Power Systems

For

Electrical Engineering

By

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Syllabus for Power Systems

Basic Power Generation Concepts; Transmission Line Models and Performance; Cable Performance, Insulation; Corona and Radio Interference; Distribution Systems; Per-Unit Quantities; Bus Impedance and Admittance Matrices; Load Flow; Voltage Control; Power Factor Correction; Economic Operation; Symmetrical Components; Fault Analysis; Principles of Over-Current, Differential and Distance Protection; Solid State Relays and Digital Protection; Circuit Breakers; System Stability Concepts, Swing Curves and Equal Area Criterion; HVDC Transmission and FACTS Concepts.

Previous Year GATE Papers and Analysis

GATE Papers with answer key

thegateacademy.com/gate-papers

Subject wise Weightage Analysis

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Contents

"Our greatest weakness lies in giving up. The most certain way to succeed is always to try just one more time."

... Thomas A. Edison

CHAPTER 1

Transmission and Distribution

Learning Objectives

After reading this chapter, you will know:

1. Basic Concepts of Line Constants in Transmission
2. Types of Conductor
3. Capacitance Calculation
4. Performance of Transmission Lines
5. Voltage Control
6. Concepts of Corona
7. Mechanical Design of Transmission Lines
8. Overhead Insulators
9. Underground Cables
10. Capacitance Grading
11. Distribution System
12. Importance of Capacitor

Basic Concepts and Line Constants in Transmission

Power Generation

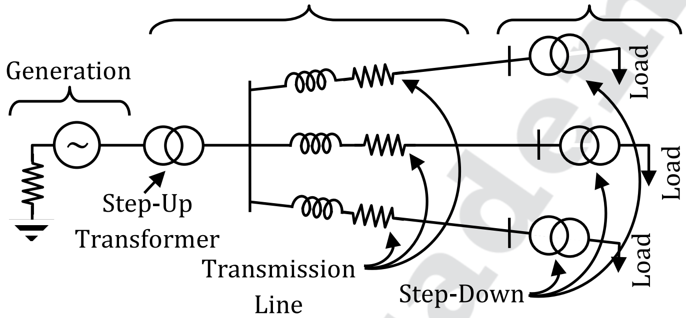
Non Conventional Energy Sources → Power Generation ← Conventional Energy Sources

Non-Conventional Energy Sources	Conventional Energy Sources
1. Small capacity power Generation over a shorter interval of time. **Ex:** Wind, Solar, Tidal, Geothermal, Diesel, Biomass and MHD	1. Bulk capacity power Generation over a Longer period. **Ex:** Steam (or) Thermal, Hydro, Nuclear and Gas
2. Most of the plants are located near to consumer premises i.e., there is no constraint in setting up of these plants	2. Most of the plants are located at remote places i.e., these plants are set-up based on geographical constraints
3. The operation of these plants are based on day-to-day weather constraints	3. There are no weather constraints while operating these plants
4. Most of these plants having less fixed cost and high running cost	4. Most of these plants are having high fixed cost and less running cost
5. Suitable to meet peak load demands except Geothermal plants	5. Suitable to meet base load demand except Gas plants
6. Asynchronous Generators are employed **Ex:** DC Generator, AC Generator and Induction Generator	6. Synchronous Generators are used

7. Distribution network is sufficient	7. Both the transmission and distribution networks are employed
8. Generated voltage will be at ≤ 1 kV	8. Generated voltage will be 3.3, 6.6, 11, 13.2 and 18.2 kV

Necessity of Transmission Lines: Bulk amount of power Generation could able to produce on economical basis by employing synchronous Generators at remote locations. The Bulk amount of power from the remote Generating station could able to be carried out to the load center by using suitable network and the network is called transmission network (or) transmission lines.

Transmission Line: It is a connection (or) line between the remote Generating station and the load center.



Level of Voltages

Low Voltage: 220V 1-phase (or) 415V 3-phase
High Voltage: 11kV, 33kV
Extra High Voltage: 66kV, 132kV, 220kV and 400kV
Ultra High Voltage: 765kV and above
Most of Power generation in India is at 11kV

Necessity of Extra High Voltages for Transmission System

1. The size of the conductor is reduced so that the cost of the conductor is reduced.

   Area $\propto \frac{1}{v^2}$

   Ex: For the same power, same length and same material the size of the conductor will become $(1/n^{th})^2$ of original size as the operating voltage increased by n times.

2. The transmission line loss will be reduced.

   $\rightarrow P_L \propto {}^1/_{v^2}$

   Ex: For the same power, same length, same material the copper loss becomes $(1/n^{th})^2$ to that of original loss as the voltage increased by n times.

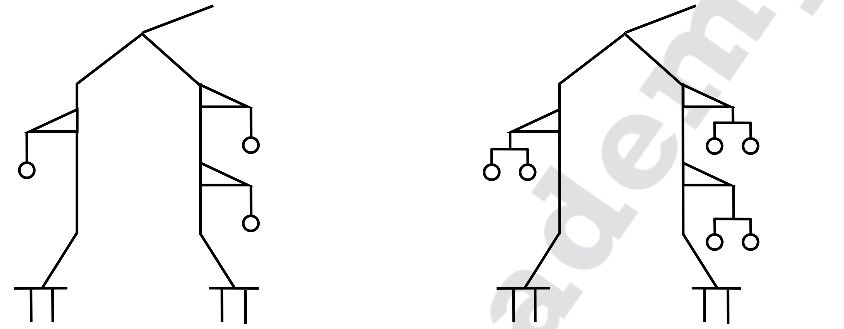
3. The transmission efficiency will increase

   $\eta = 1 - k / v \cos\phi$

4. The power transfer capacity is enhanced ($\therefore P \propto V^2$)

Special Case: For the same power, same loss, same material and same length, the size of the conductor becomes $1/n^2$ to that of original loss as the voltage increased by n times to that of original voltage. As the level of voltage is increasing beyond certain limit, for the same amount of power to be transmitted, the extra cost required for insulation is more that the saving in conductor cost. So, the selection of operating voltage to transmit the power is the compromise between saving of conductor cost and extra cost required for insulation.

Selection of the Size of Conductor in Transmission Lines: In transmission lines there are no tapings (or) consumers in the middle. So the current throughout the transmission line is same from the generating station to the load center. Hence the conductor is designed based on current carrying capacity (or) constant current density. This is up to 220kV transmission line only.
In case of the voltages beyond 220kV, the concept of corona is predominant than that of current carrying capacity. So the transmission lines are designed based on concept of corona.

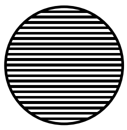


$\leq$ 220 kV - - Conductors   400 kV and above - - - Bundle Conductors

Types of Conductor

- Solid copper conductor – used is circuit breaker poles, current transformer and potential transformer terminals,
- Hollow copper conductor – used in bus duct, isolator
- Stranded conductor – used in transmission line, bus bar
  Ex: Expanded ACSR

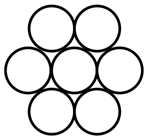
Solid Copper Conductor



Solid

1. High cost
2. High tensile strength
3. Difficult to string the conductors so difficult to transport
4. High skin effect while using an AC system

Stranded Conductor: It consists of two or more smaller cross sectional strands (or) filaments which are twisted together to get the required strength and running in parallel to increase the current capacity for the given operating voltage.



Stranded

Homogenous Stranded Conductor: It is made up of all the strands by one material only.
The advantages are.

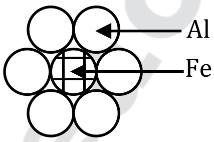
- Reduced tensile strength due to strands when compared to solid conductor
- Easy to string the conductors so easy to transport
- Reduced skin effect when compared to solid conductor

But the cost of the conductor is not reduced to greater extent even though the strands are employed.

Alluminium Homogenous Stranded Conductor

- Almost equal conductivity when compared with copper.
- Less cost of alluminium.
- Low tensile strength so that the span length is less. The reduced span length will increase the number of towers which in turn increases the cost of Insulators and Erection. So the cost of transmission will increase.

In order to improve the tensile strength and reduce the cost of transmission system by increasing the span length **Composite Stranded Conductors** are employed i.e., two or more conducting materials.



In the composite stranded conductor the outer strands are having high conductivity and low tensile strength i.e., Alluminium and central strands are having low conductivity and high tensile strength i.e., steel are used which is known as **ACSR Conductor.**

ACSR (Alluminium Conductor and Steel Reinforced)

Advantages

- Required Tensile strength
- Less cost of transmission
- Easy stringing
- Reduced skin effect when compared to solid (or) homogenous stranded conductor

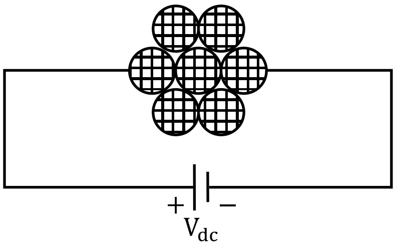
Disadvantages

1. Increased transmission loss

Skin Effect: In case of AC, the flux linkage is maximum at centre and minimum at surface. So that inductive reactance is maximum at centre causing to decrease in current at the centre and increase in current at the surface. The accumulation of current at the surface of the conductor is known as skin effect. The skin effect will result in

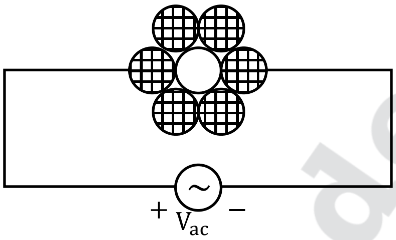
- Increased effective resistance (R_{ac})
- Internal Inductance will increase (L_{in})
- External Inductance will reduced ($L_{external}$)

Explanation



In case of dc system, there is no rate of change of current. So the current is uniformly distributed throughout the cross sectional area of the conductor. So, the entire area will be considered while calculating the **dc resistance** offered.

$R_{dc} = \frac{\rho l}{a}$



In case of AC system, there is a rate of change of current. Whenever the switch is closed, the system is under sub/transient behavior. So the flux produced in the outer stands will link with the inner stands due to low reluctance offered, whereas the flux produced by inner strands could only link with those strands and not with the external strands. So the Internal Flux Linkages will Increases which will increases the internal inductance.

Inductance will oppose the flow of current, so that the most of the current will concentrated on outer strands and very less current will be allowed through the inner strands. While calculating the effective resistance, the area in which the current concentrated is more only considered than that of entire area of cross section of the conductor. So the ac (or) effective résistance $R_{ac} = \frac{\rho l}{a}$ $(a| < a)$

R_{ac} (ac resistance) is greater than R_{dc} (dc resistance) for the same conductor

$R_{ac}. R_{dc}[\therefore R_{ac} = K\,R_{dc};\ K = 1.6]$

In case of ACSR conductor, the current distribution is non- uniform and the materials are also non-uniform. So, the entire area will be considered while calculating the effective resistance.

$R_{ac} = \frac{\rho l}{a}$

Where, a = Entire area of cross section

(or)

High current is concentrated on the surface. So the conductivity of alluminium is extracted effectively. Less current is concentrated at the inner strands. So the conductivity of steel will also be effectively utilized. Hence the entire cross-sectional area will be considered, while calculating the ac resistance.

The overall Diameter of ACSR conductors will be

$D = (2n - 1)\,d$

D = Overall Diameter in cm

n = Number of layers. Single central strand will also be considered as one layer

Number of strands $= N = 3n^2 - 3n + 1$
d = diameter of each strand in cm
Ex: An ACSR conductor consists of 30 Alluminium strands and 7 steel strands will be represented as 30/7. In general for a given ACSR conductor, the number of alluminium strands are more in number when compared to steel strands.
Ex: The ACSR conductor represented as 1/6 It consists of one steel and six Alluminium strands.
Ex: An ACSR conductor consists of 7 steel strands and 54 Alluminium strands will be represented as 7/54.
The configuration of strands in the layers will be 1+6+12+18+24+.......

- As the diameter (or) Area of cross section of the conductor increases the skin effect will increase i.e., R_{ac} will increase.
- As the permeability of the material will increase, the skin effect will increase i.e., R_{ac} will increase.
- As the operating frequency will increases, the skin effect will increase i.e., R_{ac} will increase. But it is more effective in communication circuits than that of power circuits, because the operating frequency is only 50Hz.
  Skin effect $(R_{ac}) \propto A\, \mu r\, f\, \sigma$
  Skin effect $(R_{ac}) \propto d^2\, \mu r\, f\, \sigma$

Skin Depth:
- The depth of conductor at which the surface current is dropped to $^1/_e$ of the surface value.
- Skin depth is more, indicates that skin effect is less.
- If communication line frequency is higher. So that skin depth is small i.e., skin effect is large.
- If case of power line frequency is smaller. Hence skin effect is negligible conductor skin effect is significant but for large skin depth.
  $$\delta = \frac{1}{\sqrt{\pi f \mu \sigma}}$$

Proximity Effect:
- Proximity effect occurs due to the current & fluxes of the mutual conductor. This causes non-uniform current flow in the mutual conductors causing $R_{ac} > R_{dc}$ due to effective area reduction.
- Proximity effect is more in case of underground cables, because the distance between the conductors is less.
- This effect is less in case of overhead lines because distance between conductors is more.
- Proximity effect depends upon
  (a) Distance between conductor
  (b) Frequency of supply
  (c) Relative permeability
  (d) Conductivity

Bundle Conductors: Whenever the operating voltages beyond 270kV, it is preferable to use more than one sub conductor/phase which is **known as Bundle Conductor.**
Bundle conductor is one which consists of two (or) more sub conductor / phase which are running in parallel in which the spacing between sub conductors is very high when compared to radius of