge impedance is nothing but the characteristic impedance (Zc) of the lossless transmission line. It is also known as the Natural impedance of the line.

Let us assume that the line has shunt admittance (y) per unit length series impedance (z) per unit length. Then the Characteristic impedance (Zc) of any lossless transmission line is defined as the square root of (z/y).

Where, z = R + jwL and y = G + jwC.

If we put the value of z and y in the definition of (Zc), then we found that Characteristic Impedance is a complex quantity. However, for lossless transmission line (R=0 and G= 0)

z = jwL and y = jwC

Hence according to definition Characteristic Impedance (Zc) is calculated as:

Characteristic Impedance (Zc) = square root of (jwL/jwC).

On simplifying it we got a result as:

Zs= Zc = square root of (L/C).

$$Zs = Zc = \sqrt{\frac{L}{C}}$$

Surge Impedance Loading (SIL)

Surge Impedance Loading (SIL) is a very important parameter for the prediction of the maximum loading capacity (MW loading) of transmission lines.

Calculation of Surge impedance loading (SIL)

As we know that long transmission lines (length > 250 km) are represented by the distributed parameter model. In this model, the capacitance and inductance are distributed uniformly along the line. When the line is charged then the shunt capacitance generates reactive power and feeds to the line while the series inductance absorbed the reactive power. Hence voltage drop occurs in line due to series inductance is compensated by the shunt capacitance of line.

If we take a balance of reactive powers due to inductance and capacitance then we got an expression as:

$$\frac{V^2}{X_C} = I^2 X_L$$

On simplifying we got as:

$$\frac{V}{I} = \sqrt{X_L X_C} = \sqrt{\frac{2\pi f L}{2\pi f C}}$$

$$\frac{V}{I} = \sqrt{\frac{L}{C}} = Z_S$$

Effect of Surge impedance loading (SIL)

From the above expression of SIL we observed that SIL depends on the line voltage at the receiving end. Normally a line is loaded above SIL for better utilization of conductor. In other words, we can say that SIL should always less than the maximum loading capacity of the line.

Video Content / Details of website for further learning (if any):

1. https://www.youtube.com/watch?v=Nn7_3lHhtpI
2. https://www.electrical4u.com/surge-impedance-loading-or-sil/

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 95)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 114 to 121)

Course Faculty

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Estd. 2000

LECTURE HANDOUTS **L23**

DEPT: EEE **III / V**

Course Name with Code :19EEC12 & TRANSMISSION & DISTRIBUTION

Course Teacher : Mrs.M.Selvakumari

Unit : III – MODELLING AND PERFORMANCE OF TRANSMISSION LINES

Date of Lecture:

Topic of Lecture : Real and reactive power flow in transmission lines & Ferranti Effect

Introduction :

- Real power results from energy being used for work or dissipated as heat, reactive power is the result of energy being stored, to establish electric (capacitors) or magnetic (inductors) fields. Motor loads and other loads require reactive power to convert the flow of electrons into useful work.
- Decreasing reactive power causing voltage to fall while increasing it causing voltage to rise. On an alternating current (AC) power system, voltage is controlled by managing production and absorption of reactive power.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

Need for Reactive power:

Active power is the energy supplied to run a motor, heat a home, or illuminate an electric light bulb. Reactive power provides the important function of regulating voltage.

- If voltage on the system is not high enough, active power cannot be supplied.
- Reactive power is used to provide the voltage levels necessary for active power to do useful work.

Concept of Real & Reactive power:

In a simple alternating current (AC) circuit consisting of a source and a linear load, both the current and voltage are sinusoidal. If the load is purely resistive, the two quantities reverse their polarity at the same time. At every instant the product of voltage and current is positive or zero, with the result that the direction of energy flow does not reverse. In this case, only active power is transferred.

If the loads are purely reactive, then the voltage and current are 90 degrees out of phase. For half of each cycle, the product of voltage and current is positive, but on the other half of the cycle, the product is negative, indicating that on average, exactly as much energy flows toward the load as flows back. There is no net energy flow over one cycle. In this case, only reactive power flows—there is no net transfer of energy to the load.

Practical loads have resistance, inductance, and capacitance, so both active and reactive power will flow to real loads. Power engineers measure apparent power as the magnitude of the vector sum of active and reactive power. Apparent power is the product of the root-mean-square of voltage and current.

Electrical engineers have to take apparent power into account when designing and operating power systems, because even though the current associated with reactive power does no work at the load, it heats the conductors and wastes energy. Conductors, transformers and generators must be sized to carry the total current, not just the current that does useful work.

Another consequence is that adding the apparent power of two loads will not accurately result in the total apparent power unless the two circuits have the same displacement between current and voltage (the same power factor).

Conventionally, capacitors are considered to generate reactive power and inductors to consume it. If a capacitor and an inductor are placed in parallel, then the currents flowing through the inductor and the capacitor tend to cancel rather than add. This is the fundamental mechanism for controlling the power factor in electric power transmission; capacitors (or inductors) are inserted in a circuit to partially compensate reactive power 'consumed' by the load.

Upon energization, the ac networks and the devices connected to them create associated time-varying electrical fields related to the applied voltage, as well as magnetic fields dependent on the current flow. As they build up, these fields store energy that is released when they collapse. Apart from the energy dissipation in resistive components, all energy-coupling devices, including transformers and energy conversion devices (e.g., motors and generators), operate based on their capacity to store and release energy.

The reactive power is essential for creating the needed coupling fields for energy devices. It constitutes voltage and current loading of circuits but does not result in average (active) power consumption and is, in fact, an important component in all ac power networks. In high-power networks, active and reactive powers are measured in megawatts (MW) and MVAR, respectively.

Electromagnetic devices store energy in their magnetic fields. These devices draw lagging currents, thereby resulting in positive values of Q; therefore, they are frequently referred to as the absorbers of reactive power. Electrostatic devices, on the other hand, store electric energy in fields. These devices draw leading currents and result in a negative value of Q; thus they are seen to be suppliers of reactive power. The convention for assigning signs to reactive power is different for sources and loads, for which reason readers are urged to use a consistent notation of voltage and current, to rely on the resulting sign of Q, and to not be confused by absorbers or suppliers of reactive power.

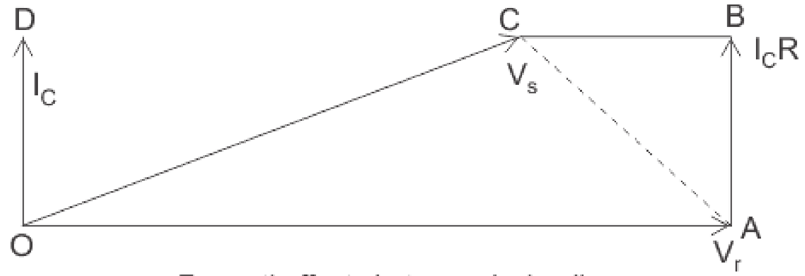
To make transmission networks operate within desired voltage limits and methods of making up or taking away reactive power is called reactive-power control. The AC networks and the devices connected to them create associated time varying electrical fields related to the applied voltage and as well as magnetic fields dependent on the current flow and they build up these fields store energy that is released when they collapse.

Ferranti Effect:

A long transmission line draws a high magnitude of charging current in long and moderate lines.
If such a line is open circuited or very lightly loaded at the receiving end, the voltage at receiving end may become greater than voltage at sending end. This is known as Ferranti Effect.

Ferranti Effect in transmission lines:

Ferranti effect is due to the charging current of the line. When an alternating voltage is applied, the current that flows into the capacitor is called charging current. A charging current is also known as capacitive current. During light load conditions, the charging current increases in the line where the receiving end voltage of the line is larger than the sending end.
A long transmission line can be considered to compose a considerably high amount of capacitance and inductance distributed across the entire length of the line. Ferranti Effect occurs when current drawn by the distributed capacitance of the line itself is greater than the current associated with the load at the receiving end of the line (during light or no load).
This capacitor charging current leads to a voltage drop across the line inductor of the transmission system which is in phase with the sending end voltages. This voltage drop keeps on increasing additively as we move towards the load end of the line and subsequently, the receiving end voltage tends to get larger than applied voltage leading to the phenomena called Ferranti effect in power system. This concept is illustrated with the help of a phasor diagram shown below.



Ferranti effects in transmission line

Methods to reduce Ferranti Effect:

- Ferranti effect can be reduced by installing shunt compensation devices at receiving end. The compensation device is a shunt reactor which is connected in parallel with the transmission line. It reduces the voltage level by absorbing the reactive power.
- Running the transmission line with higher load.

Video Content / Details of website for further learning (if any):

1. https://www.youtube.com/watch?v=LwUjt58D4mw
2. https://electricalnotes.wordpress.com/2011/03/21/importance-of-reactive-power-for-system/

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 101)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 125 to 131)

Course Faculty

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LECTURE HANDOUTS **L24**

DEPT: EEE **III / V**

Course Name with Code :19EEC12 & TRANSMISSION & DISTRIBUTION

Course Teacher : Mrs.M.Selvakumari

Unit : III – MODELLING AND PERFORMANCE OF TRANSMISSION LINES

Date of Lecture:

Topic of Lecture Power Circle Diagram

Introduction :

- Power circle diagrams drawn for either sending or receiving ends of a transmission line do not have a common center for the voltage circles, nor are the power axes within the same semicircle. There is also a possibility of confusion over the sign of reactive power when conditions at both ends of the line are estimated by means of separate diagrams.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

Circle Diagrams

Transmission line problems often involve manipulations with complex numbers, making the time and effort required for a solution several times greater than that needed for a similar sequence of operations on real numbers. One means of reducing the labor without seriously affecting the accuracy is by using transmission-line charts. Probably the most widely used one is the Smith chart. Basically, this diagram shows curves of constant resistance and constant reactance; these may represent either an input impedance or a load impedance.

An indication of location along the line is also provided, usually in terms of the fraction of a wavelength from a voltage maximum or minimum. Although they are not specifically shown on the chart, the standing-wave ratio and the magnitude and angle of the reflection coefficient are very quickly determined. As a matter of fact, the diagram is constructed within a circle of unit radius, using polar co-ordinates. The basic relationship upon which the chart is constructed is

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}$$

The impedances which we plot on the chart will be normalized with respect to the characteristic impedance. Let us identify the normalized load impedance as Z_L

$$z_L = r + jx = \frac{Z_L}{Z_0} = \frac{R_L + jX_L}{Z_0}$$

$$\Gamma = \frac{z_L - 1}{z_L + 1}$$

$$z_L = \frac{1 + \Gamma}{1 - \Gamma}$$

POWER FLOW IN A TRANSMISSION LINE

The power flow in a transmission line can be calculated by considering the system shown in Fig. It consists of a single transmission line connected between two buses. These buses are Sending end bus and Receiving end bus.

FIG.-. TRANSMISSION LINE POWER FLOW

The line is characterized by its line constants as follows

$A = |A|\angle\alpha, B = |B|\angle\beta$

So that the power received at the receiving end is given by

$S_R = P_R + jQ_R = V_R I_R^*$

As we know the line equation in terms of $ABCD$ constant are

$V_S = AV_R + BI_R$

$$I_S = CV_R + DI_R$$

$$I_R = \frac{V_S - AV_R}{B}$$

$$I_R^* = \left(\frac{V_S - AV_R}{B}\right)^*$$

$$I_R^* = \frac{(|V_S|\angle-\delta) - (|A|\angle-\alpha)(|V_R|\angle 0)}{(|B|\angle-\beta)}$$

We have

$$P_R + jQ_R = (|V_R|\angle 0)\frac{(|V_S|\angle-\delta) - (|A|\angle-\alpha)(|V_R|\angle 0)}{(|B|\angle-\beta)}$$

APPROXIMATION OF POWER FLOW EQUATION

For the transmission line series resistance is very less as compared to series reactance and $|A| \approx 1.0, \alpha \approx 0.0, |B| = Z \approx X, \beta \approx 90^\circ$

Hence (3.45) can be fairly approximated as (3.47)

$$P_R = \frac{|V_R||V_S|}{X} Sin\,\delta$$

From (3.47) we conclude that the power transmitted over a transmission line is determined by the voltage at both the ends, the reactance of the line and phase difference between the voltages of both ends. Similarly the power flow between two buses can be given by (3.48)

$$P = \frac{|V_1||V_2|}{X_{12}} Sin(\delta_1 - \delta_2)$$

Video Content / Details of website for further learning (if any):

1. https://www.youtube.com/watch?v=MA5b3Mcl6OI
2. https://www.youtube.com/watch?v=kGee2B5Pmeg

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 107)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 132 to 138)

Course Faculty

LECTURE HANDOUTS | **L25**

DEPT: EEE | **III / V**

Course Name with Code : **16EED10/TRANSMISSION & DISTRIBUTION**

Course Teacher : **Dr.R.SAGAYARAJ**

Unit : **III – MODELLING AND PERFORMANCE OF TRANSMISSION LINES**

Date of Lecture:

Topic of Lecture: Methods of Voltage Control

Introduction:

- Voltage control is an integral part of power system operation. Controlling voltages on the power system allows for the efficient transmission of power.
- Voltage variations results in malfunctioning of loads across the consumer end loads, 50% reduction in life of the home appliances, large voltage variations may cause excessive heating of distribution transformers, Standard limit of voltage variation is +/- 6%.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- AC Machines

Methods of Voltage Control:

There are several methods of voltage control. In each method, the system voltage is changed in accordance with the load to obtain a fairly constant voltage at the consumer's end of the system. The following are the methods of voltage control in an a.c. power system they are:

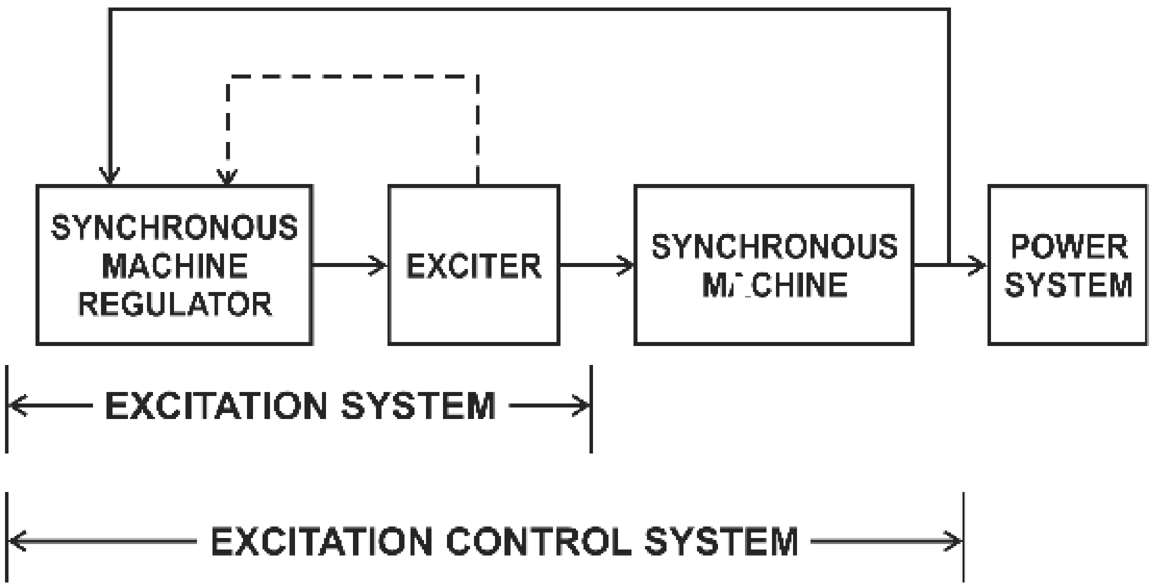
i. **Excitation Control**
ii. **Tap-Changing Transformer**
iii. **Auto-transformer Tap Changing**
iv. **Booster transformers**
v. **Induction regulators**
vi. **Synchronous Condensers**

Method (i) is used at the generating station only whereas methods (ii) to (v) can be used for transmission as well as primary distribution systems. However, methods (vi) is reserved for the voltage control of a transmission line.

Excitation Control:

When the load on the supply system changes, the terminal voltage of the alternator also varies due to the changed voltage drop in the synchronous reactance of the armature. The voltage of the alternator can be kept constant by changing the field current of the alternator in accordance with the load. This is known as excitation control method. The excitation of alternator can be controlled by the use of automatic or hand operated regulator acting in the field circuit of the alternator.

Excitation control method is satisfactory only for short lines. For longer lines, the terminal voltage of alternator has to be varied widely for the voltage at far ends to remain constant. Obviously, this method is not feasible for longer lines.



Tap-Changing Transformer

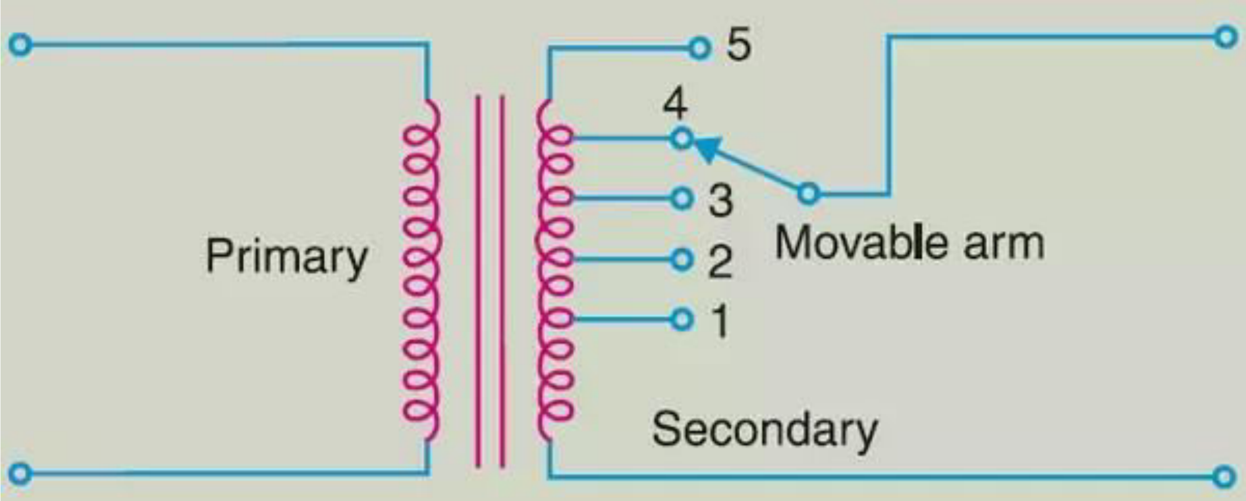
The **voltage control in** transmission **and** distribution systems is usually obtained by using tap changing transformers. In this method, the voltage in the line is adjusted by changing the secondary EMF of the transformer by varying the number of secondary turns. Secondary voltage of a transformer is directly proportional to the number of secondary turns. Thus, the secondary voltage can be adjusted by changing the turns ratio of the transformer. Secondary number of turns can be varied with the help of tappings provided on the winding. Basically, there are two types of tap changing transformers.

off-load tap changing transformers

on-load tap changing transformers

Voltage Control Using Off-Load Tap Changing Transformers

In this method, the transformer is disconnected from the supply before changing the tap. Off load tap changing transformers are relatively cheaper. But the main drawback with them is that the power supply is interrupted while changing the tap.

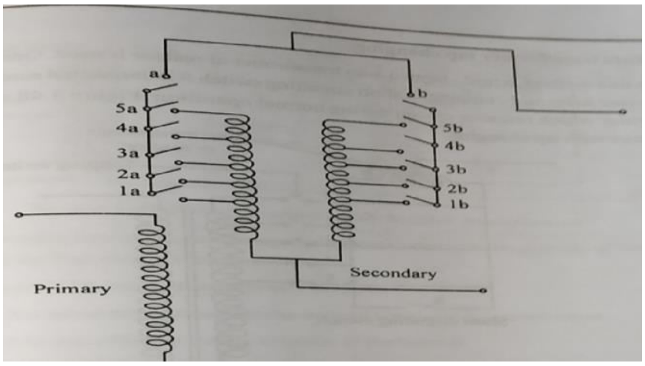


Off-Load Tap Changing Transformers

- Under light loads moving arm at 1
- Under heavy loads moving arm at 5

Voltage Control Using On-Load Tap Changing Transformers

In modern power system, continuity of the supply is important. Therefore, on-load tap changing transformers are preferred to control the voltage.



On-Load Tap Changing Transformer

- Normal switch a& b is closed
- When tappings 4a & 4b is to be changed, open a-now the total current is carried by b. Now change 4a-5a and a is closed. Now b is opened and change 4b-5b and later b is closed.

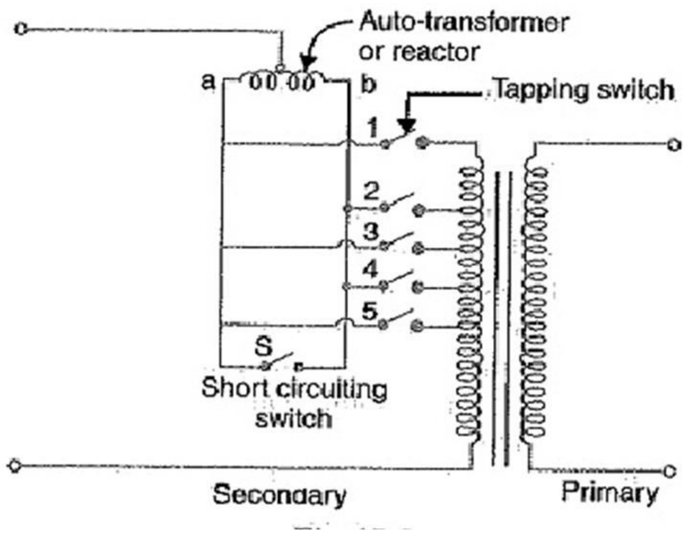
Auto-transformer Tap Changing

Here, a mid-tapped auto-transformer or reactor is used. One of the lines is connected to its mid-tapping. A switch is remains in the closed position under normal operation which is A short-circuiting switch S is connected across the auto-transformer. This Reactor transformer is connected to a series of switches across the odd tappings. The other end X is connected to switches across even tappings. During normal operation there is no inductive voltage drop across the auto transformer. Therefore, different tappings are provide on the secondary side of the autotransformer.

Circuit operation:-

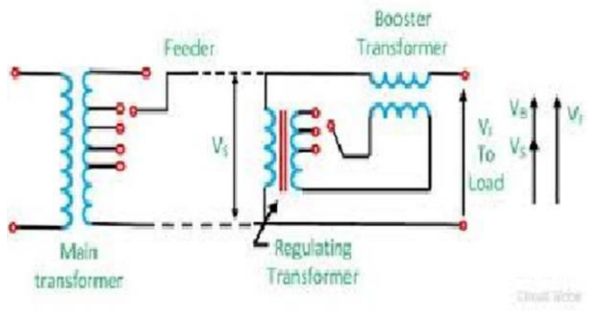
According to figure is we connect tapping no. 4 then minimum winding turn come in circuit. hence, the secondary voltage is minimum. as we connect the tapping no. 1 then maximum no of winding turn are came in circuit. hence, the voltage rating at secondary side is maximum. When connected tap chnging at no. 4 then voltage is lowest. if we want to raise in output voltage the connect tapping with the 3 no. stud. when it is connected on 4th. short circuit switch is open. But during the tap changing that short circuit switch need to close. By this way we can tap changing without interrupting the supply voltage.

When during the tap changing, short circuit switch is open the load current flows through one-half of the reactor coil, so that there is a voltage drop across the reactor. in this condition heavy current flow through the tapping and its causes of sparking during the tap changing, hence the equipment may be can damage because of that sparking and may chances to failure of insulation. When switch 3 is closed, the turns between points 3 and 4 are connected through the whole reactor winding. A circulating current flows through this local circuit, but it is limited to a low value due to high reactance of the reactor.



Booster Transformer

- The primary of the on load tap changing regulating/booster transformer is fed from the main transformer.
- The booster transformer is connected in such a way that, its secondary injects a voltage in series with the line voltage.
- By changing the tapping of the booster transformer, the magnitude of the voltage injected into the line can be varied.



Booster Transformer

Video Content / Details of website for further learning (if any):

1. https://www.youtube.com/watch?v=opocYkK_oSA
2. https://www.youtube.com/watch?v=R_NxRDXOEFk

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 112)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 141 to 155)

Course Faculty

LECTURE HANDOUTS **L26**

DEPT: EEE **III / V**

Course Name with Code :19EEC12 & TRANSMISSION & DISTRIBUTION

Course Teacher : Mrs.M.Selvakumari

Unit : III – MODELLING AND PERFORMANCE OF TRANSMISSION LINES

Date of Lecture:

Topic of Lecture : Transmission efficiency, voltage regulation and Surge impedance loading

Introduction

- Value of surge impedance can be reduced either by increasing capacitor (C) of line or by decreasing inductance (L) of line.
- But the inductance of the line cannot reduce easily. By the use of series capacitor surge impedance and also phase shift gets reduced due to a decrease in inductance value (L).

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

Effect on transmission efficiency

The power delivered to the load depends upon the power factor.

$$P = V_R * I \cos\phi_R \quad \text{(For 1-phase line)}$$

$$I = \frac{P}{V_R \cos\phi_R}$$

$$P = 3\, V_R I \cos\phi_R \quad \text{(For 3-phase line)}$$

$$I = \frac{P}{3V_R \cos\phi_R}$$

It is clear that in each case, for a given amount of power to be transmitted (P) and receiving end voltage Power Factor Meter (V R), the load current I is inversely proportional to the load p.f. cos φ R. Consequently, with the decrease in load p.f., the load current and hence the line losses are increased. This leads to the conclusion that transmission efficiency of a line decreases with the decrease in load Power

Factor Regulator p.f. and vice-versa,

The regulation and efficiency of a transmission line depend to a considerable extent upon the power factor of the load.

Effect on regulation.
The expression for voltage regulation of a short transmission line is given by :

$$\%\text{age Voltage regulation} = \frac{I R \cos \phi_R + I X_L \sin \phi_R}{V_R} \times 100 \qquad (\textit{for lagging p.f.})$$

$$\%\text{age Voltage regulation} = \frac{I R \cos \phi_R - I X_L \sin \phi_R}{V_R} \times 100 \qquad (\textit{for leading p.f.})$$

(*i*) When the load p.f. is lagging or unity or such leading that $I R \cos \varphi_R > I X_L \sin \varphi_R$, then voltage regulation is positive *i.e.* , receiving end voltage V_R will be less than the sending end voltage V_S .

(*ii*) For a given V_R and *I*, the voltage regulation of the line increases with the decrease in p.f. for lagging loads.

(*iii*) When the load p.f. is leading to this extent that $I X_L \sin \varphi_R > I \cos \varphi R$, then voltage regulation is negative *i.e.* the receiving end voltage V_R is more than the sending end voltage V_S .

(*iv*) For a given V_R and *I*, the voltage regulation of the line decreases with the decrease in p.f. for leading loads.

SURGE IMPEDANCE LOADING

Surge impedance of a line, Zo

$$SIL = \frac{(kV_{LL})^2}{Z_o}, \quad (MW)$$

A transmission line loaded to its surge impedance loading:

(i) has no net reactive power flow into or out of the line, and

(ii) will have approximately a flat voltage profile along its length.

For (i) to hold:

$$I^2 X_L = \frac{V^2}{X_c}, \quad \text{or,} \quad \frac{V^2}{I^2} = X_L X_c = \frac{\omega L}{\omega C}, \quad \text{or,} \quad \frac{V}{I} = \sqrt{\frac{L}{C}} = Z_o = \text{Load impedance}$$

This means that there will be no net reactive power flow at surge-impedance loading.

For (ii) to hold:

$$V_s = AV_r + BI_r \; ; \; I_s = CV_r + DI_r ,$$

where, $A = D = \cosh\sqrt{ZY}$; $B = Z_o \sinh\sqrt{ZY}$; $C = \frac{\sinh\sqrt{ZY}}{Z_o}$; $Z = j\omega L\ell$; $Y = j\omega C\ell$

$$\sqrt{ZY} = j\omega\ell\sqrt{LC} = \frac{j\omega\ell}{v_c} = j\frac{2\pi f\ell}{f\lambda} = j\frac{2\pi\ell}{\lambda}$$

Then, $A = D = \cos\frac{2\pi\ell}{\lambda}$; $B = jZ_o \sin\frac{2\pi\ell}{\lambda}$; $C = j\frac{\sin\frac{2\pi\ell}{\lambda}}{Z_o}$

At surge-impedance loading, $\frac{V_r}{I_r} = Z_o$.

And, $V_s = (A + \frac{B}{Z_o})V_r = (\cos\frac{2\pi\ell}{\lambda} + j\sin\frac{2\pi\ell}{\lambda})V_r = V_r \angle \tan^{-1}\frac{2\pi\ell}{\lambda}$,

$$I_s = (CZ_o + D)I_r = (j\sin\frac{2\pi\ell}{\lambda} + \cos\frac{2\pi\ell}{\lambda})I_r = I_r \angle \tan^{-1}\frac{2\pi\ell}{\lambda}$$

This means that the line will have a flat voltage profile, i.e., no voltage drop.

Video Content / Details of website for further learning (if any):

1. https://www.electricaltechnology.org/2018/02/corona-effect-discharge-transmission-lines-power-system.html
2. https://www.youtube.com/watch?v=3X289DW33iU

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 121)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 161 to 168)

Course Faculty

LECTURE HANDOUTS **L27**

DEPT: EEE **III / V**

Course Name with Code :19EEC12 & TRANSMISSION & DISTRIBUTION

Course Teacher : Mrs.M.Selvakumari

Unit : III – MODELLING AND PERFORMANCE OF TRANSMISSION LINES

Date of Lecture:

Topic of Lecture: Ferranti Effect

Introduction

- A long transmission line draws a substantial quantity of charging current. If such a line is open circuited or very lightly loaded at the receiving end, the voltage at receiving end may become greater than voltage at sending end.

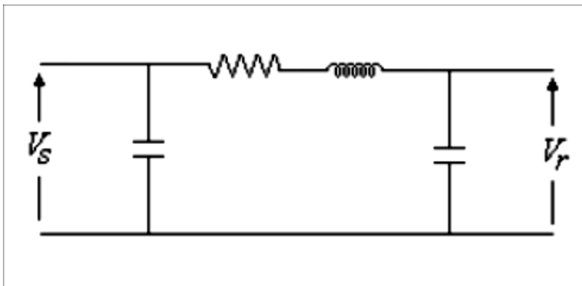
Prerequisite knowledge for Complete understanding and learning of Topic:

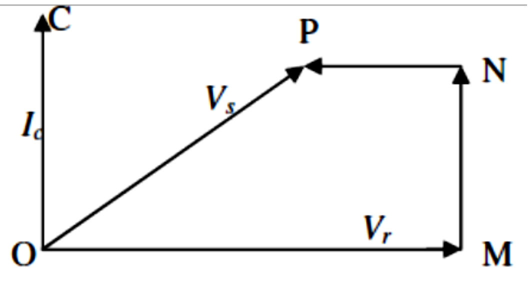
- Circuit Theory
- AC Machines

Detailed content of the Lecture:

. A long transmission line draws a substantial quantity of charging current. If such a line is open circuited or very lightly loaded at the receiving end, the voltage at receiving end may become greater than voltage at sending end. This is known as **Ferranti Effect** and is due to the voltage drop across the line inductance (due to charging current) being in phase with the sending end voltages. Therefore both capacitance and inductance is responsible to produce this phenomenon The capacitance (and charging current) is negligible in short line but significant in medium line and appreciable in long line. Therefore this phenomenon occurs in medium and long lines.

Represent line by equivalent π model.





Line capacitance is assumed to be concentrated at the receiving end.

OM = receiving end voltage Vr

OC = Current drawn by capacitance = Ic

MN = Resistance drop

NP = Inductive reactance drop

Therefore;

OP = Sending end voltage at no load and is less than receiving end voltage (Vr)

Since, resistance is small compared to reactance; resistance can be neglected in calculating Ferranti effect.

From π model,

$$V_s = \left(1 + \frac{YZ}{2}\right)V_r + ZI_r$$

For open circuit line; Ir = 0

$$\therefore \quad V_s = \left(1 + \frac{YZ}{2}\right)V_r$$

$$\text{or;} \quad V_s - V_r = \left(1 + \frac{YZ}{2}\right)V_r - V_r = V_r\left(1 + \frac{YZ}{2} - 1\right)$$

$$\text{or;} \quad V_s - V_r = \left(\frac{YZ}{2}\right)V_r = \frac{(j\omega Cl)(r + j\omega L)l}{2}V_r$$

Neglecting resistance;

$$V_s - V_r = \frac{-V_r \omega^2 l^2 LC}{2}$$

Substituting the value in above equation;

$$LC = \frac{1}{(3 \times 10^5)^2}$$

$$V_s - V_r = \frac{-V_r \omega^2 l^2}{2(3 \times 10^5)^2}$$

$$\therefore \quad V_s - V_r = \frac{-V_r \omega^2 l^2 \times 10^{-10}}{18}$$

$$\boxed{\therefore \; V_s = V_r\left[1 - \frac{\omega^2 l^2 \times 10^{-10}}{18}\right]}$$

Now, from above expression;

$$\left[1-\frac{\omega^2 l^2 \times 10^{-10}}{18}\right] < 1$$

$$V_s < V_r \qquad or; \qquad V_r > V_s$$

i.e. receiving end voltage is greater than sending end voltage and this effect is called Ferranti Effect. It is valid for open circuit condition of long line.

Video Content / Details of website for further learning (if any):

1. https://www.electricaltechnology.org/2018/02/corona-effect-discharge-transmission-lines-power-system.html
2. https://www.youtube.com/watch?v=3X289DW33iU

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 127)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 174 to 178)

Course Faculty

LECTURE HANDOUTS **L28**

DEPT: EEE **III / V**

Course Name with Code :**19EEC12 & TRANSMISSION & DISTRIBUTION**

Course Teacher : **Mrs.M.Selvakumari**

Unit : **IV – INSULATORS AND CABLES**

Date of Lecture:

Topic of Lecture: Introduction to insulators and cables

Introduction :

- Electrical Insulator must be used in electrical system to prevent unwanted flow of current to the earth from its supporting points.
- The insulator plays a vital role in electrical system. Electrical Insulator is a very high resistive path through which practically no current can flow. In transmission and distribution system, the overhead conductors are generally supported by supporting towers or poles.
- The towers and poles both are properly grounded. So there must be insulator between tower or pole body and current carrying conductors to prevent the flow of current from conductor to earth through the grounded supporting towers or poles.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory

Detailed content of the Lecture:

Insulating Material

The materials generally used for insulating purpose is called insulating material. For successful utilization, this material should have some specific properties as listed below

1.It must be mechanically strong enough to carry tension and weight of conductors.

2. It must have very high dielectric strength to withstand the voltage stresses in High Voltage system.

3. It must possess high Insulation Resistance to prevent leakage current to the earth.

4. There physical as well as electrical properties must be less affected by changing temperature

PORCELAIN

Porcelain in most commonly used material for over head insulator in present days. The porcelain is aluminium silicate. The aluminium silicate is mixed with plastic kaolin, feldspar and quartz to obtain final hard and glazed porcelain insulator material. The surface of the insulator should be glazed enough so that water should not be traced on it. Porcelain also should be free from porosity since porosity is the main cause of deterioration of its dielectric property. It must also be free from any impurity and air bubble inside the material which may affect the insulator properties.

CABLE

Electric power can be transmitted or distributed either by overhead system or by underground cables. The underground cables have several advantages such as less liable to damage through storms or lightning, low maintenance cost, less chance of faults, smaller voltage drop and better general appearance. However, their major drawback is that they have greater installation cost and introduce insulation problems at high voltages compared with the equivalent overhead system. For this reason, underground cables are employed where it is impracticable to use overhead lines. Such locations may be thickly populated areas where municipal authorities prohibit overhead lines for reasons of safety, or around plants and substations or where maintenance conditions do not permit the use of overhead construction.

The chief use of underground cables for many years has been for distribution of electric power in congested urban areas at comparatively low or moderate voltages. However, recent improvements in the design and manufacture have led to the development of cables suitable for use at high voltages. This has made it possible to employ underground cables for transmission of electric power for short or moderate distances. In this chapter, we shall focus our attention on the various aspects of underground cables and their increasing use in power system.

An underground cable essentially consists of one or more conductors covered with suitable insulation and surrounded by a protecting cover. Although several types of cables are available, the type of cable to be used will depend upon the working voltage and service requirements. In general, a cable must fulfill the following necessary requirements: (i) The conductor used in cables should be tinned stranded copper or aluminum of high conductivity. Stranding is done so that conductor may become flexible and carry more current. (ii) The conductor size should be such that the cable carries the desired load current without overheating and causes voltage drop within permissible limits. (iii) The cable must have proper thickness of insulation in order to give high degree of safety and reliability at the voltage for which it is designed. (iv) The cable must be provided with suitable mechanical protection so that it may withstand the rough use in laying it. (v) The materials used in the manufacture of cables should be such that there is complete chemical and physical stability throughout.

Video Content / Details of website for further learning (if any):

1. https://cpb-us-e1.wpmucdn.com/cobblearning.net/dist/7/4957/files/2020/03/Newsela.An-Intro-to-Insulators-and-Conductors.pdf
2. http://www.brainkart.com/article/Insulator---Introduction_12377/

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 142)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 181 to 184)

Course Faculty

LECTURE HANDOUTS | **L29**

DEPT: EEE | **III / V**

Course Name with Code :19EEC12 & TRANSMISSION & DISTRIBUTION

Course Teacher : Mrs.M.Selvakumari

Unit : IV – INSULATORS AND CABLES

Date of Lecture:

Topic of Lecture: Types of Insulators

Introduction :

- Insulated wire or cable consists of non-conductive material or some other kind of material that is resistant to an electric current. It surrounds and protects the wire and cable inside. Cable and wire insulation prevents the insulated wire's current from coming into contact with other conductors.
- The overhead line conductors should be supported on the poles or towers in such a way that currents from conductors do not flow to earth through supports i.e., line conductors must be properly insulated from supports. This is achieved by securing line conductors to supports with the help of insulators.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory

Detailed content of the Lecture:

Definition of Insulator

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

Properties of insulators

(i) High mechanical strength in order to withstand conductor load, wind load etc.

(ii) High electrical resistance of insulator material in order to avoid leakage currents to earth.

(iii) High relative permittivity of insulator material in order that dielectric strength is high.

(iv) The insulator material should be non-porous, free from impurities and cracks otherwise the permittivity will be lowered.

(v) High ratio of puncture strength to flashover.

Insulating materials

The most commonly used material for insulators of overhead line is porcelain but glass, steatite and special composition materials are also used to a limited extent. Porcelain is produced by firing at a high temperature a mixture of kaolin, feldspar and quartz. It is stronger mechanically than glass, gives less trouble from leakage and is less affected by changes of temperature.

Types of Insulators

1. Pin type insulator (11kv-33kv)

2. Suspension type insulators(Disc or String Insulators) (up to 220kv or more)-vertical position

3. Strain Insulators(horizontal position)

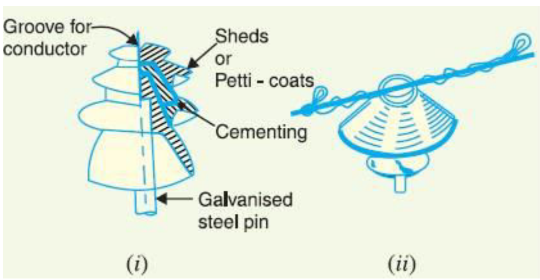
4. Shackle Insulators (spool insulators)- For low voltage distribution lines - up to 230v. ?(Used both horizontal & Vertical)

5. Stay Insulators or egg insulators

6. Stack Insulators

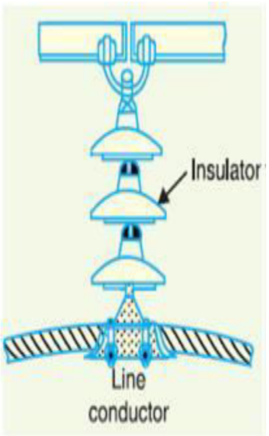
Pin type insulators

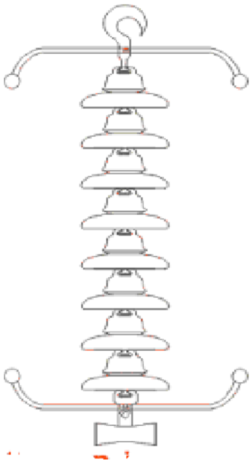
The part section of a pin type insulator is shown in Fig. As the name suggests, the pin type insulator is secured to the cross-arm on the pole. There is a groove on the upper end of the insulator for housing the conductor. The conductor passes through this groove and is bound by the annealed wire of the same material as the conductor Pin type insulators are used for transmission and distribution of electric power at voltages upto 33 kv.

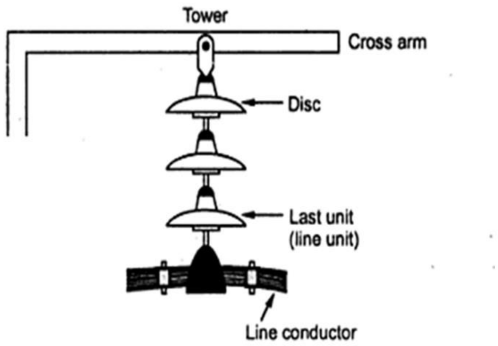


Suspension type insulators

The cost of pin type insulator increases rapidly as the working voltage is increased. Therefore, this type of insulator is not economical beyond 33 kV. For high voltages (>33 kV), it is a usual practice to use suspension type insulators shown in Fig. . They consist of a number of porcelain discs connected in series by metal links in the form of a string. The conductor is suspended at the bottom end of this string while the other end of the string is secured to the cross-arm of the tower. Each unit or disc is designed for low voltage, say 11 kV. The number of discs in series would obviously depend upon the working voltage. For instance, if the working voltage is 66 kV, then six discs in series will be provided on the string.







String of suspension insulator with 3 units

Advantages

(i) Suspension type insulators are cheaper than pin type insulators for voltages beyond 33 kV.

(ii) Each unit or disc of suspension type insulator is designed for low voltage, usually 11 kV. Depending upon the working voltage, the desired number of discs can be connected in series.

(iii) If any one disc is damaged, the whole string does not become useless because the damaged disc can be replaced by the sound one.

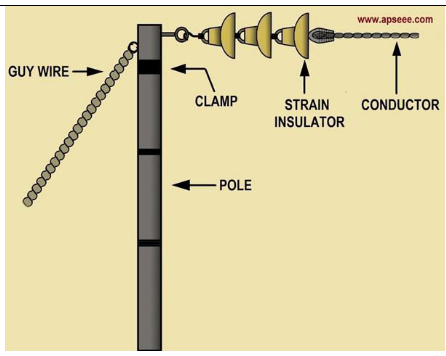
(iv) The suspension arrangement provides greater flexibility to the line. The connection at the cross arm is such that insulator string is free to swing in any direction and can take up the position where mechanical stresses are minimum.

(v) In case of increased demand on the transmission line, it is found more satisfactory to supply the greater demand by raising the line voltage than to provide another set of conductors. The additional insulation required for the raised voltage can be easily obtained in the suspension arrangement by adding the desired number of discs.

(vi) The suspension type insulators are generally used with steel towers. As the conductors run below the earthed cross-arm of the tower, therefore, this arrangement provides partial protection from lightning.

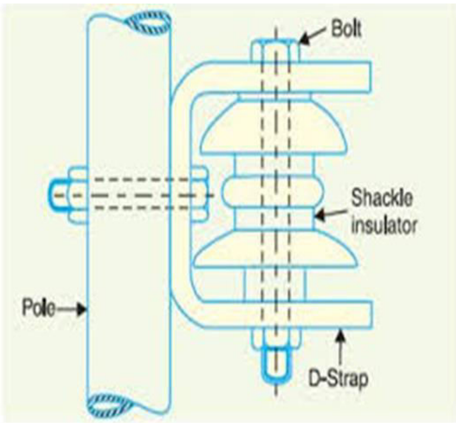
Strain insulators

When there is a dead end of the line or there is corner or sharp curve, the line is subjected to greater tension. In order to relieve the line of excessive tension, strain insulators are used. For low voltage lines (< 11 kV), shackle insulators are used as strain insulators. However, for high voltage transmission lines, strain insulator consists of an assembly of suspension insulators as shown in Fig. The discs of strain insulators are used in the vertical plane. When the tension in lines is exceedingly high, as at long river spans, two or more strings are used in parallel.



Shackle insulators

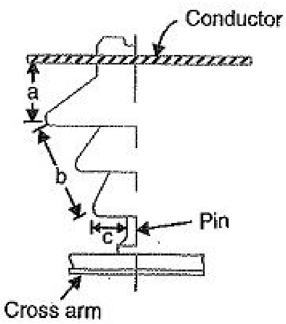
In early days, the shackle insulators were used as strain insulators. But now a days, they are frequently used for low voltage distribution lines. Such insulators can be used either in a horizontal position or in a vertical position. They can be directly fixed to the pole with a bolt or to the cross arm. Fig. shows a shackle insulator fixed to the pole. The conductor in the groove is fixed with a soft binding wire.



Shackle insulator

Causes of Insulator Failure

Insulators are required to withstand both mechanical and electrical stresses. The latter type is primarily due to line voltage and may cause the breakdown of the insulator. The electrical breakdown of the insulator can occur either by flash-over or puncture. In flash over, an arc occurs between the line conductor and insulator pin(i.e., earth) and the discharge jumps across the air gaps, following shortest distance. Fig. shows the arcing distance (i.e. a + b + c) for the insulator. In case of flash-over, the insulator will continue to act in its proper capacity unless extreme heat produced by the arc destroys the Insulator.



In case of puncture, the discharge occurs from conductor to pin through the body of the insulator. When such breakdown is involved, the insulator is permanently destroyed due to excessive heat. In practice, sufficient thickness of porcelain is provided in the insulator to avoid puncture by the line voltage. The ratio of puncture strength to flash-over voltage is known as safety factor i.e.,

$$\text{Safety factor of insulator} = \frac{\text{Puncture strength}}{\text{Flash - over voltage}}$$

It is desirable that the value of safety factor is high so that flash-over takes place before the insulator gets punctured. For pin type insulators, the value of safety factor is about 10.

Video Content / Details of website for further learning (if any):

1. http://www.electricalunits.com/insulator-in-overhead-line-and-types-of-insulators/
2. https://www.youtube.com/watch?v=FlqIs1qvqy4

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 144)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 186 to 191)

Course Faculty

Course Name with Code :**19EEC12 & TRANSMISSION & DISTRIBUTION**

Course Teacher : **Mrs.M.Selvakumari**

Unit : **IV – INSULATORS AND CABLES**

Date of Lecture:

Topic of Lecture: Voltage distribution in insulator string and string efficiency

Introduction :

- The voltage applied across the string of suspension insulators is not uniformly distributed across various units or discs. The disc nearest to the conductor has much higher potential than the other discs. Hence, an uniform potential distribution is essential across the entire string of insulators.

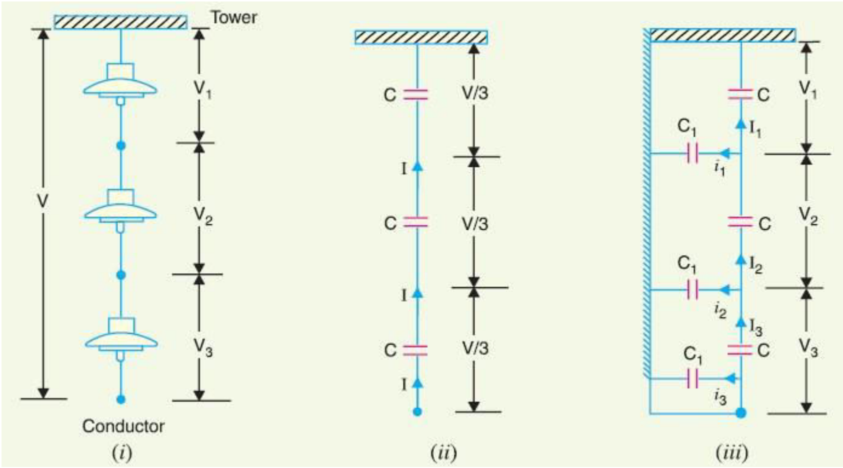
Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory

Detailed content of the Lecture:

Potential Distribution over Suspension Insulator String

A string of suspension insulators consists of a number of porcelain discs connected in series through metallic links. Fig. (i) shows 3-disc string of suspension insulators. The porcelain portion of each disc is inbetween two metal links. Therefore, each disc forms a capacitor C as shown in Fig. (ii). This is known as mutual capacitance or self-capacitance. If there were mutual capacitance alone, then charging current would have been the same through all the discs and consequently voltage across each unit would have been the same i.e., V/3 as shown in Fig. (ii). However, in actual practice, capacitance also exists between metal fitting of each disc and tower or earth. This is known as shunt capacitance C1. Due to shunt capacitance, charging current is not the same through all the discs of the string [See Fig. (iii)]. Therefore, voltage across each disc will be different. Obviously, the disc nearest to the line conductor will have the maximum* voltage. Thus referring to Fig.(iii), V3 will be much more than V2 or V1.



The following points may be noted regarding the potential distribution over a string of suspension insulators:

i.The voltage impressed on a string of suspension insulators does not distribute itself uniformly across the individual discs due to the presence of shunt capacitance.

ii.The disc nearest to the conductor has maximum voltage across it. As we move towards the cross-arm, the voltage across each disc goes on decreasing.

iii.The unit nearest to the conductor is under maximum electrical stress and is likely to be punctured. Therefore, means must be provided to equalise the potential across each unit.

iv.If the voltage impressed across the string were d.c., then voltage across each unit would be the same. It is because insulator capacitances are ineffective for dc.

String Efficiency

As stated above, the voltage applied across the string of suspension insulators is not uniformly distributed across various units or discs. The disc nearest to the conductor has much higher potential than the other discs. This unequal potential distribution is undesirable and is usually expressed in terms of string efficiency.

The ratio of voltage across the whole string to the product of number of discs and the voltage across the disc nearest to the conductor is known as string efficiency i.e.,String efficiency is an important consideration since it decides the potential distribution along the string. The greater the string efficiency, the more uniform is the voltage distribution. Thus 100% string efficiency is an ideal case for which the voltage across each disc will be exactly the same. Although it is impossible to achieve 100% string efficiency, yet efforts should be made to improve it as close to this value as possible.

Mathematical expression. Fig. 8.11 shows the equivalent circuit for a 3-disc string. Let us suppose that self capacitance of each disc is C. Let us further assume that shunt capacitance C_1 is some fraction K of self-capacitance *i.e.*, $C_1 = KC$. Starting from the cross-arm or tower, the voltage across each unit is V_1, V_2 and V_3 respectively as shown.

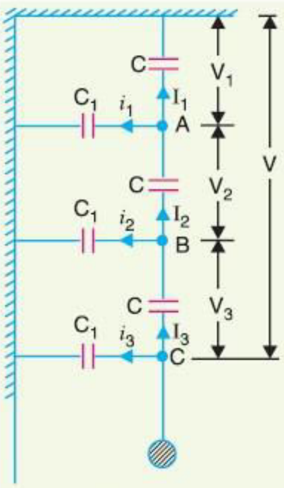


Fig. 8.11

Applying Kirchhoff's current law to node A, we get,

$$I_2 = I_1 + i_1$$

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

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

$\therefore$ $$V_2 = V_1 (1 + K) \quad ...(i)$$

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 $$V_3 = V_2 + (V_1 + V_2)K$$
$$= KV_1 + V_2 (1 + K)$$
$$= KV_1 + V_1 (1 + K)^2 \quad [\because V_2 = V_1 (1 + K)]$$
$$= V_1 [K + (1 + K)^2]$$

$\therefore$ $$V_3 = V_1 [1 + 3K + K^2] \quad ...(ii)$$

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

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

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

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

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

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

Voltage across second unit from top, $V_2 = V_1 (1 + K)$

Voltage across third unit from top, $V_3 = V_1 (1 + 3K + K^2)$

$$\%\text{age String efficiency} = \frac{\text{Voltage across string}}{n \times \text{Voltage across disc nearest to conductor}} \times 100$$
$$= \frac{V}{3 \times V_3} \times 100$$

The ratio of voltage across the whole string to the product of number of discs and the voltage across the disc nearest to the conductor is known as string efficiency

Video Content / Details of website for further learning (if any):

1. https://circuitglobe.com/string-efficiency-of-suspension-insulator.html
2. https://cpb-us-e1.wpmucdn.com/cobblearning.net/dist/7/4957/files/2020/03/Newsela.An-Intro-to-Insulators-and-Conductors.pdf

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 148)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 193 to 198)

Course Faculty

LECTURE HANDOUTS **L31**

DEPT: EEE **III / V**

Course Name with Code :19EEC12 & TRANSMISSION & DISTRIBUTION

Course Teacher : Mrs.M.Selvakumari

Unit : IV – INSULATORS AND CABLES

Date of Lecture:

Topic of Lecture: Insulator failures

Introduction :

- To ensure the desired performance of an electrical insulator that is for avoiding unwanted insulator failure each insulator has to undergo numbers of insulator test.
- Before going through testing of insulator we will try to understand different causes of insulator failure. Because insulator testing ensures the quality of electrical insulator and chances for failure of insulation depend upon the quality of insulator.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory

Detailed content of the Lecture:

Causes

There are different causes due to which failure of insulation in electrical power system may occur. Let's have a look on them one by one

Cracking Of Insulator

The porcelain insulator mainly consists of three different materials. The main porcelain body, steel fitting arrangement and cement to fix the steel part with porcelain. Due to changing climate conditions, these different materials in the insulator expand and contract in different rate. These unequal expansion and contraction of porcelain, steel and cement are the chief cause of cracking of insulator.

Defective Insulation

Material If the insulation material used for insulator is defective anywhere, the insulator may have a high chance of being puncher from that place.

Porosity In The Insulation Materials

If the porcelain insulator is manufactured at low temperatures, it will make it porous, and due to this reason it will absorb moisture from air thus its insulation will decrease and leakage current will start to flow through the insulator which will lead to insulator failure.

Improper Glazing on Insulator Surface

If the surface of porcelain insulator is not properly glazed, moisture can stick over it. This moisture along with deposited dust on the insulator surface, produces a conducting path. As a result the flash over distance of the insulator is reduced. As the flash over distance is reduced, the chance of failure of insulator due to flash over becomes more.

Flash Over Across Insulator

If flash over occurs, the insulator may be over heated which may ultimately results into shuttering of it.

Mechanical Stresses on Insulator

If an insulator has any weak portion due to manufacturing defect, it may break from that weak portion when mechanical stress is applied on it by its conductor. These are the main causes of insulator failure. Now we will discuss the different insulator test procedures to ensure minimum chance of failure of insulation.

Video Content / Details of website for further learning (if any):

1. https://www.electrical4u.com/electrical-insulator-testing-cause-of-insulator-failure/#:~:text=Mechanical%20Stresses%20on%20Insulator,main%20causes%20of%20insulator%20failure.
2. https://www.yourelectricalguide.com/2018/01/distributor-types-power-distribution-system.html

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 152)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 201 to 205)

Course Faculty

LECTURE HANDOUTS **L32**

DEPT: EEE **III / V**

Course Name with Code :**19EEC12 & TRANSMISSION & DISTRIBUTION**

Course Teacher : **Mrs.M.Selvakumari**

Unit : **IV – INSULATORS AND CABLES**

Date of Lecture:

Topic of Lecture : Testing of insulators

Introduction :

- To ensure the desired performance of an electrical insulator that is for avoiding unwanted insulator failure each insulator has to undergo numbers of insulator test.
- Before going through testing of insulator we will try to understand different causes of insulator failure. Because insulator testing ensures the quality of electrical insulator and chances for failure of insulation depend upon the quality of insulator.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

According to the British Standard, the electrical insulator must undergo the following tests

1. Flashover tests of insulator
2. Performance tests
3. Routine tests

FLASHOVER TEST

There are mainly three types of flashover test performed on an insulator and these are

Power Frequency Dry Flashover Test of Insulator First the insulator to be tested is mounted in the manner in which it would be used practically. Then terminals of variable power frequency voltage source are connected to the both electrodes of the insulator. Now the power frequency voltage is applied and gradually increased up to the specified value. This specified value is below the minimum flashover voltage. This voltage is maintained for one minute and observe that there should not be any flashover or puncher occurred. The insulator must be capable of sustaining the specified minimum voltage for one minute without flash over.

Power Frequency Wet Flashover Test or Rain Test of Insulator

In this test also the insulator to be tested is mounted in the manner in which it would be used practically. Then terminals of variable power frequency voltage source are connected to the both electrodes of the insulator. After that the insulator is sprayed with water at an angle of 45o in such a manner that its precipitation should not be more 5.08 mm per minute. The resistance of the water used for spraying must be between 9 kΩ 10 11 kΩ per cm3 at normal atmospheric pressure and temperature. In this way we create artificial raining condition. Now the power frequency voltage is applied and gradually increased up to the specified value. This voltage is maintained for either one minute or 30 second as specified and observe that there should not be any flash-over or puncher occurred. The insulator must be capable of sustaining the specified minimum power frequency voltage for specified period without flash over in the said wet condition.

Power Frequency Flashover Voltage test of Insulator

The insulator is kept in similar manner of previous test. In this test the applied voltage is gradually increased in similar to that of previous tests. But in that case the voltage when the surroundings air breaks down, is noted.

Impulse Frequency Flashover Voltage Test of Insulator

The overhead outdoor insulator must be capable of sustaining high voltage surges caused by lightning etc. So this must be tested against the high voltage surges. The insulator is kept in similar manner of previous test. Then several hundred thousands Hz very high impulse voltage generator is connected to the insulator. Such a voltage is applied to the insulator and the spark over voltage is noted. The ratio of this noted voltage to the voltage reading collected from power frequency flashover voltage test is known as impulse ratio of insulator.

PERFORMANCE TEST OF INSULATOR

Temperature Cycle Test of Insulator

The insulator is first heated in water at 70oC for one hour. Then this insulator immediately cooled in water at 7oC for another one hour. This cycle is repeated for three times. After completion of these three temperature cycles, the insulator is dried and the glazing of insulator is thoroughly observed. After this test there should not be any damaged or deterioration in the glaze of the insulator surface

Puncture Voltage Test of Insulator The insulator is first suspended in an insulating oil. Then voltage of 1.3

times of flash over voltage, is applied to the insulator. A good insulator should not puncture under this condition

Porosity Test of Insulator The insulator is first broken into pieces. Then These broken pieces of insulator are immersed in a 0.5 % alcohol solution of fuchsine dye under pressure of about 140.7 kg ⁄ cm2 for 24 hours. After that the sample are removed and examine. The presence of a slight porosity in the material is indicated by a deep penetration of the dye into it.

Mechanical Strength Test of Insulator The insulator is applied by 2½ times the maximum working strength for about one minute. The insulator must be capable of sustaining this much mechanical stress for one minute without any damage in it.

ROUTINE TEST OF INSULATOR

Proof Load Test of Insulator

In proof load test of insulator, a load of 20% in excess of specified maximum working load is applied for about one minute to each of the insulator.

Corrosion Test of Insulator The insulator with its galvanized or steel fittings is suspended into a copper sulfate solution for one minute. Then the insulator is removed from the solution and wiped, cleaned. Again it is suspended into the copper sulfate solution for one minute. The process is repeated for four times. Then it should be examined and there should not be any disposition of metal on it

Video Content / Details of website for further learning (if any):

1. https://www.allaboutcircuits.com/textbook/direct-current/chpt-10/mesh-current-method/
2. https://www.youtube.com/watch?v=k5Tlg27JDtc

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 155)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 206 to 209)

Course Faculty

LECTURE HANDOUTS **L33**

DEPT: EEE **III / V**

Course Name with Code :**19EEC12 & TRANSMISSION & DISTRIBUTION**

Course Teacher : **Mrs.M.Selvakumari**

Unit : **IV – INSULATORS AND CABLES**

Date of Lecture:

Topic of Lecture Types of cables

Introduction :

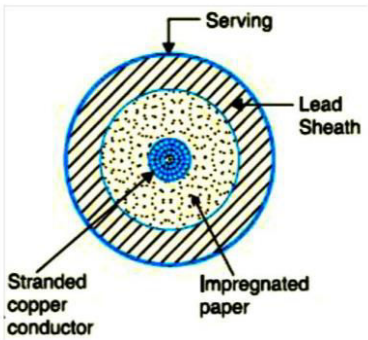
- An underground cable essentially consists of one or more conductors covered with suitable insulation and surrounded by a protecting cover. Although several types of cables are available, the type of cable to be used will depend upon the working voltage and service requirements.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

Cables for underground service may be classified in two ways according to (i) the type of insulating material used in their manufacture (ii) (ii) the voltage for which they are manufactured. However, the latter method of classification is generally preferred, according to which cables can be divided into the following groups:



Low-tension (L.T.) cables — upto 1000 V High-tension (H.T.) cables — upto 11,000 V Super-tension (S.T.) cables — from 22 kV to 33 kV Extra high-tension (E.H.T.) cables — from 33 kV to 66 kV 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

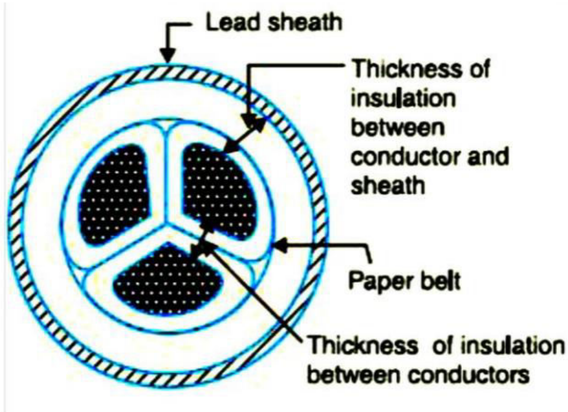
(iii) three-core

(iv) four-core etc. For a 3-phase service, either 3-single-core cables or three-core cable can be used depending upon the operating voltage and load demand. Fig. shows the constructional details of a singlecore low tension cable. The cable has ordinary construction because the stresses developed in the cable for low voltages (up to 6600 V) are generally small. It consists of one circular core of tinned stranded copper (or aluminium) insulated by layers of impregnated paper. The insulation is surrounded by a lead sheath which prevents the entry of moisture into the inner parts. In order to protect the lead sheath from corrosion, an overall serving of compounded fibrous material (jute etc.) is provided. Single-core cables are not usually armoured in order to avoid excessive sheath losses. The principal advantages of single-core cables are simple construction and availability of larger copper section.

For a 3-phase service, either 3-single-core cables or three-core cable can be used depending upon the operating voltage and load demand. Fig. shows the constructional details of a singlecore low tension cable. The cable has ordinary construction because the stresses developed in the cable for low voltages (up to 6600 V) are generally small. It consists of one circular core of tinned stranded copper (or aluminium) insulated by layers of impregnated paper. The insulation is surrounded by a lead sheath which prevents the entry of moisture into the inner parts. In order to protect the lead sheath from corrosion, an overall serving of compounded fibrous material (jute etc.) is provided. Single-core cables are not usually armoured in order to avoid excessive sheath losses. The principal advantages of single-core cables are simple construction and availability of larger copper section.

Cable For 3-Phase In practice, underground cables are generally required to deliver 3-phase power. For the purpose, either three-core cable or three single core cables may be used. For voltages upto 66 kV, 3-core cable (i.e., multi-core construction) is preferred due to economic reasons. However, for voltages beyond 66 kV, 3-core-cables become too large and unwieldy and, therefore, singlecore cables areused. The following types of cables are generally used for 3-phase service : 1. Belted cables — upto 11 kV 2. Screened cables — from 22 kV to 66 kV 3. Pressure cables — beyond 66 kV.

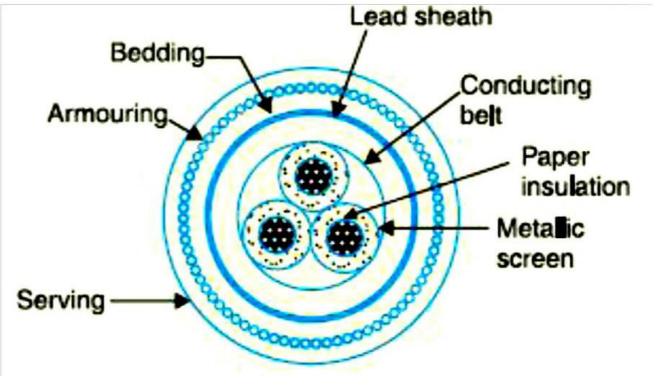
1. Belted Cables These cables are used for voltages upto 11kV but in extraordinary cases, their use may be extended upto 22kV. Fig.3 shows the constructional details of a 3-core belted cable. The cores are insulated from each other by layers of impregnated paper.

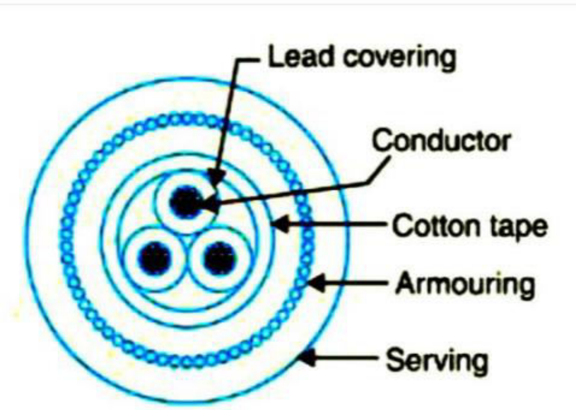


Another layer of impregnated paper tape, called paper belt is wound round the grouped insulated cores. The gap between the insulated cores is filled with fibrous insulating material (jute etc.) so as to give circular cross-section to the cable. The cores are generally stranded and may be of non circular shape to make better use of available space. The belt is covered with lead sheath to protect the cable against ingress of moisture and mechanical injury. The lead sheath is covered with one or more layers of armouring with an outer serving (not shown in the figure).The belted type construction is suitable only for low and medium voltages as the electro static stresses developed in the cables for these voltages are more or less radial i.e., across the insulation.

However, for high voltages (beyond 22 kV), the tangential stresses also become important. These stresses act along the layers of paper insulation. As the insulation resistance of paper is quite small along the layers, therefore, tangential stresses set up leakage current along the layers of paper insulation. The leakage current causes local heating, resulting in the risk of breakdown of insulation at any moment. In order to overcome this difficulty, screened cables are used where leakage currents are conducted to earth through metallic screens.

2.Screened Cables These cables are meant for use up to 33 kV, but in particular cases their use may be extended to operating voltages up to 66 kV. Two principal types of screened cables are H-type cables and S.L. type cables. (i)H-type Cables This type of cable was first designed by H. Hochstetler and hence the name. Fig. shows the constructional details of a typical 3-core, H-type cable. Each core is insulated by layers of impregnated paper. The insulation on each core is covered with a metallic screen which usually consists of a perforated aluminum foil. The cores are laid in such a way that metallic screens





Make contact with one another. An additional conducting belt (copper woven fabric tape) is Wrapped round the three cores. The cable has no insulating belt but lead sheath, bedding, armouring and serving follow as usual. It is easy to see that each core screen is in electrical contact with the conducting belt and the lead sheath. As all the four screens (3 core screens and one conducting belt) and the lead sheath are at earth potential, therefore, the electrical stresses are purely radial and consequently dielectric losses are reduced. Two principal advantages are claimed for H-type cables. Firstly, the perforations in the metallic screens assist in the complete impregnation of the cable with the compound and thus the possibility of air pockets or voids (vacuous spaces) in the dielectric is eliminated. The voids if present tend to reduce the breakdown strength of the cable and may cause considerable damage to the paper insulation. Secondly, the metallic screens increase the heat dissipating power of the cable

3. Pressure cables For voltages beyond 66 kV, solid type cables are unreliable because there is a danger of breakdown of insulation due to the presence of voids. When the operating voltages are greater than 66 kV, pressure cables are used. In such cables, voids are eliminated by increasing the pressure of compound and for this reason they are called pressure cables. Two types of pressure cables viz oil-filled cables and gas pressure cables are commonly used. (i)Oil-filled cables. In such types of cables, channels or ducts are provided in the cable for oil circulation. The oil under pressure (it is the same oil used for impregnation) is kept constantly supplied to the channel by means of external reservoirs placed at suitable distances (say 500 m) along the route of the cable. Oil under pressure compresses the layers of paper insulation and is forced in to any voids that may have formed between the layers. Due to the elimination of voids, oil-filled cables can be used for higher voltages, the range being from 66 kV up to 230 kV. Oilfilled cables are of three types viz., single-core conductor channel, single-core sheath channel and three-core fillerspace channels.

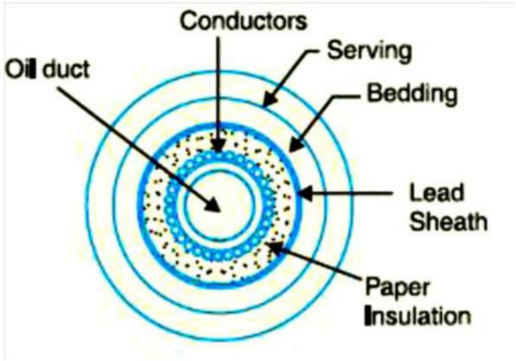


Fig. shows the constructional details of a single-core conductor channel, oil filled cable. The oil channel is formed at the center by stranding the conductor wire around a hollow cylindrical steel spiral tape. The oil under pressure is supplied to the channel by means of external reservoir. As the channel is made of spiral steel tape, it allows the oil to percolate between copper strands to the wrapped insulation. The oil pressure compresses the layers of paper insulation and prevents the possibility of void formation. The system is so designed that when the oil gets expanded due to increase in cable temperature, the extra oil collects in the reservoir. However, when the cable temperature falls during light load conditions, the oil from the reservoir flows to the channel. The disadvantage of this type of cable is that the channel is at the middle of the cable and is at full voltage w.r.t. earth, so that a very complicated system of joints is necessary. Fig. shows the constructional details of a single core sheath channel oil-filled cable. In this type of cable, the conductor is solid similar to that of solid cable and is paper insulated. However, oil ducts are provided in them etallic sheath as shown. In the 3-core oil-filler cable shown in Fig. the oil ducts are located in the filler spaces. These channels are composed of perforated metalribbon tubing and are at earth potential.

Video Content / Details of website for further learning (if any):

1. https://www.youtube.com/watch?v=MA5b3Mcl6OI
2. https://www.youtube.com/watch?v=kGee2B5Pmeg

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 161)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 210 to 214)

Course Faculty

MUTHAYAMMAL ENGINEERING COLLEGE
(An Autonomous Institution)
(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)
Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

LECTURE HANDOUTS **L34**

DEPT: EEE **III / V**

Course Name with Code :19EEC12 & TRANSMISSION & DISTRIBUTION

Course Teacher : Mrs.M.Selvakumari

Unit : IV – INSULATORS AND CABLES

Date of Lecture:

Topic of Lecture Capacitance of Single-core cable, Grading of cables

Introduction :

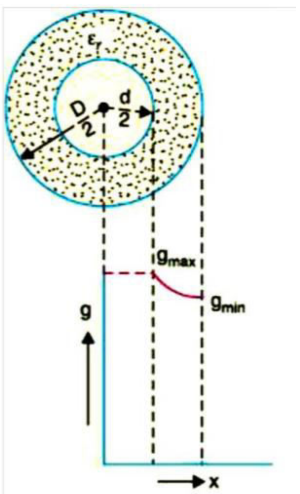
- Under operating conditions, the insulation of a cable is subjected to electrostatic forces. This is known as dielectric stress. The dielectric stress at any point in a cable is in fact the potential gradient (or electric intensity) at that point.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

Consider a single core cable with core diameter d and internal sheath diameter D. As proved in Art 8, the electric intensity at a point x metres from the centre of the cable is



$$E_x = \frac{Q}{2\pi \varepsilon_o \varepsilon_r x} \text{ volts/m}$$

By definition, electric intensity is equal to potential gradient. Therefore, potential gradient g at a point x meters from the Centre of cable is

$$g = E_x$$

or $$g = \frac{Q}{2\pi \varepsilon_o \varepsilon_r x} \text{ volts/m} \quad ...(i)$$

As proved, potential difference V between conductor and sheath is

$$V = \frac{Q}{2\pi \varepsilon_o \varepsilon_r} \log_e \frac{D}{d} \text{ volts}$$

or $$Q = \frac{2\pi \varepsilon_o \varepsilon_r V}{\log_e \frac{D}{d}} \quad ...(ii)$$

Substituting the value of Q from exp. (ii) in exp. (i), we get,

$$g = \frac{\frac{2\pi \varepsilon_o \varepsilon_r V}{\log_e D/d}}{2\pi \varepsilon_o \varepsilon_r x} = \frac{V}{x \log_e \frac{D}{d}} \text{ volts/m} \quad ...(iii)$$

It is clear from exp. (iii) that potential gradient varies inversely as the distance x. Therefore, potential gradient will be maximum when x is minimum i.e., when x = d/2 or at the surface of the conductor. On the other hand, potential gradient will be minimum at x = D/2 or at sheath surface. Maximum potential gradient is

$$g_{max} = \frac{2V}{d \log_e \frac{D}{d}} \text{ volts/m} \quad [\text{Putting } x = d/2 \text{ in exp. } (iii)]$$

Minimum potential gradient is

$$g_{min} = \frac{2V}{D \log_e \frac{D}{d}} \text{ volts/m} \quad [\text{Putting } x = D/2 \text{ in exp. } (iii)]$$

$$\therefore \quad \frac{g_{max}}{g_{min}} = \frac{\frac{2V}{d \log_e D/d}}{\frac{2V}{D \log_e D/d}} = \frac{D}{d}$$

The variation of stress in the dielectric is shown in Fig.14. It is clear that dielectric stress is maximum at the conductor surface and its value goes on decreasing as we move away from the conductor. It may be noted that maximum stress is an important consideration in the design of a cable. For instance, if a cable is to be operated at such a voltage that maximum stress is 5 kV/mm, then the insulation used must have a dielectric strength of at least 5 kV/mm, otherwise breakdown of the cable will become inevitable.

GRADING OF CABLES

The process of achieving uniform electrostatic stress in the dielectric of cables is known as grading of cables. It has already been shown that electrostatic stress in a single core cable has a maximum value (gmax) at the conductor surface and goes on decreasing as we move towards the sheath. The maximum voltage that can be safely applied to a cable depends upon gmax i.e., electrostatic stress at the conductor surface. For safe working of a cable having homogeneous dielectric, the strength of dielectric must be more than gmax .If a dielectric of high strength is used for a cable, it is useful only near the conductor where stress is maximum. But as we move away from the conductor, the electrostatic stress decreases, so the dielectric will be unnecessarily over strong. The unequal stress distribution in a cable is undesirable for two reasons. Firstly, insulation of greater thickness is required which increases the cable size. Secondly, it may lead to the break down of insulation. In order to overcome above disadvantages, it is necessary to have a uniform stress distribution in cables. This can be achieved by distributing the stress in such a way that its value is increased in the outer layers of dielectric. This is known as grading of cables. The following are the two main methods of grading of cables: (i) Capacitance grading (ii) Intersheath grading

Video Content / Details of website for further learning (if any):

1. https://www.youtube.com/watch?v=MA5b3Mcl6OI
2. https://www.youtube.com/watch?v=kGee2B5Pmeg

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 168)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 215 to 219)

Course Faculty

LECTURE HANDOUTS **L35**

DEPT: EEE **III / V**

Course Name with Code :**19EEC12 & TRANSMISSION & DISTRIBUTION**

Course Teacher : **Mrs.M.Selvakumari**

Unit : **IV – INSULATORS AND CABLES**

Date of Lecture:

Topic of Lecture : Power factor and heating of cables

Introduction

- The phase relationship between the ac-power-line voltage and current is related by a term called power factor. For a purely resistive load on the power line, voltage and current are in phase and the power factor is 1.0.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

When an ac motor is placed on the power line, the voltage-current phase difference increases and power factor decreases because of the motor's inductive load. When this occurs it reduces motor/transmission-line system efficiency and generates harmonics that can cause problems for other systems connected to the same power line.

Power-factor correction modifies the relationship between power-line voltage and current by making them closer to being in phase. This improves the power factor of the transmission line/motor as a system, and possibly reduces the harmonics and improves the system's efficiency.

BREAKING DOWN THE EXAMPLE ANALYSIS

For convenience, this analysis assumes the use of a 1-hp motor. Many applications using a low-horsepower electric motor will be fed by a #12-gauge cable and protected at the load center (main panel) by a 20-A circuit breaker. For this analysis, the average two-conductor cable lengths from the load center to an appliance containing an electric motor is assumed to be between 25 ft to 50 ft from the main panel to the appliance, for a total length of 50 ft to 100 ft. Also, we're assuming that motor-driven appliances in the home may have a 1/3- to 1-hp motor with an 85% efficiency and a lagging power factor of 0.75. The cost of electricity in the U.S. may be anywhere from $0.10/kW-h and higher. For this example, the present (May 2009) cost of electricity in the Annapolis, MD area ($0.118/kW-h) was used.

Power-factor analysis of the power delivered to a single-phase, 1-hp electric motor fed by a 120-V electric circuit requires a knowledge of motor and cable characteristics. The feed line is assumed to be a 50-ft-long, #12-gauge Romex Cable.

The first task is to determine the resistance of 100 feet of cable (resistance of both the hot and neutral wires). The resistance of #12-gauge wire is 1.588 Ω/1,000 feet, so:

Rcable = 1.588 Ω/1,000 ft × 100 feet = 0.1588 Ω

The electrical equivalent of an electric motor can be symbolized as an inductive reactance in series with a resistance. The inductive reactance is due to the stator inductance and reflected inductance of the rotor.

The resistance is caused by wire resistance (both stator and reflected resistance of the rotor) combined with losses due to hysteresis and eddy currents, mechanical resistances such as bearing losses, and windage.

Also, the mechanical load on the motor may be depicted as a resistance loss.

Heating in cable

The temperature rise of cable depends on the following factors:

1. The production of heat within the external periphery of the cable.
2. The conveyance of the heat as far as the periphery - that is, up to the boundary of the surrounding medium.
3. The conveyance of the heat through this medium, and therefore away from the cable.
4. The current rating of the cables.
5. The nature of the load, i.e. whether continuous or intermittent; not infrequently the rating under short-circuit conditions has to be considered.

Heat generation in cable

Following are the sources of heat generation in the cable

a) I^2R losses in the conductors

b) Dielectric losses in the cable insulation

c) Sheath and armour loss

a).I^2R losses in the conductors

Copper loss is the term often given to heat produced by electrical currents in the conductors, or other electrical devices. Copper losses are an undesirable transfer of energy, as are core losses, which result from induced currents in adjacent components. The term is applied regardless of whether the windings are made of copper or another conductor, such as aluminium.

Resistance of conductor at an temperature of 70 deg. C (assumed) is determined from the resistance given in standard table (usually at 20 deg,C) from the following relation-

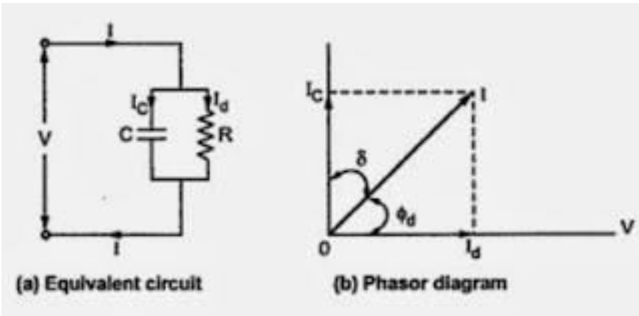
R_h = Ra(1+α (70-20))

Where R_h, R_a are the hot resistance, resistance at 20deg.C.

b).Dielectric losses in the cable insulation

The energy losses occurring in the dielectric of cables are due to leakage and so called dielectric hysteresis.

The charging current of cable I_c is assumed to have two components –



· One being true capacitance current which is equal to ωC V and leads the applied voltage by 90deg.

· The other being the energy component which in phase with the applied voltage and represents the dielectric loss components of current.

If V is the applied voltage, C is the capacitance, of cable, Φ is the phase angle between voltage and current called the power factor of the cable and δ is the loss angle of the dielectric,

Charging current, $I_c = V/X_c = \omega C V$

The dielectric loss, due to leakage and hysteresis effects in the dielectric, is usually expressed in terms of the loss angle,δ:

$\delta = 90 - \varphi$

Where, φ is the dielectric power factor angle.

Dielectric loss $= \omega C V^2 \tan\delta$,

Where,

C= capacitance to neutral

V= phase voltage

A typical value of tanδ lies in the range 0.002 to 0.003. In low voltage cables the dielectric loss is negligible, but is appreciable in EHV cables.

c).Sheath loss

In 3 core cable the effect is negligible but for single core cable the effect is of great importance. The electromagnetic fields produced by the current flowing through the conductors induce emfs in sheath and under certain condition heavy currents are set up therein. The actual current flowing along the sheath depends magnitude and frequency of the current in the conductor, the arrangement and spacing between the cables. Two different cables having sheath electrically connected are bounded or unbounded. The induced sheath currents are of two types-

i) The currents, which have both outward and inward directions, called the sheath eddies.

ii) The currents, which have outward and inward current path in separate sheath called the sheath circuit eddies.

The approximate formulae for eddy loss for unbounded cables given by Arnold is as under-

$$\text{Sheath loss} = I^2 \left[\frac{78\omega^2}{R_s}\left(\frac{r}{d}\right)^2 \times 10^{-9}\right] \text{ watts/phase}$$

Where,

I = current per conductor,

r = mean radius of sheath,

d=inter axial spacing of conductors

R_s = sheath resistance in ohm

Video Content / Details of website for further learning (if any):

1. https://www.electricaltechnology.org/2018/02/corona-effect-discharge-transmission-lines-power-system.html
2. https://www.youtube.com/watch?v=3X289DW33iU

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 171)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 221 to 225)

Course Faculty

Course Name with Code :19EEC12 & TRANSMISSION & DISTRIBUTION

Course Teacher : Mrs.M.Selvakumari

Unit : IV – INSULATORS AND CABLES

Date of Lecture:

Topic of Lecture : Capacitance of 3-core belted cable

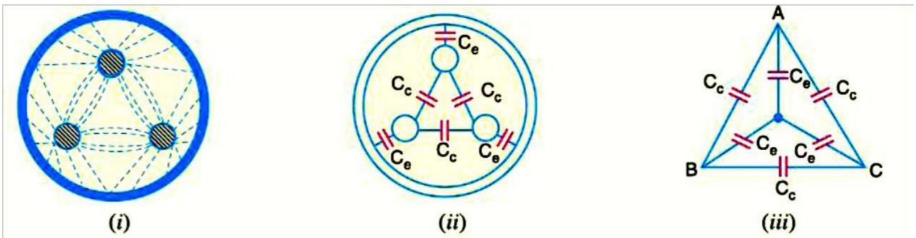
Introduction

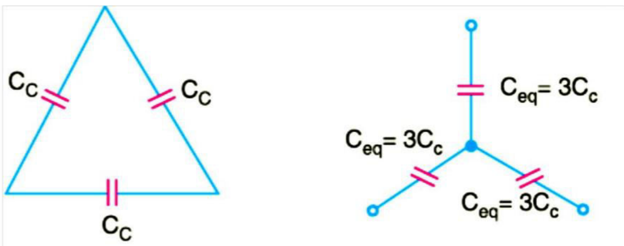
- The capacitance of a cable system is much more important than that of overhead line because in cables (i) conductors are nearer to each other and to the earthed sheath (ii) they are separated bya dielectric of permittivity much greater than that of air.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

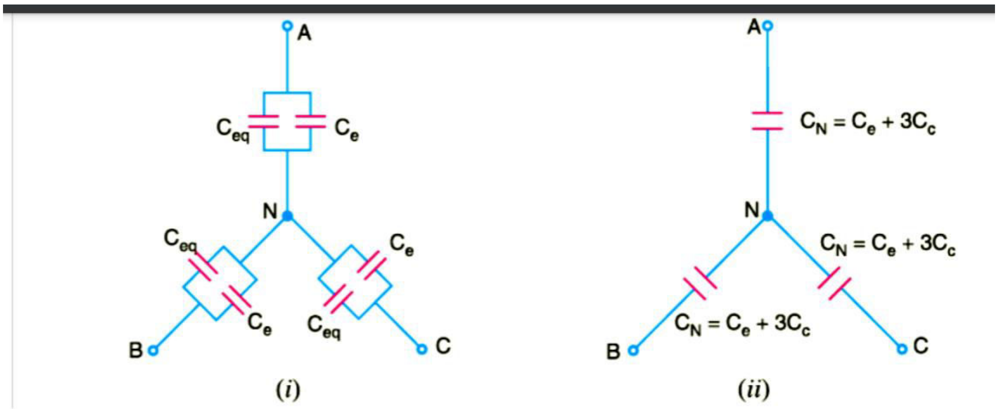
Detailed content of the Lecture:





A system of capacitances in a 3-core belted cable used for 3-phase system. Since potential difference exists between pairs of conductors and between each conductor and the sheath, electrostatic fields are set up in the cable as shown in Fig (i). These electrostatic fields give rise to core-core capacitances Cc and conductor-earth capacitances Ceas shown in Fig.(ii). The three Cc are delta connected whereas the three Ceare star connected, the sheath forming the star point

They lay of a belted cable makes it reasonable to assume equality of each Cc and each Ce. The three delta connected capacitances Cc (i)can be converted into equivalent star connected capacitances as shown in Fig. It can be easily *shown that equivalent star capacitance Ceqis equal to three times the delta capacitance Cc i.e. Ceq= 3Cc. The system of capacitances shown in Fig.(iii) reduces to the equivalent circuit shown in Fig. Therefore, the whole cable is equivalent to three star-connected capacitors each of capacitance



$$C_N = C_e + C_{eq}$$
$$= C_e + 3C_c$$

If V_{ph} is the phase voltage, then charging current I_C is given by ;

$$I_C = \frac{V_{ph}}{\text{Capacitive reactance per phase}}$$
$$= 2\pi f V_{ph} C_N$$
$$= 2\pi f V_{ph} (C_e + 3C_c)$$

Video Content / Details of website for further learning (if any):

1. https://www.electricaltechnology.org/2018/02/corona-effect-discharge-transmission-lines-power-system.html
2. https://www.youtube.com/watch?v=3X289DW33iU

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 175)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 235 to 236)

Course Faculty

LECTURE HANDOUTS **L37**

DEPT: EEE **III / V**

Course Name with Code :19EEC12 & TRANSMISSION & DISTRIBUTION

Course Teacher : Mrs.M.Selvakumari

Unit : V – MECHANICAL DESIGN OF LINES AND GROUNDING

Date of Lecture:

Topic of Lecture : Introduction to Mechanical design of overhead transmission lines.

Introduction :

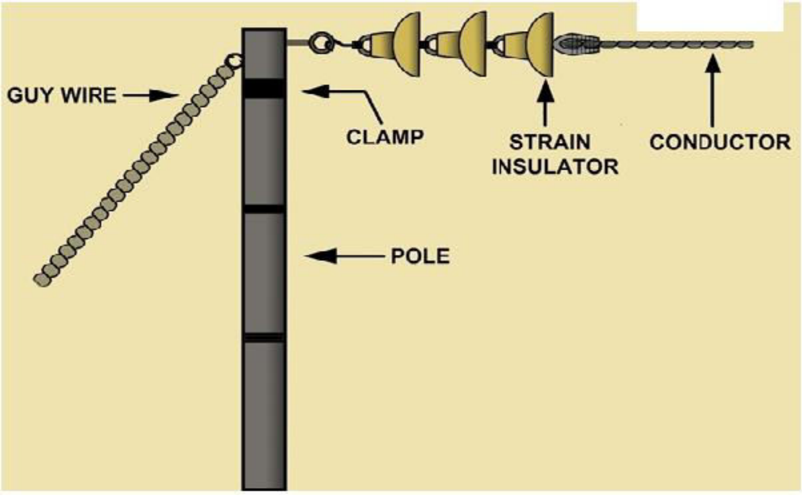
- A transmission and distribution system is so designed and constructed that it is efficient, technically sound and reliable system. The transmission lines are of two types: overhead and underground system.
- The line should have sufficient current carrying capacity so as to transmit the required power over a given distance without an excessive voltage drop and overheating.
- The line should have sufficient mechanical strength to cope with the worst probable weather conditions and provide satisfactory service over a long period of time without the necessity of too much maintenance.
- The basic consideration regarding the minimum spacing between conductors is that the electrical clearances between conductors under the worst condition i.e. maximum temperature and wind pressure shall not be less than the limits for safety, particularly at the mid spans.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

Accessories in an overhead line:



Desirable Characteristics:

i. Overhead transmission lines:

- Line should have sufficient current carrying capacity
- Less line losses
- Adequate insulation
- Line conductors, supports and cross arms must have sufficient mechanical strength to withstand worst whether condition.

ii. Line Conductors:

- High electrical conductivity
- High tensile strength
- Low cost

iii. Line Supports:

- High mechanical strength to withstand the weight of conductors and wind loads etc.
- Light in weight without the loss of mechanical strength.
- Cheap in cost and economical to maintain.
- Long life
- Easy availability

Types of towers:

A transmission tower is a tall structure used to support an overhead power line.

1.Wooden tower/pole

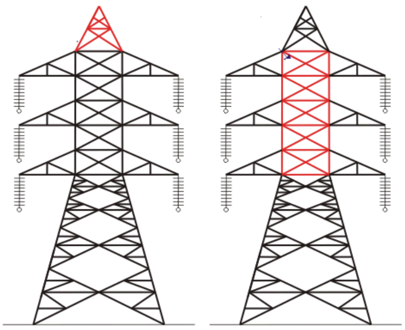
These are made of seasoned wood and are suitable for lines of the moderate X-sectional area and of relatively shorter spans, say upto 50 metres. Such supports are cheap, easily available, provide insulating properties and, therefore, are widely used for distribution purposes in rural areas.

2. RCC pole:

The reinforced concrete poles have become very popular as line supports in recent years. They have greater mechanical strength, longer life and permit longer spans than steel poles. Moreover, they give a good outlook, require little maintenance and have good insulating properties.

3.Steel pole:

The steel poles are often used as a substitute for wooden poles. They possess greater mechanical strength, longer life and permit longer spans to be used. Such poles are generally used for distribution purposes in the cities.



Steel pole

Video Content / Details of website for further learning (if any):

1. https://www.electrical4u.com/facts-on-facts-theory-and-applications/
2. https://www.youtube.com/watch?v=ed0TznCliYw

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 179)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 238 to 245)

Course Faculty

LECTURE HANDOUTS | **L38**

DEPT: EEE | **III / V**

Course Name with Code : **19EEC12 & TRANSMISSION & DISTRIBUTION**

Course Teacher : **Mrs.M.Selvakumari**

Unit : **V – MECHANICAL DESIGN OF LINES AND GROUNDING**

Date of Lecture:

Topic of Lecture : Testing of insulators

Introduction :

- While erecting an overhead line, it is very important that conductors are under safe tension.
- If the conductors are too much stretched between supports in a bid to save conductor material, the stress in the conductor may reach unsafe value and in certain cases the conductor may break due to excessive tension.
- In order to permit safe tension in the conductors, they are not fully stretched but are allowed to have a dip or sag.

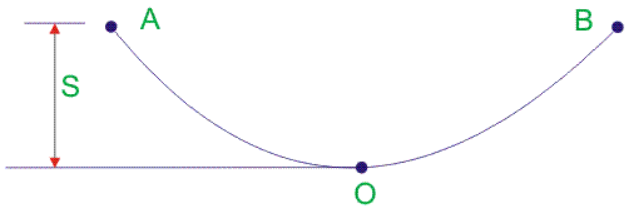
Prerequisite knowledge for Complete understanding and learning of Topic:

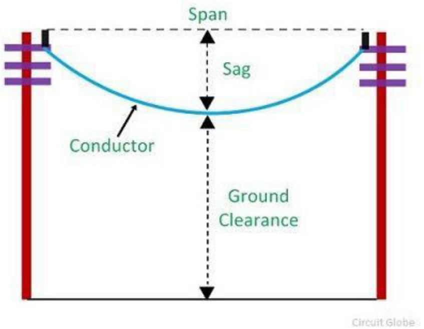
- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

Definition of sag:

The difference in level between points of supports and the lowest point on the conductor is called Sag.





Shape of Sag:

If the weight of a conductor is uniformly distributed along the **line**, then it is assumed that a freely suspended conductor shape is a parabola. The shape of sag increases with the increase in the length of the **span**.

Span:

The horizontal distance between two electrical supports is called the **span**.

Ground Clearance

The distance between the lowest point 'O' in the transmission line and the ground.

Factors affecting Sag:

- Conductor weight – **Sag** of the conductor is directly proportional to its weight. In locations where ice formation takes place on the conductor, this will increase the sag.
  Span – **Sag** is directly proportional to the square of the span length. ($S \alpha l^2$)
- Tension -The **sag** is inversely proportional to the tension in the conductor. S α 1/T
- **Tensile strength**-Sag inversely proportional to the tensile strength of the conductor provided the other parameters are constant.
- Temperature- All metallic bodies expand with rise in temperature and therefore length of the conductor increases with rise in temperature and so the sag. If the temperature is low, the conductor(being metallic) contracts and hence sag is less due to which the tension in the conductor is increased.
- Wind – It increases **sag** in the inclined direction.

Sag calculation is classified on two conditions:

a. When supports are at equal levels

b. When supports are not at equal levels

Note:

- When same leveled two supports hold the conductor, bend shape arises in the conductor. Sag is very small with respect to the span of the conductor. Sag span curve is like parabola.
- Factor of Safety = S_f = Breaking Stress/Working stress

oR

S_f = Ultimate strength/ Allowable working tension

When Supports are at equal levels:

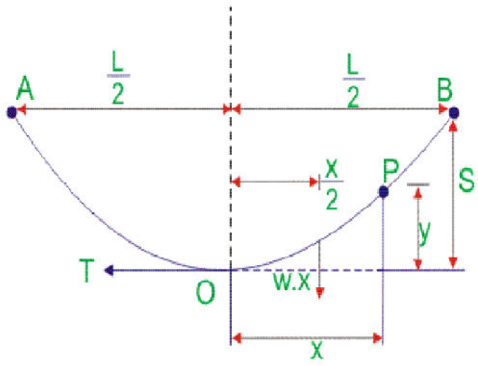
- Let us consider a line conductor between two equal height line supports.
- Line supports are A and B with O as the lowest point as shown in the figure.
- Point O will be the lowest point as two levels are equal lowest point will be at the mid-span.

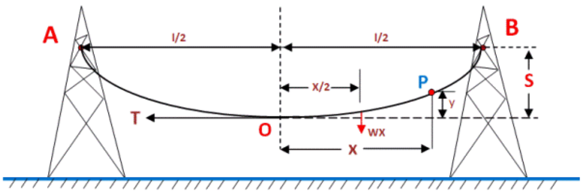
Let

l = Length of span

w = Weight per unit length of conductor

T = Tension in the conductor.





- Now consider any point on the conductor. Let's say point 'P'. By considering lowest point O as the origin, let the coordinates of point P be x and y.
- Assuming that the curvature is so small that curved length is equal to its horizontal projection (i.e., OP = x), the two forces acting on the portion OP of the conductor are :

(i) The weight wx of conductor acting at a distance x/2 from O.

(ii) The tension T acting at O.

Equating the moments of above two forces about point O, (i.e. upforce = downforce) we get,

$T\ y = w.x * x/2$ (since, Moment of inertia, M= Force x distance)

or

$y=wx^2/2T$

The maximum dip (sag) is represented by the value of y at either of the supports A and B.

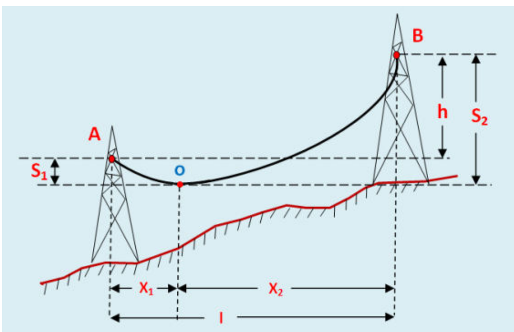
At support A, $x = l/2$ and $y = S$

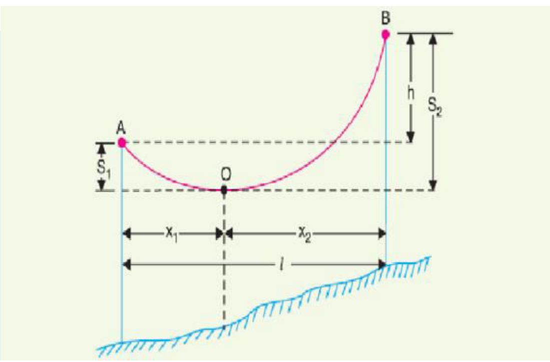
Sag, $S=w(l/2)^2/2T$

$S=wl^2/8T$

When Supports are at unequal levels:

- When transmission lines run on steep inclines as in the case of hilly areas, we generally come across conductors suspended between supports at unequal levels. The shape of the conductor between the supports may be assumed to be a part of the parabola. In this case, the lowest point of the conductor will not lie in the middle of the span.
- Consider a conductor suspended between two supports A and B which are at different levels as shown in the following figure.





Let

l = Span length

h = Difference in levels between two supports

x1 = Distance of support at the lower level (i.e., A) from O

x2 = Distance of support at the higher level (i.e. B) from O

T = Tension in the conductor.

If w is the weight per unit length of the conductor, then,

Sag $S_1 = wx_1^2/2T$

and Sag $S_2 = wx_2^2/2T$

Also $X_1 + X_2 = l$ ....(i)

Now $S_2 - S_1 = \frac{w}{2T}[x_2^2 - x_1^2] = \frac{w}{2T}(x_2 + x_1)(x_2 - x_1)$

$\therefore$ $S_2 - S_1 = \frac{w\,l}{2T}(x_2 - x_1)$ $[\because x_1 + x_2 = l]$

But $S_2 - S_1 = h$

$\therefore$ $h = \frac{w\,l}{2T}(x_2 - x_1)$

or $x_2 - x_1 = \frac{2\,Th}{w\,l}$ ...(ii)

Solving exps. (i) and (ii), we get,

$$x_1 = \frac{l}{2} - \frac{T\,h}{w\,l}$$

$$x_2 = \frac{l}{2} + \frac{T\,h}{w\,l}$$

If image is not clear on mobile device please download first and view

$$X_1 = l/2 - Th/wl$$

$$X_2 = l/2 + Th/wl$$

Having found X_1 and X_2, values of S_1 and S_2 can be easily calculated.

Video Content / Details of website for further learning (if any):

1. https://www.electrical4u.com/facts-on-facts-theory-and-applications/
2. https://www.youtube.com/watch?v=ed0TznCliYw

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 182)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 245 to 248)

Course Faculty

LECTURE HANDOUTS **L39**

DEPT: EEE **III / V**

Course Name with Code : **19EEC12 & TRANSMISSION & DISTRIBUTION**

Course Teacher : **Mrs.M.Selvakumari**

Unit : **V – MECHANICAL DESIGN OF LINES AND GROUNDING**

Date of Lecture:

Topic of Lecture : Sag and tension calculation for different weather condition.

Introduction :

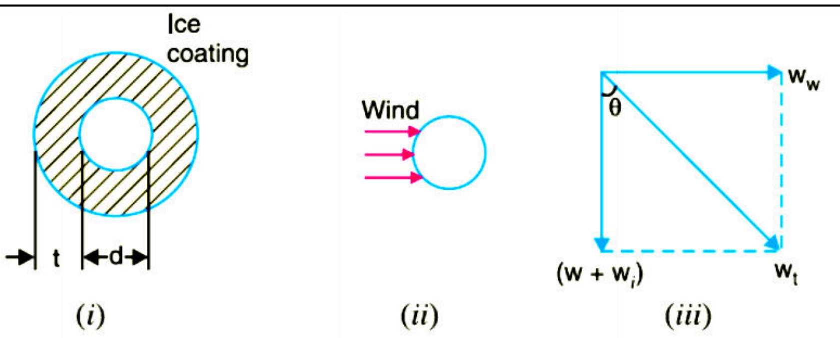
- The transportation of electricity from the point of generation to the consumer premises is termed as a power system. Power system comprises of three entities, power generation, transmission and distribution. Among these entities, the inefficiency in transmission part contributed to most of the losses. These losses depend on the resistance, inductance and capacitance, which are termed as the constants of a transmission line.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

Sag are true only in still air and at normal temperature when the conductor is acted by its weight only. However, in actual practice, a conductor may have ice coating and simultaneously subjected to wind pressure. The weight of ice acts vertically downwards i.e. , in the same direction as the weight of conductor. The force due to the wind is assumed to act horizontally i.e ., at right angle to the projected surface of the conductor. Hence, the total force on the conductor is the vector sum of horizontal and vertical forces as shown in



Total weight of conductor per unit length is

$$w_t = \sqrt{(w+w_i)^2 + (w_w)^2}$$

Where w = weight of conductor per unit length
= conductor material density · volume per unit length
Wi = weight of ice per unit length
= density of ice * volume of ice per unit length

$$= \text{density of ice} \times \frac{\pi}{4}[(d+2t)^2 - d^2] \times 1$$
$$= \text{density of ice} \times \pi\, t\,(d+t)^*$$

w_w = wind force per unit length
= wind pressure per unit area projected area per unit length

When the conductor has wind and ice loading also, the following points may be noted :
i)The conductor sets itself in a plane at an angle to the vertical where

$$\tan\theta = \frac{w_w}{w + w_i}$$

ii)The sag in the conductor is given by

$$\tan\theta = \frac{w_w}{w + w_i}$$

Hence S represents the slant sag in a direction making an angle to the vertical. If no specific mention is made in the problem, then slant slag is calculated by using the above formula.

iii)The vertical sag = $S\cos\theta$

Video Content / Details of website for further learning (if any):

1. https://www.electrical4u.com/facts-on-facts-theory-and-applications/
2. https://www.youtube.com/watch?v=ed0TznCliYw

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 184)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 249 to 252)

Course Faculty

LECTURE HANDOUTS **L40**

DEPT: EEE **III / V**

Course Name with Code : **19EEC12 & TRANSMISSION & DISTRIBUTION**

Course Teacher : **Mrs.M.Selvakumari**

Unit : **V – MECHANICAL DESIGN OF LINES AND GROUNDING**

Date of Lecture:

Topic of Lecture : Example Problems on sag tension calculations .

Introduction :

- This is an example calculation for sag and tension in transmission line. You may opt to review first the fundamental principles and formulas from the last lecture. Creep is not considered as a factor in final sag in this calculation. Also, loading of the conductors are based on the National Electrical Safety Code 2017.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

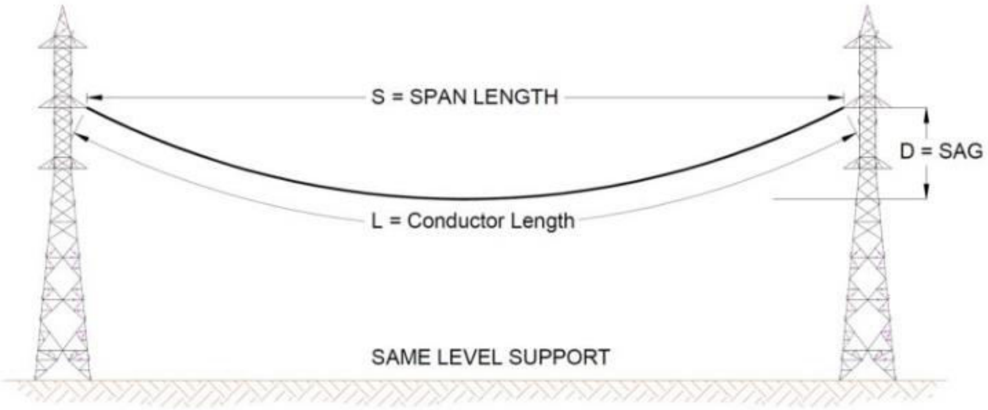
Detailed content of the Lecture:

Problem:

A transmission line conductor was strung between two towers, 300 meters apart and same elevation. During the time of installation, the conditions were t =15°C and initial horizontal tension = 25% of Rated Tensile Strength (RTS).

Calculate the sag and tension at:

1. No load conditions (no wind/ice load)
2. Heavy loading district: Ice thickness = 12.5 mm, Wind load = 190 Pa, t = -20 °C



Conductor Name	403-A1-37	
Conductor Common Name	403 mm^2 37 AAC (Arbutus)	
Span Length	300	m
Outside Diameter	26.1	mm
Conductor Unit Weight	10.89	N/m
Rated Tensile Strength	81.8	kN
Modulus of Elasticity	58.9	GPa
Coefficient of Thermal Expansion	23 x 10^{-6}	/°C
Total Conductor Area	402.9	mm^2

1. No load conditions (no wind/ice load)

$t_1 = 15°C$
$H_1 = 25\%\ RTS = 58,900 * 0.25 = 15{,}450\ N$
$A = 0.0004029\ m^2$
$S = 300\ m$
$W_1 = 10.89\ N/m$
$E = 58.9 \times 10^9\ Pa$

Total conductor length:

$$L_1 = S\left(1 + \frac{S^2 W_1^2}{24 H_1^2}\right) = 300\left(1 + \frac{300^2 * 10.89^2}{24 * 15,450^2}\right) = 300.56\ meters$$

Initial Sag:

$$D = \frac{H_1}{W_1}\left(\cosh\left(\frac{S}{2H_1/W_1}\right) - 1\right) = \frac{W_1 S^2}{8H_1} = \frac{10.89 * 300^2}{8 * 15,450} = 7.93\ \ meters$$

2. Heavy loading district: Ice thickness = 12.5 mm, Wind load = 190 Pa, t = -20 °C

a. Calculate ice load (Assume ice density is 915 kg/m^3)

$$W_{ice} = \rho_{ice} * \pi t_{ice}(D + t_{ice}) = 915 * \pi * 0.0125\,(0.0261 + 0.0125)$$

$$W_{ice} = 1.386\,kg/m \text{ or } 13.6\,N/m$$

b. Calculate wind load

$$Total\ Diameter = D + 2t_{ice} = 0.0261 + 2 * 0.0125 = 0.0511\,m$$

$$W_{wind} = Wind\ pressure * Conductor\ diameter(including\ ice)$$

$$W_{wind} = 190 * 0.0511 = 9.71\,N/m$$

c. Total unit weight

$$W_{total} = \sqrt{W_{wind}^2 + (W_1 + W_{ice})^2} = \sqrt{9.71^2 + (10.89 + 13.6)^2}$$

$$W_{total} = 26.34\,N/m$$

d. Final Conductor tension, H_2

Initial Condition	Final Condition
t_1 = 15°C H_1 = = 15,450 N A = 0.0004029 m^2 S = 300 m W_1 = 10.89 N/m E = 58.9 x 10^9 Pa α =23 x 10^{-6} /°C	t_2 = -20°C H_2 = _______N ? A = 0.0004029 m^2 S = 300 m W_2 = 26.34 N/m E = 58.9 x 10^9 Pa

From the conductor state change equation:

$$H_2^3 + H_2^2\left(\frac{(W_1S)^2AE}{24H_1^2} - H_1 + (t_2 - t_1)\alpha AE\right) - \frac{(W_2S)^2AE}{24} = 0$$

$$H_2^3 + H_2^2\left(\frac{(10.89*300)^2 0.0004029*58.9*10^9}{24*15,450^2} - 15,450 + (-20-15)*23*10^{-6}*58.9*10^9\right) - \frac{24.36*300)^2*0.0004029*58.9*10^9}{24} = 0$$

Simplification to cubic equation:

$$H_2^3 + 9658.95\,H_2^2 - 6.174x\,10^{13} = 0$$

By trial and error method or goalseek in excel or modern pocket calculator:

H_2 = 36,552 Newtons (45% of RTS)

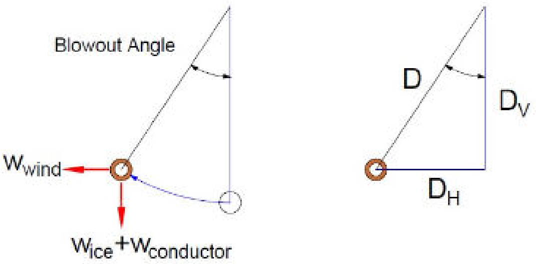
e. Calculate final sag and blowout angle

$$\theta = \tan^{-1}\left(\frac{W_{wind}}{W_{ice} + W}\right) = \tan^{-1}\left(\frac{9.71}{13.6 + 10.89}\right) = 21.63^{\circ}$$

$$D_{slant} = \frac{W_2 S_2^2}{8H_2} = \frac{26.34*300^2}{8*36,552} = 8.11\,meters$$

$$D_{vertical} = D\cos\theta = 8.11\cos 21.63 = 7.54\,meters$$

$$D_{horizontal} = D\sin\theta = 8.11\sin 21.63 = 2.99\,meters$$



TOTAL EFFECT OF ICE AND WIND

Video Content / Details of website for further learning (if any):

1. https://electricalengineerresources.com/2018/01/13/sample-calculation-of-sag-and-tension-of-transmissionline/#:~:text=A%20transmission%20line%20conductor%20was,(no%20wind%2Fice%20load)

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 188)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 255 to 258)

Course Faculty

Course Name with Code :19EEC12 & TRANSMISSION & DISTRIBUTION

Course Teacher : Mrs.M.Selvakumari

Unit : V – MECHANICAL DESIGN OF LINES AND GROUNDING

Date of Lecture:

Topic of Lecture : Tower spotting

Introduction :

- The efficient location of structures on the profile is an important component of line design. Structures of appropriate height and strength must be located to provide adequate conductor ground clearance and minimum cost. In the past, most tower spotting has been done manually, using templates, but several computer programs have been available for a number of years for the same purpose.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

Manual Tower Spotting

A celluloid template, shaped to the form of the suspended conductor, is used to scale the distance from the conductor to the ground and to adjust structure locations and heights to (1) provide proper clearance to the ground; (2) equalize spans; and (3) grade the line.

The template is cut as a parabola on the maximum sag (usually at 49#C) of the ruling span and should be extended by computing the sag as proportional to the square of the span for spans both shorter and longer than the ruling span. By extending the template to a span of several thousand feet, clearances may be scaled on steep hillsides.

The form of the template is based on the fact that, at the time when the conductor is erected, the horizontal tensions must be equal in all spans of every length, both level and inclined, if the insulators hang plumb. This is still very nearly true at the maximum temperature.

The template, therefore, must be cut to a catenary or, approximately, a parabola. The parabola is accurate to within about one-half of 1% for sags up to 5% of the span, which is well within the necessary refinement.

Since vertical ground clearances are being established, the 49#C no-wind curve is used in the template. Special conditions may call for clearance checks. For example, if it is known that a line will have high temperature rise because of load current, conductor clearance should be checked for the estimated maximum conductor temperature.

One crossing over a navigable stream was designed for 88#C at high water. Ice and wet snow many times cause weights several times that of the 1/2-in radial ice loading, and conductors have been known to sag to within reach of the ground.

Such occurrences are not normally considered in line design, and when they occur, the line is taken out of service until the ice or snow drops. Checks made afterward have nearly always shown no permanent deformation.

All the Railway crossings coming enroute the transmission line have already been identified by the HVPN. At the time of detailed survey, the Railway crossings shall be finalized as per the regulation laid down by the Railway Authorities. The following are the important features of the prevailing regulations (revised in 1987):

i) The crossing shall be supported on DD/D type tension towers only (as the case may be) on either side and Double tension insulator string shall be used on both the towers on the side of the crossing.

ii) The crossing shall normally be at right angle to the Railway track.

iii) The minimum distance of the crossing tower shall be at least equal to the height of the tower plus 6 metres away measured from the center of the nearest Railway track.

iv) No crossing shall be located over a booster transformer, traction switching station, traction sub-station or a track cabin location in an electrified area.

v) Minimum ground clearance above Rail level of the lowest portion of any conductor under condition of maximum sag shall be maintained as per latest Railway regulations amended from time to time.

vi) The approval for crossing Railway track shall be obtained by the HVPN from the Railway Authorities, however six copies of profile and plan, tower and foundation design and drawings, required for the approval from the Railway Authorities shall be supplied by the contractor to the HVPN.

e) ROAD CROSSING

At all important road crossings, the towers shall be fitted with normal suspension or tension insulator strings depending on type of tower, but the ground clearance at the highest point of the roads under maximum temperature and still air shall be such that even with the conductor broken in adjacent span, ground clearance of the conductor from the road surfaces will not be less than 6.100 meters . At all National Highways, tension towers with double insulator strings on crossing side shall be used.

f) RIVER CROSSING

In case of major river crossing, towers shall be of suspension type and the anchor towers on either side of the main river crossing shall be 'DD/D' type tower. For navigable river, clearance required by navigation authority shall be provided. For non-navigable river, clearance shall be reckoned with respect to highest flood level (HFL).

g) POWER LINE CROSSINGS

Where the line is to cross over another line of the same voltage or lower voltage, towers with suitable extensions shall be used. Where the line is to cross under the power lines, gantries shall be used. Provisions to prevent the possibility of its coming into the contact with other overhead lines shall be made in accordance with Indian Electricity Rules,1956. In order to reduce the height of the crossing towers, it may be advantageous to remove the ground wire of the line to be crossed (if this is possible and permitted by the owner of the line to be crossed).All the works related to the above proposal shall be deemed to be included in the scope of the contractor except if modifications are required to line below, in which case, the conditions to be agreed upon. Suitable Extension for towers over 11kV line crossing shall be used, where requisite electrical as per I.E. rules is not available.

h) TELECOMMUNICATION LINE CROSSING

The angle of crossing shall be as near to 90o as possible. However, deviation to the extent of 30o may be permitted under exceptionally difficult situations. When the angle of crossing has to be below 60o, the matter will be referred to the authority incharge of the telecommunication system. On a request from the contractor, the permission of the telecommunication authority may be obtained by the HVPN. Also, in the crossing span, power line support will be as near the telecommunication line as possible, to obtain increased vertical clearance between the wires.

i) DETAILS ENROUTE

All topographical details, permanent features, such as trees, building etc. 13.5 m on either side of the alignment for 132kV line shall be detailed on the profile plan.

Video Content / Details of website for further learning (if any):

1. http://www.transmission-line.net/2011/06/tower-spotting-of-transmission-lines.html
2. https://www.youtube.com/watch?v=ed0TznCliYw

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 191)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 260 to 264)

Course Faculty

Course Name with Code : **19EEC12 & TRANSMISSION & DISTRIBUTION**

Course Teacher : **Mrs.M.Selvakumari**

Unit : **V – MECHANICAL DESIGN OF LINES AND GROUNDING**

Date of Lecture:

Topic of Lecture : Types of towers

Introduction :

- Transmission towers have to carry the heavy transmission conductors at a sufficient safe height from the ground. In addition to that, all towers have to sustain all kinds of natural calamities. So transmission tower design is an important engineering job where civil, mechanical, and electrical engineering concepts are equally applicable.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

Types of Electrical Transmission Towers

According to different considerations, there are different types of transmission towers. The transmission line goes as per available corridors. Due to the unavailability of the shortest distance straight corridor transmission line has to deviate from its straightway when obstruction comes. In the total length of a long transmission line, there may be several deviation points. According to the angle of deviation, there are four types of transmission tower–

1. A – type tower – angle of deviation 0^o to 2^o.
2. B – type tower – angle of deviation 2^o to 15^o.
3. C – type tower – angle of deviation 15^o to 30^o.
4. D – type tower – angle of deviation 30^o to 60^o.

As per the force applied by the conductor on the cross arms, the transmission towers can be categorized in another way-

1. Tangent suspension tower and it is generally A – type tower.
2. Angle tower or tension tower or sometime it is called section tower. All B, C and D types of transmission towers come under this category.

Apart from the above-customized type of tower, the tower is designed to meet special usages listed below:

These are called special type tower

1. River crossing tower
2. Railway/ Highway crossing tower
3. Transposition tower

Based on numbers of circuits carried by a transmission tower, it can be classisfied as-

1. Single circuit tower
2. Double circuit tower
3. Multi circuit tower.

A) FOR KRR Design D/C Towers:-

Type of Tower	Deviation limit	Typical use
DA	0 deg.-2 deg.	To be used as tangent tower.
DB	2 deg.-15 deg.	a) Tension towers with tension insulators string. b) Tension towers for uplift forces resulting from an uplift span upto 200 m. c) Also to be designed for anti-cascading condition.
	0 deg.	d) To be used as Section Tower
DC	15 deg.-30 deg.	a) Tension towers with tension insulators string. b) Tension towers for uplift forces resulting from an uplift span upto 200 m. c) Also to be designed for anti-cascading condition.
DD	30 deg.-60 deg.	a) Tension towers with tension insulators string. b) Tension towers for uplift forces resulting from an uplift span upto 200 m. c) Dead end with 0 deg. to 15 deg. deviation both on line and substation side (slack span).
	55 deg	d) When DD type tower used with **+12m to +25m** Extension by restricting the span to **250m.** e) For river crossing anchoring with longer wind span with 0 deg. deviation on crossing span side and 0 to 30 deg. deviation on other side.

B) For New 132kV S/C towers of 0.4sq" (to be designed by the Bidder):-

Type of Tower	Deviation limit	Typical use
A	0 deg.-2 deg.	To be used as tangent tower upto 2 deg. deviation
B	0 deg.-15 deg.	a) To be used for line Angle deviation from 0 to 15 Deg. b) Tension towers for uplift forces resulting from an uplift span upto 200 m. c) Also to be designed for anti-cascading condition.
	0 deg.	d) Section tower.
C	15 deg.-30 deg.	a) To be used for line Angle deviation from 15 to 30 Deg. b) Tension towers for uplift forces resulting from an uplift span upto 200 m. c) Also to be designed for anti-cascading condition.
D	30 deg.-60 deg.	a) To be used for line Angle deviation from 30 deg. to 60 Deg. b) Tension towers for uplift forces resulting from an uplift span upto 200 m. c) Complete Dead end with 0 deg. to 15 deg. deviation both on line and gantry side (slack span).
	0 deg.	d) For river crossing anchoring anchoring with longer wind span with 0 deg. deviation on crossing span side and 0 to 30 deg. deviation on other side.

Video Content / Details of website for further learning (if any):

1. https://www.electrical4u.com/electrical-transmission-tower-types-and-design/
2. https://www.youtube.com/watch?v=ed0TznCliYw

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 201)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 265 to 269)

Course Faculty

LECTURE HANDOUTS **L43**

DEPT: EEE **III / V**

Course Name with Code : **19EEC12 & TRANSMISSION & DISTRIBUTION**

Course Teacher : **Mrs.M.Selvakumari**

Unit : **V – MECHANICAL DESIGN OF LINES AND GROUNDING**

Date of Lecture:

Topic of Lecture : Introduction to Substation

Introduction :

- The assembly of apparatus used to change some characteristic (e.g. voltage, a.c. to d.c., frequency, p.f. etc.) of electric supply is called a sub-station. Sub-stations are important part of power system. The continuity of supply depends to a considerable extent upon the successful operation of sub-stations. It is, therefore, essential to exercise utmost care while designing and building a sub-station.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

The following are the important points which must be kept in view while laying out a sub-station :

(i) It should be located at a proper site. As far as possible, it should be located at the centre of gravity of load.
(ii) It should provide safe and reliable arrangement. For safety, consideration must be given to the maintenance of regulation clearances, facilities for carrying out repairs and maintenance, abnormal occurrences such as possibility of explosion or fire etc. For reliability, consideration must be given for good design and construction, the provision of suitable protective gear etc.
(iii) It should be easily operated and maintained.
(iv) It should involve minimum capital cost.

Classification of Sub-Stations

There are several ways of classifying sub-stations. However, the two most important ways of classifying them are according to (1) service requirement and (2) constructional features.

1.According to service requirement

A sub-station may be called upon to change voltage level or improve power factor or convert a.c. power into d.c. power etc. According to the service requirement, sub-stations may be classified into :

i)Transformer sub-stations.

Those sub-stations which change the voltage level of electric supply are called transformer sub-stations. These sub-stations receive power at some voltage and deliver it at some other voltage. Obviously, transformer will be the main component in such sub- stations. Most of the sub-stations in the power system are of this type.

(ii) Switching sub-stations

These sub-stations do not change the voltage level i.e. incoming and outgoing lines have the same voltage. However, they simply perform the switching operations of power lines.

(iii) Power factor correction sub-stations.

Those sub-stations which improve the power factor of the system are called power factor correction sub-stations. Such sub-stations are generally located at the receiving end of transmission lines. These sub-stations generally use synchronous condensers as the power factor improvement equipment.

(iv) Frequency changer sub-stations

Those sub-stations which change the supply frequency are known as frequency changer sub-stations. Such a frequency change may be required for industrial utilisation.

(v) Converting sub-stations

Those sub-stations which change a.c. power into d.c. power are called converting sub-stations. These sub-stations receive a.c. power and convert it into d.c power with suitable apparatus to supply for such purposes as traction, electroplating, electric welding etc.

(vi) Industrial sub-stations

Those sub-stations which supply power to individual industrial concerns are known as industrial sub-stations.

2. According to constructional features

A sub-station has many components (e.g. circuit breakers, switches, fuses, instruments etc.) which must be housed properly to ensure continuous and reliable service. According to constructional features, the sub-stations are classified as :

(i) Indoor sub-station

(ii Outdoor sub-station

(iii) Underground sub-station

(iv) Pole-mounted sub-station

(i) Indoor sub-stations

For voltages upto 11 kV, the equipment of the sub-station is installed indoor because of economic considerations. However, when the atmosphere is contaminated with impurities, these sub-stations can be erected for voltages upto 66 kV.

(ii) Outdoor sub-stations

For voltages beyond 66 kV, equipment is invariably installed out- door. It is because for such voltages, the clearances between conductors and the space required for switches, circuit breakers and other equipment becomes so great that it is not economical to install the equipment indoor.

(iii) Underground sub-stations

In thickly populated areas, the space available for equipment and building is limited and the cost of land is high. Under such situations, the sub-station is created underground.

(iv) Pole-mounted sub-stations

This is an outdoor sub-station with equipment installed over- head on H-pole or 4-pole structure. It is the cheapest form of sub-station for voltages not exceeding 11kV (or 33 kV in some cases). Electric power is almost distributed in localities through such sub- stations. For complete discussion on pole-mounted sub-station,

Video Content / Details of website for further learning (if any):

1. https://electrical-engineering-portal.com/electrical-substation-introduction-and-elements
2. https://automationforum.co/introduction-to-electrical-substation

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 205)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 271 to 275)

Course Faculty

MUTHAYAMMAL ENGINEERING COLLEGE

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(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)
Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

Estd. 2000

LECTURE HANDOUTS **L44**

DEPT: EEE **III / V**

Course Name with Code	**: 19EEC12 & TRANSMISSION & DISTRIBUTION**
Course Teacher	**: Mrs.M.Selvakumari**
Unit	**: V – MECHANICAL DESIGN OF LINES AND GROUNDING**

Date of Lecture:

Topic of Lecture : Substation Layout (AIS) & Substation Layout (GIS)

Introduction :

- The metal-enclosed gas insulated switchgear> inherently follows the criteria for new substation design and offers a higher reliability and flexibility than other solutions. Due to the gas enclosed design, GIS is the most suitable solution for indoor and underground substations.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

1.Substation Layout AIS

AIS Substation Description

An Air Insulated Switchgear substation (AIS substation) uses atmospheric air as the phase to ground insulation for the switchgear of an electrical substation. The main advantage of the AIS substation is the scope of the substation for future offloading, for this reason AIS substations tend to be the most popular 400kV substation type. The equipment of an AIS substation is easily sourced and has a short lead-time; this means that the required future offloading does not need to be built immediately, unlike GIS where it must be considered. The main disadvantage to the AIS substation is its overall size. At 400kV level these substations can have a significant footprint and require sensitive locating in any rural environment. AIS are usually installed outdoor.

AIS Substation Size

Based on the single line diagrams given in Appendix B the minimum size of an AIS substation for this project would be as follows:

1.Overall substation Compound Size 46,864.5m2(235.5m x 199m or approximately 11.6 acres)

2.Height of highest element of substation ~ 28m (lightning protection structures situated in the substation

compound)
Note: The switchgear in an AIS substation is outdoors therefore no building sizes are considered.
AIS Maintenance Requirements
1.Ongoing maintenance requirements, all equipment exposed to weather conditions
2.Disconnect contacts must be cleaned regularly, operating mechanisms must be checked and maintained

2.Substation Layout GIS

A gas insulated substation (GIS) is a high voltage substation in which the major structures are contained in a sealed environment with sulfur hexafluoride gas as the insulating medium. GIS technology originated in Japan, where there was a substantial need to develop technology to make substations as compact as possible. The clearance required for phase to phase and phase to ground for all equipment is much lower than that required in an air insulated substation; the total space required for a GIS is 10% of that needed for a conventional substation.

Gas insulated substations offer other advantages in addition to the reduced space requirements. Because the substation is enclosed in a building, a GIS is less sensitive to pollution, as well as salt, sand or large amounts of snow. Although the initial cost of building a GIS is higher than building an air insulated substation, the operation and maintenance costs of a GIS are less.

The primary applications for gas insulated substations include:

High voltage installations The higher the voltage, the more favorable gas insulated technology becomes. The footprint of 765kV conventional substation is enormous, and GIS technology allows a significant size reduction.
Urban Installations GIS technology can be used for installations in areas where the cost of real estate or aesthetic appeal is a significant consideration.
Indoor Installations Building an air insulated substation indoors is usually impractical, but a GIS can easily go inside buildings.
Environmentally Sensitive Installations GIS technology is popular in desert and arctic areas because it can be enclosed in a building with environmental control. Gas insulated substations also contain the electrical components within a Faraday cage and are therefore totally shielded from lightning.

Video Content / Details of website for further learning (if any):

1. https://electrical-engineering-portal.com/gas-insulated-substation-gis-vs-ais
2. http://www.brainkart.com/article/Substation--Classification--and-Layout_12393/

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 209)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 279 to 280)

Course Faculty

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Estd. 2000

LECTURE HANDOUTS **L45**

DEPT: EEE **III / V**

Course Name with Code : **19EEC12 & TRANSMISSION & DISTRIBUTION**

Course Teacher : **Mrs.M.Selvakumari**

Unit : **V – MECHANICAL DESIGN OF LINES AND GROUNDING**

Date of Lecture:

Topic of Lecture : Methods of grounding

Introduction :

- In power system, grounding or earthing means connecting frame of electrical equipment (non-current carrying part) or some electrical part of the system (e.g. neutral point in a star-connected system, one conductor of the secondary of a transformer etc.) to earth i.e. soil. This connection to earth may be through a conductor or some other circuit element (e.g. are resistor, a circuit breaker etc.) depending up on the situation, grounding or earthing

Prerequisite knowledge for Complete understanding and learning of Topic:

- Circuit Theory
- Electromagnetic Theory
- AC Machines

Detailed content of the Lecture:

Concept of Grounding

The process of connecting the metallic frame (i.e. non-current carrying part) of electrical equipment or some electrical part of the system (e.g. neutral point in a star- connected system, one conductor of the secondary of a transformer etc.) to earth (i.e. soil) is called grounding or earthing. It is strange but true that grounding of electrical systems is less understood aspect of power system. Nevertheless, it is a very important subject. If grounding is done systematically in the line of the power system, we can effectively prevent accidents and damage to the equipment of the power system and at the same time continuity of supply can be maintained. Grounding or earthing may be classified as:(i) Equipment grounding (ii) System grounding. Equipment grounding deals with earthing the non-current-carrying metal parts of the electrical equipment. On the other hand, system grounding means earthing some part of the electrical system e.g. earthing of neutral point of star-connected system in generating stations and substations.

Neutral Grounding

The process of connecting neutral point of 3-phase system to earth (i.e. soil) either directly or through some circuit element is called neutral grounding. Neutral grounding provides protection to personal and equipment. It is because during earth fault, the current path is completed through the earthed neutral and the protective devices (e.g. a fuse etc.) operate to isolate the faulty conductor from the rest of the system. This point is illustrated in Fig

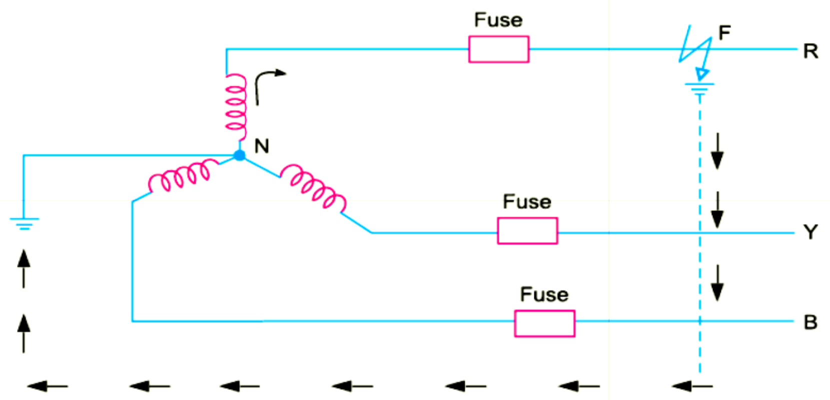


Fig. shows a 3-phase, star-connected system with neutral earthed. Suppose a single line to ground fault occurs in line R at point F. This will cause the current to flow through ground path as shown in Fig.1. Note that current flows from R phase to earth, then to neutral point N and back to R-phase. Since the impedance of the current path is low, a large current flows through this path. This large current will blow the fuse in R-phase and isolate the faulty line R. This will protect the system from the harmful effects of the fault. One important feature of grounded neutral is that the potential difference between the live conductor and ground will not exceed the phase voltage of the system i.e. it will remain nearly constant.

Methods of Neutral Grounding

The methods commonly used for grounding the neutral point of a 3-phase system are :

(i) Solid or effective grounding

(ii) Resistance grounding

(iii) Reactance grounding

(iv) Peterson-coil grounding

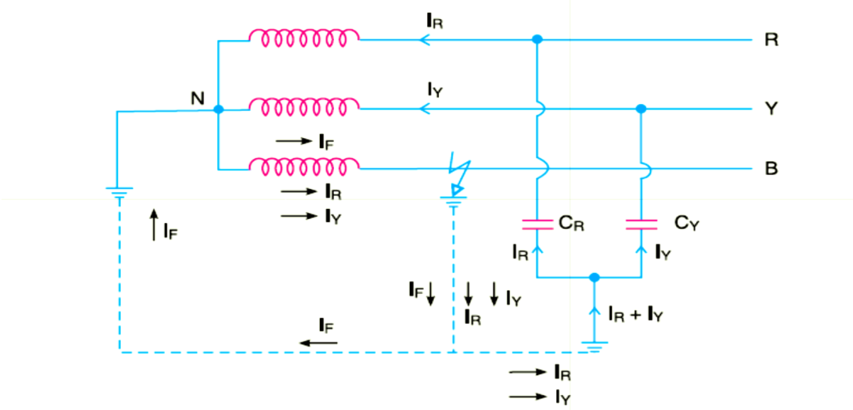
The choice of the method of grounding depends upon many factors including the size of the system, system voltage and the scheme of protection to be used.

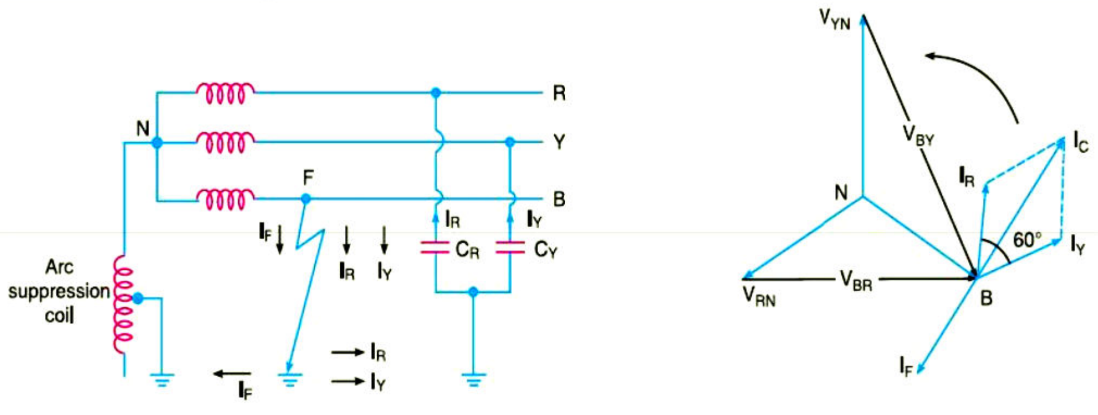
The solid grounding of neutral point has the following advantages:

(i) The neutral is effectively held at earth potential.

(ii)When earth fault occurs on any phase, the resultant capacitive current IC is in phase opposition to the fault current IF . The two currents completely cancel each other. Therefore, no arcing ground or over-voltage conditions can occur. Consider a line to ground fault in line B as shown in Fig. The capacitive currents flowing in the healthy phases R and Y are IR and IY respectively. The resultant capacitive current IC is the phasor sum of IR and IY . In addition to these capacitive currents, the power source also supplies the fault current IF . This fault current will go from fault point to earth, then to neutral point N and back to the fault point through the faulty phase. The path of IC is capacitive and that of IF is *inductive. The two currents are in phase opposition and completely cancel each other. Therefore, no arcing ground phenomenon or over-voltage conditions can occur.

(iii)When there is an earth fault on any phase of the system, the phase to earth voltage of the faulty phase becomes zero. However, the phase to earth voltages of the remaining two healthy phases remain at normal phase voltage because the potential of the neutral is fixed at earth potential. This permits to insulate the equipment for phase voltage. Therefore, there is a saving in the cost of equipment.





(*i*) (*ii*)

Video Content / Details of website for further learning (if any):

1. https://www.electricaltechnology.org/2015/05/earthing-and-electrical-grounding-types-of-earthing.html
2. http://www.brainkart.com/article/Methods-of-Neutral-Grounding_12394/

Important Books/Journals for further learning including the page nos.:

1. B.R. Gupta, Power System Analysis and Design, S.Chand, 2003. (Page no 211)
2. S.N.Singh, Electric Power Generation, Transmission and Distribution, Prentice Hall of India Pvt Ltd, 2002. (Page no 281 to 286)

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