

QUANTUM *Series*

Semester - 5

Electrical & Electronics Engineering

Power System - I



- Topic-wise coverage of entire syllabus in Question-Answer form.
- Short Questions (2 Marks)

**Session
2024-25**
Odd Semester

Includes solution of following AKTU Question Papers
2020-21 • 2021-22 • 2022-23 • 2023-24

सजग सूचना

छात्रों, डीलरों, दुकानदारों, कॉपियर्स और जिनसे यह संबंधित हो सकता है क्वांटम पुस्तकों के कॉपीराइट उल्लंघन के संबंध में दिल्ली के माननीय उच्च न्यायालय का आदेश

यह छात्रों, डीलरों, दुकानदारों, कॉपियर्स और आम जनता को सूचित करना है कि क्वांटम पेज प्राइवेट लिमिटेड पुस्तकों की क्वांटम श्रृंखला में कॉपीराइट का मालिक है।

क्वांटम पुस्तकों (चाहे सॉफ्ट कॉपी या हार्ड कॉपी में) की कोई भी अनधिकृत प्रतिलिपि, स्कैनिंग, पुनरुत्पादन, वितरण या संचलन, क्वांटम पेज प्राइवेट लिमिटेड के कॉपीराइट और ट्रेडमार्क अधिकारों के उल्लंघन के बराबर है, जो दिवानी अपराध के साथ-साथ दंडिक अपराध है, जिनकी सजा कारावास तक है।

क्वांटम पेज प्राइवेट लिमिटेड ने दिल्ली के माननीय उच्च न्यायालय के समक्ष क्वांटम पुस्तकों के उल्लंघनकर्ताओं के खिलाफ क्वांटम पेज प्राइवेट लिमिटेड बनाम टेलीग्राम एफजेड एलएलसी और अन्य, सीएस (कॉम) १२१/२०१२ मामले का एक मुकदमा शुरू किया है। 23 दिसंबर, 2022 के अपने आदेश में, माननीय उच्च न्यायालय ने माना है कि क्वांटम पुस्तकों का अनधिकृत पुनरुत्पादन कॉपीराइट उल्लंघन के बराबर है और टेलीग्राम चैनलों सहित विभिन्न सोशल मीडिया प्लेटफॉर्मों पर क्वांटम पुस्तकों की उल्लंघनकारी प्रतियों को हटाने का निर्देश दिया है।

यह सूचना छात्रों, डीलरों, दुकानदारों, कॉपीयरों और आम जनता को एतद्वारा आगह किया जा रहा है कि वे क्वांटम पुस्तकों (चाहे सॉफ्ट कॉपी या हार्ड कॉपी में) की कोई भी अनधिकृत नकल, स्कैनिंग, पुनरुत्पादन, वितरण और वितरण न करें।

क्वांटम पुस्तकों के ऐसे किसी भी अनधिकृत उपयोग से उल्लंघनकर्ताओं पर क्वांटम पेज प्राइवेट लिमिटेड द्वारा दिवानी और आपराधिक कार्यवाही शुरू की जाएगी।

QUANTUM SERIES

For
B.Tech Students of Third Year
of All Engineering Colleges Affiliated to
Dr. A.P.J. Abdul Kalam Technical University,
Uttar Pradesh, Lucknow
(Formerly Uttar Pradesh Technical University)

Power System - I

By
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QUANTUM PAGE PVT. LTD.
Ghaziabad ■ New Delhi

PUBLISHED BY :

Apram Singh
Quantum Publications®
(A Unit of Quantum Page Pvt. Ltd.)
Plot No. 59/2/7, Site - 4, Industrial Area,
Sahibabad, Ghaziabad-201 010

Phone : 0120 - 4160479

Email : pagequantum@gmail.com Website: www.quantumpage.co.in

Delhi Office : M-28, Naveen Shahdara, Delhi-110032

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Power System - I (EN : Sem-5)

1st Edition : 2010-11

2nd Edition : 2011-12

3rd Edition : 2012-13

4th Edition : 2013-14

5th Edition : 2014-15

6th Edition : 2015-16

7th Edition : 2016-17

8th Edition : 2017-18

9th Edition : 2018-19

10th Edition : 2019-20

11th Edition : 2020-21

12th Edition : 2021-22

13th Edition : 2022-23

14th Edition : 2023-24

15th Edition : 2024-25

(Thoroughly Revised Edition)

Price: Rs. 100/- only

Printed at : Sachdeva Offset Printers, Delhi-110093.

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1-1 B (EN-Sem-5)

PART-1*Introduction : Basic Structure of Power System.*

Que 1.1. Draw the basic structure of power system.

Answer

An electrical power system is a network of electrical elements that are used to transfer the power from the power stations to the end consumers. A power system has three main stages :

1. **Generation :** The place where power is generated is known as 'power plant' or 'power house'.

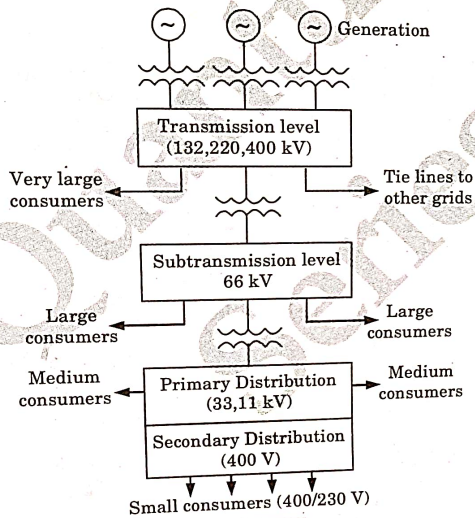


Fig. 1.1.1.

2. **Transmission :** Transmission of electrical supply is the part of a power system where the electric supply is transmitted from one station to another station.
3. **Distribution :** Distribution of power supply is the part of power system where the supply is distributed among the consumers.

Que 1.2. What are the equipments used in sub-station ? Discuss them.

AKTU 2023-24, Marks 10

Answer

Some common equipment found in substations includes :

1. **Transformers :** Transformers are essential components that step-up or step-down the voltage levels of electricity for efficient transmission and distribution.
2. **Circuit breakers :** Circuit breakers are devices that automatically interrupt electrical circuits during abnormal conditions, such as overload or short circuits, to protect the equipment and prevent damage to the system.
3. **Busbars :** Busbars are conductors that interconnect various components within the substation, such as transformers, circuit breakers, and switchgear. They provide a low-resistance path for electricity to flow between different parts of the substation.
4. **Disconnectors (Isolators) :** Disconnectors are mechanical switches used to isolate electrical equipment for maintenance or repair. They ensure the safety of personnel working on the equipment by physically disconnecting it from the power source.
5. **Capacitor banks :** Capacitor banks are used to improve the power factor of the electrical system by compensating for reactive power. They help in reducing losses, improving voltage stability, and increasing the overall efficiency of the system.

PART-2*Sources of Electric Energy : Conventional and Non-Conventional.*

Que 1.3. What are the conventional and non conventional sources of energy ? Explain with examples.

AKTU 2021-22, Marks 10

Answer**A. Conventional sources of energy :**

1. Conventional sources of energy refer to the traditional and widely used sources of energy that have been in use for a long time.
2. They are generally well-established and have been the primary sources of energy for various sectors.

3. Examples of conventional source of energy :

- Fossil fuels :** Fossil fuels are the most common conventional sources of energy. They include coal, oil, and natural gas.
- Nuclear energy :** Nuclear reactors use controlled nuclear reactions (fission) to release energy, which is then converted into electricity.

B. Non-conventional sources of energy :

- Non-conventional sources of energy are newer and alternative forms of energy that have gained importance due to environmental concerns and finite availability of conventional sources.
- These sources are considered renewable or sustainable, as they are naturally replenished and have lower environmental impacts.

3. Examples of non-conventional source of energy :

- Solar energy :** Solar panels capture sunlight and convert it into electricity through photovoltaic cells.
- Wind energy :** Wind turbines convert the kinetic energy of wind into electricity.
- Hydropower :** The energy of flowing water is harnessed to generate electricity using hydroelectric power plants.
- Biomass :** Organic materials like wood, agricultural residues and waste are burned or processed to produce energy.

PART-3

Layout of Hydro-electric, Thermal and Nuclear Power Plants.

Que 1.4. Give the layout of hydro-electric power plant and explain its components in detail.

Answer

A. Layout of hydro-electric power plant :

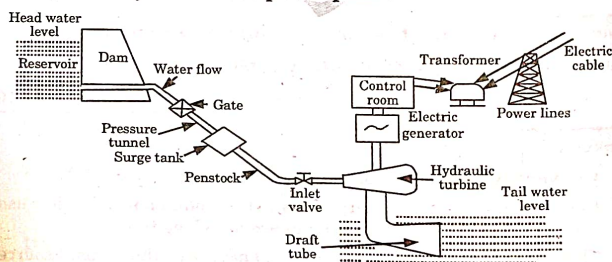


Fig. 1.4.1. Layout of hydro electric power plant.

The different components in hydro-electric power plant are :

1. Reservoir :

- It is a basic requirement of a hydro-electric plant.
- Its purpose is to store water which may be utilised to run the prime mover to produce electrical power.
- A reservoir stores water during the rainy season and supplies the same during the dry season.

2. Dam :

- The function of dam is to provide a head of water to be utilised in the water turbine.
- Though many times all high dams may be built solely to provide the necessary head to the plant.
- A dam also increases the reservoir capacity.

- Forebay :** The forebay serves as a regulating reservoir storing water temporarily when load on the plant is reduced and providing water for initial increase on account of increasing load during which time water in the canal is being accelerated.

4. Surge tank :

- This may be considered as an additional storage space near the turbine, usually provided in high-head, medium head plants when there is a considerable distance between the water source and turbine which necessitates a long penstock.
- As the load on the turbine decrease or during load rejection by the turbine the surge tank provides space for holding water.

- Pen stock :** It is a conduit system for taking water from the intake works and forebay to the turbines.

6. Spillway :

- This may be considered a sort of safety valve for a dam.
- A spillway serves to discharge excess in the reservoir beyond the full permissible level.

7. Power house :

- It is generally located at the foot of the dam and near the storage reservoir.
- If the power house is near the dam, the loss of head due to friction in the penstock would be less.

8. Prime mover :

- The purpose of prime mover is to convert kinetic energy of water into mechanical energy.
- Commonly used prime movers are Pelton wheel, Francis, Kaplan and propeller turbines.

Que 1.5. A hydro-electric power station has a reservoir of area 2.4 square kilometres and capacity $5 \times 10^9 \text{ m}^3$. The effective head of water is 100 metres. The penstock, turbine and generation efficiencies are respectively 95 %, 90 % and 85 %:

- Calculate the total electrical energy that can be generated from the power station.
- If a load of 15,000 kW has been supplied for 3 hours, find the fall in reservoir level.

AKTU 2022-23, Marks 10

Answer

1. **Given :** Area of reservoir = 2.4 km², Volume of reservoir = $5 \times 10^9 \text{ m}^3$, Head of water (H) = 100 m, Penstock efficiency = 95 %, Turbine efficiency = 90 %, Generation efficiency = 85 %.

To Find : i. Total electrical energy that can be generated.
ii. Fall in reservoir level.

i.

- Weight of water available,

$$\begin{aligned} W &= \text{Volume of reservoir} \times \text{Weight of } 1 \text{ m}^3 \text{ of water} \\ &= 5 \times 10^9 \times 1000 \\ &= 5 \times 10^9 \text{ kg} \\ &= 5 \times 10^9 \times 9.81 \text{ N} \end{aligned}$$

- Overall efficiency,

$$\begin{aligned} \eta_{\text{overall}} &= 0.95 \times 0.9 \times 0.85 \\ &= 0.726 \end{aligned}$$

- Electrical energy that can be generated,

$$\begin{aligned} &= W \times H \times \eta_{\text{overall}} \\ &= (5 \times 10^9 \times 9.81) \times (100) \times (0.726) \text{ watt-sec} \\ &= \frac{5 \times 10^9 \times 9.81 \times 100 \times 0.726}{1000 \times 3600} \text{ kWh} \\ &= 989175 \text{ kWh} \end{aligned}$$

ii.

- Let x metres be the fall in reservoir level in 3 hours.

$$\begin{aligned} \text{Average discharge/sec} &= \frac{\text{Area of reservoir} \times x}{3 \times 3600} \\ &= \frac{2.4 \times 10^6 \times x}{3 \times 3600} = 222.2x \text{ m}^3 \end{aligned}$$

- Weight of water available/sec, $W = 222.2x \times 1000 \times 9.81$
 $= 21.8x \times 10^5 \text{ N}$

- Average power produced = $W \times H \times \eta_{\text{overall}}$
 $= (21.8x \times 10^5) \times 100 \times (0.726) \text{ W}$
 $= 15.84x \times 10^7 \text{ W}$
 $= 15.84x \times 10^4 \text{ kW}$

But kW produced = 15000 (given)

$$\therefore 15.84x \times 10^4 = 15000$$

$$x = \frac{15000}{15.84 \times 10^4} = 0.0947 \text{ m}$$

$$x = 9.47 \text{ cm}$$

- Therefore, the level of reservoir will fall by 9.47 cm

Que 1.6. Give the layout of thermal power plant and explain its

components in details.

AKTU 2023-24, Marks 10

OR

With a neat sketch explain the function of main parts of thermal power plant.

AKTU 2020-21, Marks 10

Answer

A. Layout of thermal power plant :

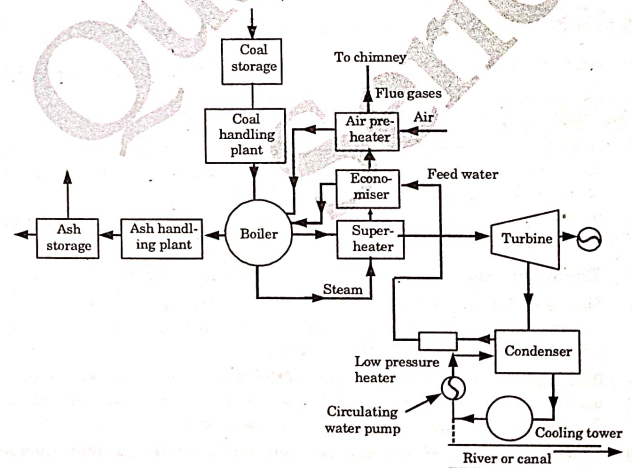


Fig. 1.6.1. Layout of a thermal power plant.

B. Components of thermal power plant (Functions of main parts of thermal power plant) :

1. **Coal storage** : A designated area for storing coal before processing.
2. **Coal handling plant** : Manages coal delivery, crushing, and conveying to the boiler.
3. **Boiler** : Burns coal to generate steam from water.
4. **Turbine** : Converts steam energy into mechanical energy.
5. **Generator** : Converts mechanical energy from the turbine into electrical energy.
6. **Condenser** : Condenses exhaust steam from the turbine into water.
7. **Cooling tower** : Dissipates waste heat from the condenser to the atmosphere.
8. **Pumps** : Circulate water and steam within the plant.
9. **Superheater** : Heats steam above its saturation point for efficiency.
10. **Economiser** : Preheats feedwater using residual heat from flue gases.
11. **Air pre-heater** : Warms incoming air to improve combustion efficiency.
12. **Chimney** : Expels flue gases safely into the atmosphere.
13. **Ash handling system** : Manages the removal and transport of ash produced from coal combustion.
14. **Ash storage** : Stores ash residues safely before disposal or recycling.

Que 1.7. With neat sketch, describe the nuclear power plant.

AKTU 2020-21, Marks 10

Answer

1. A nuclear power plant is a complex facility designed to generate electricity using nuclear reactions, typically involving the fission of uranium atoms, which release a significant amount of heat.
2. This heat is used to produce steam from water, which drives turbines connected to generators to produce electrical power.
3. **The basic components of a nuclear power plant are :**
 - i. **Nuclear fuel** : The plant uses uranium fuel, typically in the form of pellets, as a source of energy. Uranium atoms undergo controlled fission, releasing a significant amount of heat.
 - ii. **Nuclear reactor** : This is the core of the plant where nuclear reactions occur. Control rods are inserted or withdrawn to regulate the rate of fission, maintaining a controlled chain reaction.
 - iii. **Fission process** : Uranium nuclei split into smaller fragments during fission, releasing a substantial amount of heat energy along with neutrons that can trigger further fission reactions.

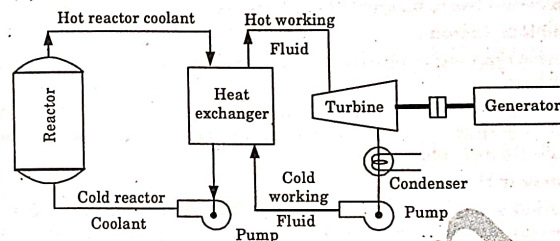


Fig. 1.7.1.

- iv. **Heat generation** : The heat produced from fission reactions is absorbed by a coolant (often water), which circulates through the reactor core, carrying away the heat.
- v. **Steam generation** : The hot coolant is used to heat water, creating steam. This steam is under high pressure and is directed to a steam turbine.
- vi. **Turbine and generator** : The steam drives a turbine, causing it to spin. The turbine is connected to a generator, and the mechanical energy from the turbine's motion is converted into electrical energy.
- vii. **Cooling systems** : After passing through the turbine, the steam is condensed back into water using cooling systems. This condensed water is then re-circulated back into the reactor core to repeat the process.

Que 1.8. Explain in detail the nuclear reaction theory and working principle of a nuclear power station with plant layout.

AKTU 2022-23, Marks 10

Answer**A. Nuclear reaction theory :**

1. The nuclear reaction theory is the study of the changes in the nucleus of an atom that occur during a nuclear reaction.
2. It involves the study of the forces that hold the nucleus together, the properties of various particles that make up the nucleus, and the interaction between these particles.
3. The nuclear reaction theory involves the use of mathematical models and experimental data to predict the behavior of nuclei during a nuclear reaction.
4. The models used in the theory take into account the properties of the particles that make up the nucleus, as well as the forces that hold them together.

5. There are two main types of nuclear reactions: fusion and fission.
- a. Nuclear fusion :**
1. Fusion reactions involve the combination of two light nuclei into a heavier nucleus.
 2. This type of reaction occurs naturally in the sun and other stars, where the intense heat and pressure in the core of the star cause hydrogen nuclei to fuse into helium.
- b. Nuclear fission :**
1. Fission reactions, on the other hand, involve the splitting of a heavy nucleus into two or more smaller nuclei.
 2. This type of reaction is used in nuclear power plants and nuclear weapons.
 3. Fission reactions can be initiated by bombarding a heavy nucleus with a neutron, which causes the nucleus to become unstable and split into two or more smaller nuclei, releasing energy in the process.
- B. Working principle of nuclear power plant :**
1. A nuclear power station operates on nuclear fission, where fuel rods (uranium-235 or plutonium-239) in the reactor core split atoms to release heat.
 2. This heat converts water into steam in the steam generator. The steam drives a turbine connected to a generator, producing electricity.
 3. Post-turbine, the steam is condensed back into water and recycled. Safety is ensured with control rods regulating fission and multiple safety systems.
- C. Nuclear power plant layout :** Refer Q. 1.7, Page 1-8B, Unit-1.

PART-4

Concept of Cogeneration, Combined Heat and Power, and Captive Power Plants.

Que 1.9. Discuss about the concept of cogeneration (Combined heat and power).

Answer

1. Cogeneration, or Combined Heat and Power (CHP), is an energy-efficient technology that produces electricity and useful heat simultaneously from a single fuel source.
2. Unlike traditional power plants, which waste a significant amount of energy as heat, cogeneration systems capture and utilize this heat, achieving overall efficiencies of 60-80% compared to the 30-40% efficiency of conventional plants.

3. Cogeneration can use various fuels, including natural gas, biomass, and waste heat from industrial processes.
4. It is commonly used in industrial facilities, commercial buildings, and residential complexes where both electricity and thermal energy are needed.
5. The primary advantage of cogeneration is its ability to significantly reduce fuel consumption and lower energy costs, while also cutting greenhouse gas emissions.

Que 1.10. Discuss the captive power plants.

Answer

1. A captive power plant is a facility that provides a localised source of power to an energy user.
2. These are typically industrial facilities, large offices or data centres.
3. The plants may operate in grid parallel mode with the ability to export surplus power to the local electricity distribution network. Alternatively they may have the ability to operate in island mode, i.e., independently of the local electricity distribution system.
4. Captive power plants are a form of distributed generation, generating power close to the source of use. Distributed generation facilities the high fuel efficiency along with minimising losses associated with the transmission of electricity from centralised power plants.

PART-5

SPV Generation at Household Level.

Que 1.11. Discuss about the SPV generation at household level.

Answer

1. Solar Photovoltaic (SPV) generation at the household level involves installing solar panels on rooftops to generate electricity for personal use.
2. The system includes solar panels that convert sunlight into direct current (DC) electricity, an inverter that converts DC to alternating current (AC) for household appliances, and optionally, a battery storage system to store excess energy for later use.
3. Households can also benefit from net metering, which allows them to sell surplus electricity back to the grid.
4. This approach reduces reliance on grid power, lowers electricity bills, and supports environmental sustainability by harnessing renewable

energy. Although initial setup costs can be high, long-term savings and incentives can make SPV generation economically beneficial.

PART-6

Basic Structure of Smart Grid.

Que 1.12. Draw the basic structure of smart grid.

Answer

1. A smart grid is an electric network that uses digital and other advanced technologies to supervise and manage the transport of electricity from all generation sources to meet the unstable electricity demands of end-users (consumers).
2. Smart grid manages the needs and capabilities of all generations, grid operations, consumers and electricity market stakeholders to operate all parts of the system as professionally as possible, reducing costs and environmental impacts while increasing system reliability, flexibility and stability.

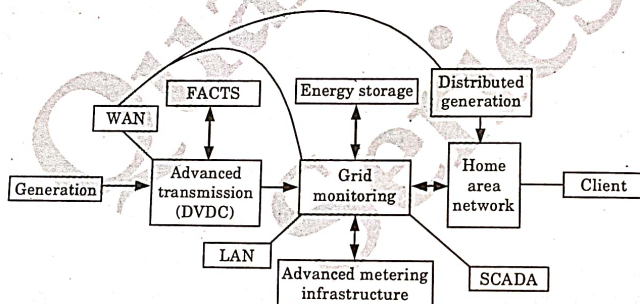


Fig. 1.12.1. Block diagram of smart grid.

PART-7

Communication and IT Components In Power System.

Que 1.13. Discuss about communication and IT components in power system.

Answer

A. Communication components :

1. **SCADA systems** : Enable real-time monitoring and control of the power grid by transmitting data between control centers and remote sites, allowing operators to manage and respond to grid conditions.
2. **Advanced Metering Infrastructure (AMI)** : Facilitates two-way communication between utilities and consumers, providing real-time data on electricity usage and enabling efficient billing and demand response.
3. **Communication networks** : Include fiber optics and wireless systems that support data exchange and control signals across the grid, ensuring reliable connectivity between various grid components.

B. IT components :

1. **Energy Management Systems (EMS)** : Optimize generation and transmission operations using real-time data and advanced algorithms to balance supply and demand efficiently.
2. **Distribution Management Systems (DMS)** : Improve local grid reliability and efficiency by automating functions like outage management and voltage control.
3. **Data Analytics Platforms** : Process and analyze vast amounts of grid data to support predictive maintenance, operational optimization, and decision-making.

PART-8

Load Curve, Load Duration Curve, Concept of Connected Load, Maximum Demand, Average Load, Demand Factor, Load Factor, Diversity Factor, Capacity Factor, Utilization Factor, Plant Use Factor, Installed Capacity, Reserves.

Que 1.14. Define the terms :

- | | |
|------------------------|-------------------------|
| i. Load curve | ii. Load duration curve |
| iii. Connected load | iv. Maximum demand |
| v. Average demand | vi. Demand factor |
| vii. Load factor | viii. Diversity factor |
| ix. Utilization factor | x. Plant use factor |
| xi. Installed capacity | xii. Reserves capacity. |

Answer

i. Load curve :

1. Load curve is a graphical representation between load and time where the load in kW or (MW) and the time in hours. It shows the variation of load on the power station.

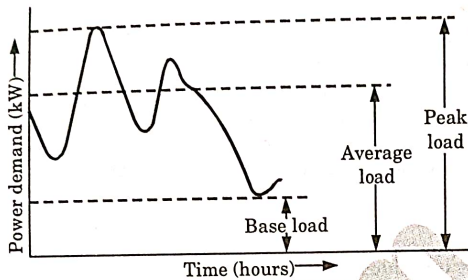


Fig. 1.14.1. Load curve.

- ii. **Load duration curve** : A load duration curve represents rearrangements of all the load elements of chronological load curve in order of descending magnitude. This curve is derived from the chronological load curve.
- iii. **Connected load** : Connected load is the sum of continuous ratings of all loads connected to the system.
- iv. **Maximum demand** : The maximum demand of an installation or system is the greatest of all demands which have occurred during the specific period of time.
- v. **Average demand** : It is the ratio of energy consumed in a given period of the time in hours.

$$\text{Average load} = \frac{\text{Energy consumed in a given period}}{\text{Hours in that time period}}$$

- vi. **Demand factor (DF)** : The demand factor is the ratio of the actual maximum demand of the system to the total connected load of the system.

$$DF = \frac{\text{Maximum demand}}{\text{Total connected load}}$$

- vii. **Load factor** : Load factor of a system is the ratio of the average load over a given period of the time to the maximum demand (peak load) occurring in that period.

$$\text{Load factor} = \frac{\text{Average load}}{\text{Peak load}}$$

- viii. **Diversity factor (F_D)** : Diversity factor is the ratio of the sum of the individual maximum demands of the various subdivisions of a system to the maximum demand of the whole system.

Diversity factor

$$(F_D) \triangleq \frac{\text{Sum of individual maximum demands}}{\text{Coincident maximum demand of the whole system}}$$

- ix. **Utilization factor (F_u)** : It is the ratio of maximum demand of a system to the rated capacity of the system.

$$F_u \triangleq \frac{\text{Maximum demand}}{\text{Rated system capacity}}$$

- x. **Plant use factor** : Plant use factor is the ratio of kWh generated to the product of plant capacity and the number of hours for which the plant was in operation.
Plant use factor = Actual energy produced / (plant capacity * plant operation time in hours)
- xi. **Installed capacity** : Installed capacity of a power system represents the maximum capacity that the system is designed to run at. It is also known as "peak installed capacity" or rated capacity.
- xii. **Reserves capacity** : It is the difference between plant capacity and maximum demand.
Reserved capacity = Plant capacity - Maximum demand

Que 1.15. Define and explain the importance of the following terms in generation: (i) Connected load, (ii) Maximum demand, (iii) Diversity factor, (iv) Average load. AKTU 2021-22, Marks 10

Answer

- A. **Definition of the terms in generation** : Refer Q. 1.14, Page 1-13B, Unit-1.
- B. **Importance of the following terms in generation** :
 - i. **Connected load** : Connected load helps in determining the overall capacity and design of the power generation system, ensuring that it can handle the total power requirements of all connected loads efficiently.
 - ii. **Maximum load** : Maximum demand is crucial for sizing generators and power plants to meet the highest expected load during peak hours, preventing power shortages and ensuring a reliable power supply.
 - iii. **Diversity factor** : Diversity Factor helps in optimizing the sizing of generation and distribution equipment, as it accounts for the fact that not all loads operate at their maximum capacity simultaneously.
 - iv. **Average load** : Average load is essential for planning the daily operational schedule and sizing the power generation capacity to meet the average power demand, ensuring an efficient and cost-effective power supply.

Que 1.16. A generating station has a connected load of 450 MW and a maximum demand of 250 MW; the unit generated being 615×10^6 per annum. Calculate the demand factor and load factor.

AKTU 2020-21, Marks 10

Answer

Given : Connected load = 450 MW, Maximum demand = 250 MW, Unit generated/Annum = 615×10^6

To Find : Demand factor, Load factor.

1. Demand factor = $\frac{\text{Maximum demand}}{\text{Connected load}} = \frac{250}{450} = 0.55$
2. Average demand = $\frac{\text{Units generated per annum in (kWh)}}{\text{Hours in a year}} = \frac{615 \times 10^6}{8760} = 70205.47 \text{ kW}$
3. Load factor = $\frac{\text{Average demand}}{\text{Maximum demand}} = \frac{70205.47}{250 \times 10^3} = 0.28$

Que 1.17. A generating station has a maximum demand of 35 MW, a load factor of 50 %, a plant capacity factor of 80 % and a plant use factor of 62 %. Find (i) the reserve capacity of the plant (ii) the daily energy produced and (iii) Maximum energy that could be produced daily if the plant while running as per schedule, were fully loaded.

AKTU 2021-22, Marks 10

Answer

Given : Maximum demand = 35 MW, Load factor = 50 %, Plant capacity factor = 80 %, Plant use factor = 62 %

To Find : Reserve capacity, Daily energy produced, Maximum energy that could be produced daily.

i. The reserve capacity of the plant :

1. Load factor = $\frac{\text{Average demand}}{\text{Maximum demand}}$
 $0.5 = \frac{\text{Average demand}}{35}$

2. Average demand = $35 \times 0.50 = 17.5 \text{ MW}$
3. Plant capacity factor = $\frac{\text{Average demand}}{\text{Plant capacity}}$
 $= \frac{17.50}{0.80} = 21.875 \text{ MW}$
4. Plant capacity = $\frac{17.50}{0.80} = 21.875 \text{ MW}$
5. Reserve capacity of plant = Plant capacity - Maximum demand
 $= 21.875 - 35$
 $= -13.12 \text{ MW}$

ii. The daily energy produced :

$$\begin{aligned} \text{Daily energy produced} &= \text{Average demand} \times 24 \\ &= 17.5 \times 24 = 420 \text{ MWh} \end{aligned}$$

iii. Maximum energy that could be produced :

$$\begin{aligned} &= \frac{\text{Actual energy produced in a day}}{\text{Plant use factor}} \\ &= \frac{420}{0.62} = 677.41 \text{ MWh/day} \end{aligned}$$

Que 1.18. A plant having daily energy production and plant factor is 1296 MWhr and 50 % respectively. Calculate the maximum rating of the power plant.

AKTU 2022-23, Marks 10

Answer

Given : Actual energy production = 1296 MWhr, Plant factor = 50 %

To Find : Maximum rating of the plant.

1. Plant factor = $\frac{\text{Actual energy produced in time 24 hours}}{\text{Maximum rating of the plant} \times 24}$
2. Maximum rating of the plant = $\frac{\text{Actual energy produced in time 24 hours}}{\text{Plant factor} \times 24}$

$$\begin{aligned}
 &= \frac{1296 \times 10^6}{0.50 \times 24} \\
 &= 108 \times 10^6 \text{ W} \\
 &= 108 \text{ MW}
 \end{aligned}$$

Que 1.19. A generating station has the following daily load cycle :

Time (Hours)	0-6	6-10	10-12	12-16	16-20	20-24
Load (MW)	40	50	60	50	70	40

Draw the load curve and find

- Maximum demand
- Units generated per day
- Average load

iv. Load factor.

AKTU 2023-24, Marks 10

Answer

i. Maximum demand, MD = 70 MW

ii. Units generated during 24 hours

$$\begin{aligned}
 &= 70 \times 4 + 60(6 - 4) + 50(14 - 6) + 40(24 - 14) \\
 &= 280 + 120 + 400 + 400 \\
 &= 1200 \text{ MWh or } 12 \times 10^5 \text{ kWh}
 \end{aligned}$$

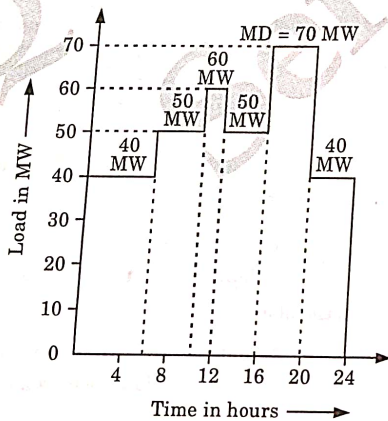


Fig. 1.19.1. Load curve.

- Average load = $\frac{\text{Energy generated in MWh during the day}}{24}$
 $= \frac{1200}{24} = 50 \text{ MW}$
- Load factor = $\frac{\text{Average load}}{\text{Maximum demand}} = \frac{50}{70} = 0.714 \text{ or } 71.4 \%$

PART-9

Role of Load Diversity in Power System Economy, Load Sharing between Base Load and Peak Load.

Que 1.20. What is load diversity ? Also explain the role of load diversity in power system economy.

Answer

A. Load diversity : Load diversity in a power system refers to the variation in electricity demand across different consumers and sectors over time. It plays a crucial role in optimizing the economic efficiency of power systems.

B. Role of load diversity in power system economy :

- Reduces the need for expensive peak power plants.
- Improves overall system efficiency.
- Lowers operational and infrastructure costs.
- Enhances reliability and stability of the power supply.
- Optimizes the use of existing resources.
- Supports better integration of renewable energy sources.

Que 1.21. Discuss about load sharing between base load and peak load.

Answer

- Load sharing between base load and peak load involves strategically distributing electricity generation to match varying demand.
- Base load refers to the continuous, stable demand met by base-load plants (e.g., coal, nuclear) that operate efficiently at a steady output.

3. Peak load denotes temporary, high demand during specific periods, addressed by peaking plants (e.g., gas turbines) that can quickly adjust output.
4. Base-load plants provide consistent power, while peaking plants handle demand spikes.
5. This approach optimizes overall system efficiency, reduces operational costs, and ensures a reliable power supply, balancing the steady generation with the ability to meet sudden increases in demand.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. What are the conventional and non conventional sources of energy? Explain with examples.

Ans: Refer Q. 1.3.

Q. 2. Give the layout of hydro-electric power plant and explain its components in detail.

Ans: Refer Q. 1.4.

Q. 3. Give the layout of thermal power plant and explain its components in details.

Ans: Refer Q. 1.6.

Q. 4. With neat sketch, describe the nuclear power plant.

Ans: Refer Q. 1.7.

Q. 5. Explain in detail the nuclear reaction theory and working principle of a nuclear power station with plant layout.

Ans: Refer Q. 1.8.

Q. 6. Define and explain the importance of the following terms in generation: (i) Connected load (ii) Maximum demand (iii) Diversity factor (iv) Average load.

Ans: Refer Q. 1.15.

Q. 7. A plant having daily energy production and plant factor is 1296 MWhr and 50 % respectively. Calculate the maximum rating of the power plant.

Ans: Refer Q. 1.18.

Q. 8. What is load diversity? Also explain the role of load diversity in power system economy.

Ans: Refer Q. 1.20.



Quantum Series

2

UNIT

Transmission and Distribution of Electric Power-I

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System, Choice of Transmission Voltage
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Lines : Types of Conductors, Bundled
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2-1 B (EN-Sem-5)

2-2 B (EN-Sem-5)

Transmission & Distribution of Electric Power-I

PART-1

Single Line Diagram of Power System,
Choice of Transmission Voltage.

Que 2.1. Draw and explain single line diagram of power system.

Answer

1. A single-line diagram of a power system illustrates the flow of electrical power from generation to utilization.
2. It typically includes the generating station, step-up transformers, high-voltage transmission lines, substations, step-down transformers, distribution lines, and finally, the load or utilization level.
3. The diagram simplifies complex electrical systems by representing components and connections with single lines.



Fig. 2.1.1. Single line representation of a typical power system.

4. In a single line diagram, the system components are usually drawn in the form of their symbols.

S.No.	Components	Symbol
1.	Motor or generator	
2.	Two winding transformer	
3.	Transmission line	
4.	Liquid (oil) circuit breaker	
5.	Air circuit breaker	
6.	Delta connection	
7.	Y-connection, ungrounded	
8.	Y-connection, grounded	

Que 2.2. Draw single line diagram of a four-bus system having generator G_1 connected to bus-1 through transformer T_1 , generator G_2 connected to bus-2 through transformer T_2 , load A and load B connected to bus-3 through transformer T_3 , four synchronous motors M_1 to M_4 connected to bus-4 through transformer T_4 , transmission lines TL_1 , TL_2 , TL_3 and TL_4 connected between bus 1, 2, 2-3, 3-4 and 4-1 respectively.

AKTU 2021-22, Marks 10

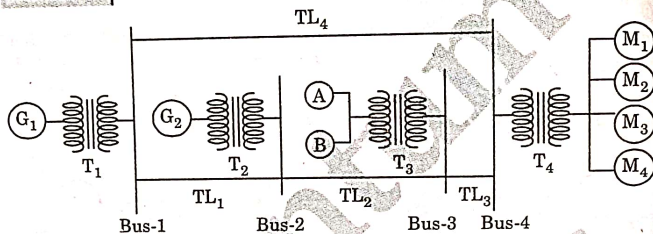
Answer

Fig. 2.2.1.

Que 2.3. Discuss choice of transmission voltage in power system.

Answer

While selecting an optimum transmission voltage following two factors are to be considered :

- Power to be transmitted :** If the power to be transmitted is large, large generating and transforming units are required which reduces the cost per kW of terminal station equipment.
- Distance of transmission line :** If power is transmitted over a long distance then the cost of terminal equipments is decreased which causes reduction in overall cost of transmission.
- Above two terms can be related in an empirical formula which is as follows :

$$V = 5.5 \left[\frac{L}{1.6} + \frac{P}{100} \right]^{0.5}$$

where,

 V = Line voltage in kV L = Distance of line in km P = Power to be transmitted in kW

A standard voltage nearest to this calculated value should be selected.

4. Following are voltages which are generally adopted :

Generation = 6.6 kV, 11 kV

Primary transmission = 132 kV, 220 kV, 400 kV

Secondary transmission = 11 kV, 22 kV, 33 kV

Primary distribution = 11 kV, 22 kV, 33 kV

Secondary distribution = 440 V

PART-2

One-Line diagram, Impedance and Reactance Diagram, Per Unit System Changing the Base of Per Unit Quantities, Advantages of Per Unit System.

Que 2.4. What do you understand by impedance and reactance diagram ?

OR

What is the single line diagram of power system from generating station to utilization level ? Obtain reactance diagram for any arbitrary chosen power system.

AKTU 2020-21, Marks 10

Answer

Single line diagram of power system : Refer Q, 2.1, Page 2-2B, Unit-2.

Impedance and reactance diagram :

- In the impedance diagram, the different components of the power system are replaced by their equivalent circuits.
- The synchronous generator is replaced by a constant voltage source behind proper impedance.
- The transformer is replaced by its equivalent circuit.
- The transmission line is replaced by nominal π -equivalent circuit.

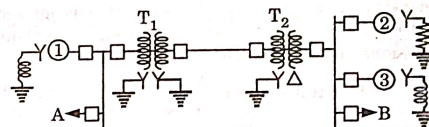


Fig. 2.4.1. One line representation of a simple power system.

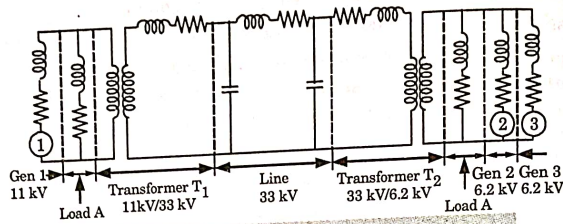


Fig. 2.4.2. Impedance diagram of the power system.

- This is only true for normal operation (i.e., for steady-state analysis) when both excitation and three-phase network are balanced and they can be analysed on per phase basis.
- In many power system studies the synchronous generator resistance, resistance of transformer windings, resistance of transmission lines, line charging and magnetizing circuits of transformer are neglected. The impedance diagram then becomes the reactance diagram.

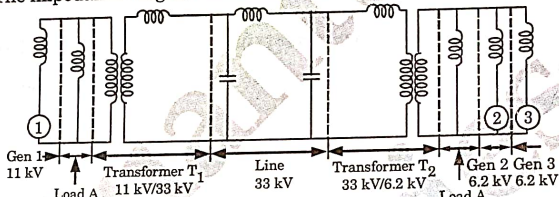


Fig. 2.4.3. Reactance diagram of the power system.

Que 2.5. What do you understand by "PER UNIT SYSTEM" ? What are the significances in power system ? And give its advantages.

Answer

A. Per unit system :

- The numerical per unit (pu) value of any quantity is defined as the ratio of its actual value to another arbitrarily chosen value of quantity of the same dimensions, assumed as the base or reference.

$$\text{Per unit value} = \frac{\text{Actual value of quantity}}{\text{Base value of quantity}}$$

- The following relationship holds on a per phase basis :

$$\text{Base current} = \frac{\text{Base volt amperes}}{\text{Base voltage}} \quad (\text{in amperes})$$

$$\text{Base impedance} = \frac{\text{Base voltage}}{\text{Base current}} \quad (\text{in ohm})$$

- In a three phase system the base kVA may be chosen as the three phase kVA and the base voltage as the line-to-line voltage or the base values may be taken as the phase quantities.
- Change of base :**
(per unit impedance)_{new base} =

$$\frac{(VA)_{\text{new base}} (kV)_{\text{old base}}^2}{(VA)_{\text{old base}} (kV)_{\text{new base}}^2} \times (\text{pu impedance})_{\text{old base}}$$

B. Significances :

- The ordinary parameters (current, impedance, losses, etc.) vary considerably with the variation of physical size, terminal voltage, power rating, etc., while the per unit parameters are independent of these quantities over a wide range of the same type of apparatus.
- Per unit values provide more meaningful information.
- A per unit phase quantity has the same numerical value as the corresponding per unit line quantity regardless of the three-phase connection whether star or delta.
- The impedances of machines are specified by the manufacturers in terms of per unit values.
- The per unit impedance referred to either side of a single or three-phase transformer is the same.

C. Advantages :

- Per unit system leads to great simplification of 3 ϕ networks involving transformers.
- Unit values can be obtained directly by using 3 ϕ base quantities.

PART-3

Different Kinds of Supply System and their Comparison.

Que 2.6. Classify different types of supply system and compare the volume of conductor DC two wire system and 3- ϕ 3-wire system.

AKTU 2023-24, Marks 10

Answer

- In overhead system, maximum voltage between each conductor and earth forms the basis of comparison.
- Maximum voltage to earth is same.

a. DC Systems :

i. DC 2-Wire system with one conductor earthed :

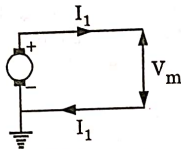


Fig. 2.6.1.

- Maximum voltage between conductors = V_m volts
Power to be transmitted = P watts

Load current, $I_1 = \frac{P}{V_m}$

- Line losses, $W = 2I_1^2 R_1 = 2 \left(\frac{P}{V_m} \right)^2 \rho \frac{l}{a_1} \quad \left[R_1 = \rho \frac{l}{a_1} \right]$

- Area of cross section of conductor, $a_1 = \frac{2\rho P^2 l}{W V_m^2}$

- Volume of conductor material required = $2a_1 l = \frac{4\rho P^2 l^2}{W V_m^2} = K$ (say)

ii. DC two-wire system with midpoint earthed :

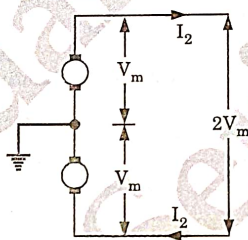


Fig. 2.6.2.

- Load current, $I_2 = \frac{P}{2V_m}$

- Line losses, $W = 2I_2^2 R_2 = 2 \left(\frac{P}{2V_m} \right)^2 \rho \frac{l}{a_2} = \frac{P^2 \rho l}{2a_2 V_m^2}$

- $a_2 = \frac{P^2 \rho l}{2W V_m^2}$

- Volume of conductor material required = $2a_2 l = \frac{P^2 \rho l^2}{W V_m^2} = 0.25 K$

- Hence volume of conductor material required is one-fourth of that required in two-wire DC system with one conductor earthed.

iii. DC three-wire system :

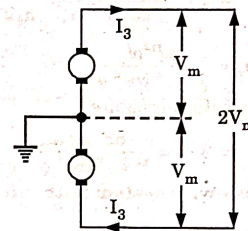


Fig. 2.6.3.

- Load current, $I_3 = \frac{P/2}{V_m} = \frac{P}{2V_m}$

- Line losses, $W = 2I_3^2 R_3 = 2 \left(\frac{P}{2V_m} \right)^2 \rho \frac{l}{a_3} = \frac{P^2 \rho l}{2a_3 V_m^2}$

$$a_3 = \frac{P^2 \rho l}{2W V_m^2}$$

- Assuming area of cross section of neutral wire as half of that of any of the outers.

$$\text{Volume of conductor material required} = 2.5a_3 l = \frac{2.5P^2 \rho l^2}{2W V_m^2} = 0.3125 K$$

b. Single-phase AC systems :

i. AC single-phase two-wire system with one conductor earthed :

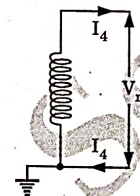


Fig. 2.6.4.

- Peak value of voltage between conductors = V_m volts

$$\text{RMS value of voltage between conductors} = \frac{V_m}{\sqrt{2}} \text{ volts}$$

$$\text{Load current, } I_4 = \frac{P}{\frac{V_m}{\sqrt{2}} \cos \phi} = \frac{\sqrt{2}P}{V_m \cos \phi}$$

where $\cos \phi$ is the power factor of the load

- Line losses, $W = 2I_4^2 R_4$

$$= 2 \left(\frac{\sqrt{2}P}{V_m \cos \phi} \right)^2 \frac{\rho l}{a_4} = \frac{4P^2 \rho l}{a_4 V_m^2 \cos^2 \phi}$$

$$a_4 = \frac{4P^2 \rho l}{W V_m^2 \cos^2 \phi}$$

Volume of conductor material required

$$= 2a_4 l = \frac{8P^2 \rho l^2}{W V_m^2 \cos^2 \phi} = \frac{2}{\cos^2 \phi} K$$

ii. AC single-phase two-wire system with midpoint earthed :

1. Load current, $I_5 = \frac{P}{\sqrt{2}V_m \cos \phi}$

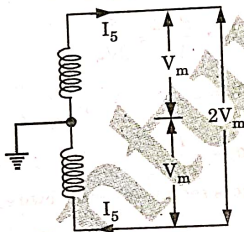


Fig. 2.6.5.

2. Line losses, $W = 2I_5^2 R_5 = 2 \left(\frac{P}{\sqrt{2}V_m \cos \phi} \right)^2 \frac{\rho l}{a_5} = \frac{P^2 \rho l}{a_5 V_m^2 \cos^2 \phi}$

$$a_5 = \frac{P^2 \rho l}{W V_m^2 \cos^2 \phi}$$

3. Volume of conductor material required

$$= 2a_5 l = \frac{2P^2 \rho l^2}{W V_m^2 \cos^2 \phi} = \frac{0.5 K}{\cos^2 \phi}$$

iii. AC single-phase three-wire system :

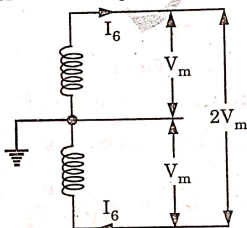


Fig. 2.6.6.

1. Load current, $I_6 = \frac{P/2}{\frac{V_m}{\sqrt{2}} \cos \phi} = \frac{P}{\sqrt{2}V_m \cos \phi}$

2. Line losses, $W = 2I_6^2 R_6 = 2 \left(\frac{P}{\sqrt{2}V_m \cos \phi} \right)^2 \frac{\rho l}{a_6} = \frac{P^2 \rho l}{a_6 V_m^2 \cos^2 \phi}$

$$a_6 = \frac{P^2 \rho l}{W V_m^2 \cos^2 \phi}$$

3. Volume of conductor material required

$$= 2.5a_6 l = \frac{2.5P^2 \rho l^2}{W V_m^2 \cos^2 \phi} = \frac{0.625 K}{\cos^2 \phi}$$

c. Two-phase AC system :

i. AC two-phase four-wire system :

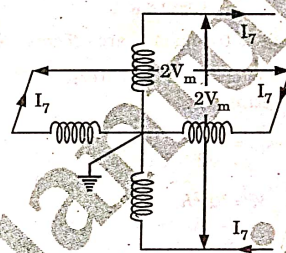


Fig. 2.6.7.

1. Load supplied by each phase = $\frac{P}{2}$

2. $I_7 = \frac{P/2}{2\sqrt{2}V_m \cos \phi} = \frac{P}{4\sqrt{2}V_m \cos \phi}$

3. Line losses, $W = 4I_7^2 R_7 = 4 \left(\frac{P}{4\sqrt{2}V_m \cos \phi} \right)^2 \frac{\rho l}{a_7} = \frac{P^2 \rho l}{2V_m^2 a_7 \cos^2 \phi}$

$$a_7 = \frac{P^2 \rho l}{2V_m^2 W \cos^2 \phi}$$

4. Volume of conductor material required

$$= 4a_7 l = \frac{2P^2 \rho l^2}{V_m^2 \cos^2 \phi W} = \frac{0.5 K}{\cos^2 \phi}$$

ii. AC two-phase three-wire system :

1. Current in each of outer conductors, $I_8 = \frac{P/2}{V_m / \sqrt{2} \cos \phi} = \frac{P}{\sqrt{2} V_m \cos \phi}$
2. Current in neutral wire = $\sqrt{(I_8^2 + I_8^2)} = \sqrt{2} I_8$

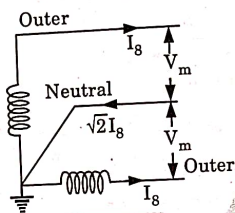


Fig. 2.6.8.

3. Assuming current density constant, area of cross section of neutral wire is $\sqrt{2}$ times of that of either of the outers.
So resistance of neutral wire

$$= \frac{R_8}{\sqrt{2}} = \frac{\rho l}{\sqrt{2} a_8}$$

4. Line losses, $W = 2I_8^2 R_8 + (\sqrt{2} I_8)^2 \frac{R_8}{\sqrt{2}}$
 $= I_8^2 \frac{\rho l}{a_8} (2 + \sqrt{2}) = \frac{P^2 \rho l}{2 V_m^2 \cos^2 \phi a_8} (2 + \sqrt{2})$
 $a_8 = \frac{P^2 \rho l}{2 V_m^2 W \cos^2 \phi} (2 + \sqrt{2})$

5. Volume of conductor material required
 $= 2a_8 l + \sqrt{2} a_8 l = a_8 l (2 + \sqrt{2})$
 $= \frac{P^2 \rho l^2}{2 V_m^2 W \cos^2 \phi} (2 + \sqrt{2})^2$
 $= \frac{P^2 \rho l^2}{2 V_m^2 W \cos^2 \phi} (\sqrt{2} + 1)^2 = \frac{1.457}{\cos^2 \phi} K$

d. 3-phase AC systems :

i. AC 3-phase 3-wire system :

1. Load current per phase, $I_9 = \frac{P/3}{\frac{V_m}{\sqrt{2}} \cos \phi} = \frac{\sqrt{2} P}{3 V_m \cos \phi}$
2. Line losses, $W = 3 I_9^2 R_9$

$$= 3 \left(\frac{\sqrt{2} P}{3 V_m \cos \phi} \right)^2 \frac{\rho l}{a_9} = \frac{2 P^2 \rho l}{3 V_m^2 \cos^2 \phi a_9}$$

$$a_9 = \frac{2 P^2 \rho l}{3 V_m^2 W \cos^2 \phi}$$

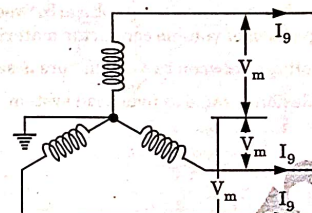


Fig. 2.6.9.

3. Volume of conductor material required

$$= 3 a_9 l = \frac{2 P^2 \rho l^2}{V_m^2 W \cos^2 \phi} = \frac{0.5 K}{\cos^2 \phi}$$

ii. AC 3-phase 4-wire system :

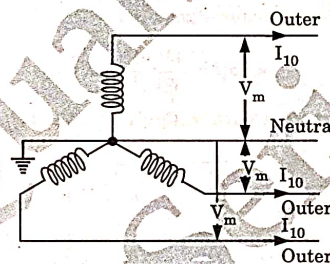


Fig. 2.6.10.

1. Assuming balanced load, there will be no current in neutral wire and copper losses will be same as in 3-phase 3-wire system

$$i.e., \quad W = \frac{2 P^2 \rho l}{3 V_m^2 \cos^2 \phi a_{10}}$$

$$a_{10} = \frac{2 P^2 \rho l}{3 V_m^2 \cos^2 \phi W}$$

2. Taking cross section of neutral wire as half of either outer.
Volume of conductor material required

$$= 3.5 a_{10} l = \frac{7 \rho P^2 l^2}{3 \cos^2 \phi V_m^2 W} = \frac{0.583}{\cos^2 \phi} K$$

Que 2.7. Discuss comparison of cost of conductors for underground systems.

Answer

1. In the underground system, maximum voltage between conductors forms the basis of comparison of volume conductor material required.
2. The maximum voltage between two conductors is same (say, V_m volts).
3. Remaining calculation is same as overhead system.

a. DC systems :

i. DC two-wire system :

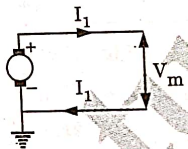


Fig. 2.7.1.

Volume of conductor material required

$$= 2a_1 l = \frac{4P^2 \rho l^2}{WV_m^2} = K \text{ (say)}$$

ii. DC two-wire system with midpoint earthed :

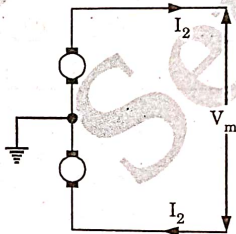


Fig. 2.7.2.

Volume conductor material required

$$= \frac{4P^2 \rho l^2}{WV_m^2} = K$$

iii. DC three-wire system :

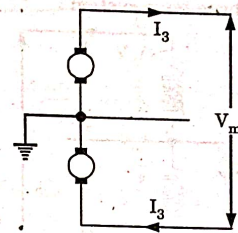


Fig. 2.7.3.

$$\text{Volume of conductor material required} = 2.5a_3 l = \frac{5P^2 \rho l^2}{V_m^2 W} = 1.25 K$$

b. Single-phase AC systems :

i. AC single-phase two-wire system :

Volume of conductor material required

$$= 2a_4 l = \frac{8P^2 \rho l^2}{V_m^2 \cos^2 \phi W} = \frac{2K}{\cos^2 \phi}$$

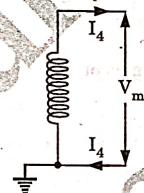


Fig. 2.7.4.

ii. AC single-phase two-wire system with midpoint earthed :

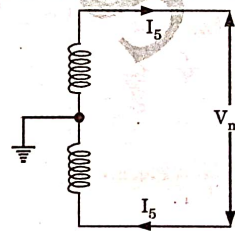


Fig. 2.7.5.

This system is the same as a 2-wire single-phase AC system.

iii. AC single-phase three-wire system :

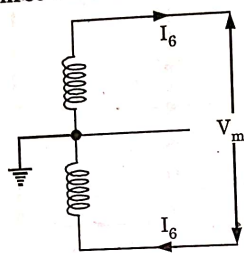


Fig. 2.7.6.

Volume of conductor material required

$$= 2.5a_4l = \frac{10\rho P^2 l^2}{V_m^2 \cos^2 \phi W} = \frac{2.5}{\cos^2 \phi} K$$

c. Two-phase AC systems :

- i. AC two-phase four-wire system : This system is equivalent to two-wire AC system. In this case cross section area of each conductor is taken half of that of single phase two-wire AC system but four wires are required in place of two wires, so the same volume of conductor material is required i.e., $\frac{2}{\cos^2 \phi}$ times of that required in case of two-wire DC system.

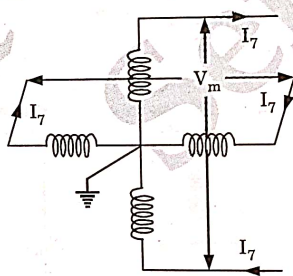


Fig. 2.7.7.

ii. AC two-phase three-wire system :

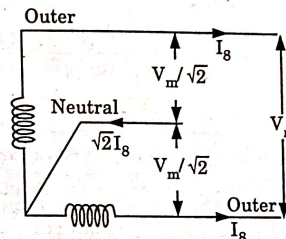


Fig. 2.7.8.

$$\text{Volume of conductor material required} = \frac{2.914 K}{\cos^2 \phi}$$

d. 3-phase AC systems :

i. AC three-phase three-wire system :

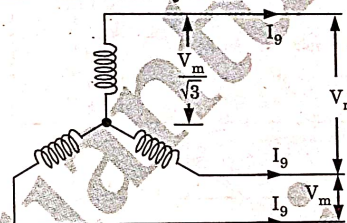


Fig. 2.7.9.

Volume of conductor material required

$$= 3a_9l = \frac{6P^2 \rho l^2}{V_m^2 \cos^2 \phi W} = \frac{1.5}{\cos^2 \phi} K$$

ii. AC three-phase four-wire system :

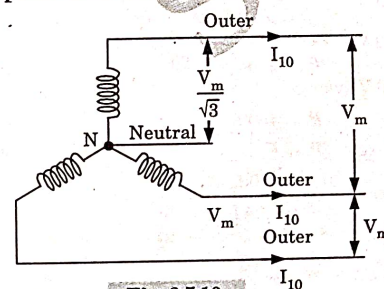


Fig. 2.7.10.

Volume of conductor material required

$$= 3.5a_9 l = \frac{7P^2 \rho l^2}{V_m^2 \cos^2 \phi W} = \frac{1.75 K}{\cos^2 \phi}$$

Table 2.7.1.

S. No.	System	Volume of conductor material required	
		Maximum voltage between conductor and earth	Maximum voltage between any two conductors
1.	DC System :		
i.	Two-wire	1	1
ii.	Two-wire with mid-point earthed	0.25	1
iii.	Three-wire	0.3125	1.25
2.	AC single phase system :		
i.	Two-wire	$\frac{2}{\cos^2 \phi}$	$\frac{2}{\cos^2 \phi}$
ii.	Two-wire with mid-point earthed	$\frac{0.5}{\cos^2 \phi}$	$\frac{2}{\cos^2 \phi}$
iii.	Three wire	$\frac{0.625}{\cos^2 \phi}$	$\frac{2.5}{\cos^2 \phi}$
3.	AC two-phase system :		
i.	Two-phase four-wire	$\frac{0.5}{\cos^2 \phi}$	$\frac{2}{\cos^2 \phi}$

Que 2.8. What is the percentage saving in copper feeder if the line voltage in a 2-wire DC system is raised from 220 V to 450 V for the same power transmitted over the same distance and having the same power loss ?

Answer

- Power, $P = VI$
- Power in 220 V system
 $P_1 = 220 I_1$
- Power in 450 V system
 $P_2 = 450 I_2$
- As given, $P_1 = P_2$
 $220 I_1 = 450 I_2$
 $I_1 = 2.04 I_2$
- Now power loss,
 $W = 2I^2 R$
 $W_1 = 2I_1^2 R_1 = 2(2.04 I_2)^2 R_1$

$$= 8.32 I_2^2 R_1$$

And $W_2 = 2I_2^2 R_2$

6. As given, $W_1 = W_2$
 $8.32 I_2^2 R_1 = 2I_2^2 R_2$

$$\frac{R_2}{R_1} = 4.16$$

$$\frac{A_1}{A_2} = 4.16 \quad \left(R \propto \frac{1}{\text{Area}} \right)$$

$$\frac{V_1}{V_2} = 4.16 \quad (A \propto \text{Volume})$$

7. % Saving = $\left(1 - \frac{V_2}{V_1} \right) \times 100$
 $= (1 - 0.24) \times 100 = 76 \%$

PART-4

Configurations of Transmission Lines : Types of Conductors, Bundled Conductors, Resistance of Line, Skin Effect.

Que 2.9. Explain different types of conductors in power system.

Answer

Conductors which are generally used for transmission lines are :

A. Hard-Drawn Copper Conductor :

- It is mostly used for short lines for voltages up to 33 kV. It has high electrical conductivity and long life.
- It is most suitable for distribution work where tapings are more. Also hard drawn copper has high tensile strength.

B. Aluminium Conductor Steel Reinforced (ACSR) :

- ACSR is used for high voltage lines having large span and heavy weight is to be supported.
- Aluminium alone cannot be used for construction of long span transmission line due to low mechanical strength. So to make it strong we use steel wire in the core aluminium conductors.

C. Cadmium Copper Conductor :

- By adding cadmium to copper, the strength can be increased to 50 percent but the conductivity decreases by 15 percent.
- Due to high tensile strength the longer spans of transmission line can be erected with same sag.

3. This conductor is widely used in hilly areas.

D. Steel Cored Copper Conductor (SCC) :

1. In SCC a steel wire is surrounded by layers of copper strands. Steel core increases the tensile strength of conductor. So the overall strength of conductor increases.
2. Bituminized cotton tape is used between the steel core and copper strands to protect conductor from the galvanic action.

E. Hard-Drawn Aluminium Conductor :

1. Due to increase in the cost of copper, the aluminium is replacing copper for transmission work. For a given resistance the cross-section of aluminium is greater while weight is lesser.
2. So handling, transportation and erection of aluminium conductor lines is economical. For conductor use, aluminium is electrolytically refined and is rolled and hard drawn.
3. These conductors are used in urban areas having short transmission lines with lower voltages. Corona effect is also reduced due to higher conductor diameter.

F. Phosphor-Bronze Conductor :

1. Phosphor-Bronze Conductor is stronger than copper conductor, but has a low conductivity. Its conductivity can be improved by using cadmium copper core.
2. It is generally used as a conductor material where very long spans are required such as river crossings.

G. Galvanized Steel Conductor :

1. This conductor is used for very long spans particularly in rural areas where load is small. These conductors have high tensile strength.
2. Galvanized steel conductor is a magnetic material having large resistance, inductance and voltage drop. It has comparatively short life.

Que 2.10. What is a bundle conductor and how does the use of bundled conductor reduce corona loss in EHV line ?

Answer

1. A bundled conductor is a conductor made up of two or more conductors, called the sub-conductors, per phase in close proximity compared with the spacing between phases Fig. 2.10.1.
2. A bundled conductor is the sub-conductors of a bundled conductor separated from each other by a constant distance varying from 0.2 m to 0.6 m depending upon designed voltage and surrounding conditions throughout the length of the line with the help of spacers.
3. The bundled conductors have filter material or air space inside so that the overall diameter is increased.

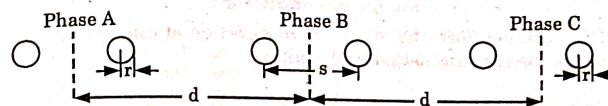


Fig. 2.10.1.

4. The use of bundled conductors per phase reduces the voltage gradient in the vicinity of the line and thus, reduces the possibilities of the corona discharge.
5. Hence the bundled conductors are used on EHV transmission lines to reduce corona loss and radio interference.

Que 2.11. Explain resistance of transmission line. Also discuss effect of skin effect on effective resistance of conductor.

OR

What is Skin effect ?

Answer

A. Resistance of transmission line :

1. Every electric conductor offers opposition to the flow of current and this opposition is called the resistance.
2. The resistance of a solid conductor (wire) is given by

$$R = \frac{\rho l}{a}$$

where,

ρ = Resistivity of conductor

l = Length of conductor

a = Cross-sectional area of conductor

B. Skin effect :

1. When a direct current flows through a conductor, it is uniformly distributed in a conductor.
2. But when an alternating current passes through a conductor, it is non-uniformly distributed in cross section of the conductor.
3. Due to which current density at the surface of conductor is higher than the current density at the centre of the conductor. This effect is known as skin effect.

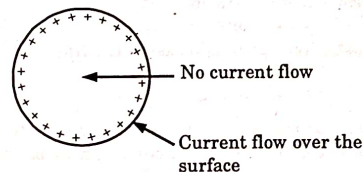


Fig. 2.11.1.

C. Skin effect on resistance of conductor :

1. Due to skin effect, the effective cross-section of conductor, through which the current flows, is reduced.
2. Since, resistance $\propto \frac{1}{\text{Area of cross-section}}$. Hence, skin effect increases effective resistance of conductor.

PART-5*Kelvin's Law, Proximity Effect.*

Que 2.12. State and prove Kelvin's law for size of conductor for transmission line. Discuss its limitations.

AKTU 2023-24, Marks 10**Answer**

A. Kelvin's law : The most economical area of conductor is that for which the total cost of transmission line is minimum. This is known as Kelvin's law.

B. Derivation :

1. Total annual cost consists of two parts :
 - i. **The fixed standing charges :** The fixed charges consist of the interest on the capital cost of the conductor, the allowance for depreciation, and the maintenance cost.
 - ii. **The running charges :** The running charges consist of cost of electrical energy wasted due to losses during operation.
2. But, the capital cost (the interest and depreciation on it) and cost of electrical energy wasted in the line are governed by the size of the conductor.
3. The interest and depreciation on the initial investment will be directly proportional to the area of cross-section of the conductor.
4. The cost of energy loss will be inversely proportional to the conductor cross-section.
5. Mathematically,

- i. Annual interest and depreciation cost
 $C_1 \propto a$ or $C_1 = K_1 a$
 and annual cost of energy dissipated in the line

$$C_2 \propto 1/a \text{ or } C_2 = \frac{K_2}{a}$$

where K_1 and K_2 are constants, and a represents the area of cross-section of conductor. The total annual cost may be given by

$$C = C_1 + C_2 = K_1 a + \frac{K_2}{a}$$

- ii. For an economical design there will be one size of conductor at which the total cost is minimum.
- iii. For the most economical cross-section, the total annual cost is differentiated with respect to the cross-section and the result is equated to zero.

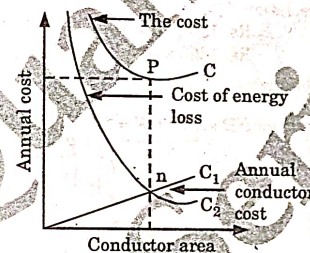
$$\frac{dC}{da} = 0$$

$$\frac{d}{da} \left(K_1 a + \frac{K_2}{a} \right) = 0$$

$$K_1 - \frac{K_2}{a^2} = 0; K_1 a = \frac{K_2}{a}$$

$$C_1 = C_2 \text{ and } a = \sqrt{\frac{K_2}{K_1}} \quad \dots(2.12.1)$$

- iv. Hence the most economical cross-sectional area of the conductor is that which makes the annual cost of energy loss equal to the annual interest and depreciation on the capital cost of the conductor material. This is known as Kelvin's law.

**Fig. 2.12.1.** Graphical representation of Kelvin's law.**C. Limitations :**

1. Total amount of energy losses cannot be estimated accurately due to difference in load, load factors and future load conditions, which are difficult to predict accurately.
2. Cost of energy loss is difficult to calculate because prices of conductor material and the rates of interest are continuously changing.
3. Two systems having same energy demand can have different cost due to different energy costs.

Que 2.13. Determine the best current density in amperes/mm² for a three phase overhead line. The line is in use for 3600 hours per year and if the conductor costs Rs. 3.0/kg. It has a specific resistance of $1.73 \times 10^{-8} \Omega\text{-m}$ and weights 6200 kg/m³ cost of energy is 12 paise/unit. Interest and depreciation is 10 % of conductor cost.

Answer

Given : Line in use = 3600 hours per year;
Conductor costs = Rs. 3 per kg; $\rho = 1.73 \times 10^{-8} \Omega\text{-m}$
Weights = 6200 kg/m³; Cost of energy = 12 paise/unit.
To Find : Current density in amperes/mm².

1. l = Length of each conductor
 a = Area of cross section
2. Volume of conductor = $la \times 6200 \text{ kg}$
= $6200 \times la \text{ kg}$
3. Capital cost of the conductor
= Rs. $3 \times la \times 6200$
= Rs. $18600 \times la$
4. Interest and depreciation
= Rs. $186 \times la \times 10$
= Rs. $1860 \times la$
5. Copper loss per conductor
= $I^2 R \times 10^{-3} \text{ kW} = I^2 \left[\frac{\rho l}{a} \right] \times 10^{-3}$
= $I^2 \left[1.73 \times 10^{-6} \times \frac{l}{a} \right] \times 10^{-3}$
= $I^2 \times 1.73 \times 10^{-9} \frac{l}{a}$
= $1.73 \times 10^{-9} \times I^2 \frac{l}{a} \text{ kW}$
6. According to Kelvin's law, the two costs should be equal for the best current density.

$$1860 la = 1.73 \times 10^{-9} \times I^2 \frac{l}{a}$$

$$\frac{I^2}{a^2} = \frac{1860}{1.73} \times 10^9$$

$$\frac{I}{a} = 1.03 \times 10^6 \text{ A/mm}^2$$

Que 2.14. Briefly explain proximity effect.

Answer**Proximity effect :**

1. When two or more conductors are near to each other, their magnetic field interacts and it results in circulating currents inside the conductor. This effect is known as proximity effect.
2. Due to proximity effect, the current in each conductor is redistributed and it flows through that part of conductor which is farthest from the other conductors. This effect results in apparent increase in resistance of conductor.
3. Proximity effect can be influenced by following factors :
i. Size of conductor
ii. Frequency of supply
iii. Resistivity of material
iv. Distance between conductors.

Que 2.15. Explain difference between skin effect and proximity effect. What is the percentage saving in copper feeder if the line voltage in a 2-wire DC system is raised from 220 V to 450 V for the same power transmitted over the same distance and having the same power loss ?

AKTU 2021-22, Marks 10

Answer**A. Difference :**

S.No.	Aspect	Skin effect	Proximity effect
1.	Occurrence	In single conductors carrying AC current.	In closely spaced conductors carrying AC current.
2.	Frequency dependency	More pronounced at higher frequencies.	More pronounced at lower frequencies.
3.	Effect on resistance	Increases effective resistance of the conductor.	Increases resistance of each conductor due to unequal current distribution.
4.	Application	Significant in high-frequency applications.	Significant in high-current, low-frequency applications.
5.	Importance in power systems	Less significant in power transmission lines due to lower frequencies involved.	Can be significant in high-current power transmission lines with parallel conductors.

B. Numerical : Refer Q. 2.8, Page 2-17B, Unit-2.

PART-6

Corona Effect, Factors Affecting the Corona, Corona Power Loss, Advantages and Disadvantages.

Que 2.16. What is corona ? Discuss phenomenon of corona and how it is formed.

Answer

A. **Corona** : The phenomenon of violet glow, hissing noise and production of ozone gas in an overhead transmission line is known as corona.

B. **Phenomenon of corona** :

1. When an alternating potential difference is applied across two conductors, whose spacing is large in comparison with their diameters, then the atmospheric air surrounding the conductors is subjected to electrostatic stresses.
2. At low voltage there is no change in the condition of atmospheric air around the conductors.
3. However, when the potential difference is gradually increased, a stage arrives when a luminous glow of violet colour appears together with a hissing noise and production of ozone gas.
4. If the potential difference is raised still further, the glow and the noise will increase until a spark-over owing to breakdown of air insulation will take place.

C. **Theory of corona formation** :

1. The air around the conductor contains a number of free electrons. When the potential is applied between the two conductors a potential gradient is established and under its influence the electrons acquire a uniformly increasing acceleration.
2. Thus, the free electrons attain speed and these free electrons collide with the other slow moving or neutral molecules and in the process dislodge electron from it.
3. When the potential gradient reaches about 30 kV (max. value) per cm, the velocity acquired by the free electrons dislodge one or more electrons from it.
4. These dislodged electrons and the previous free electrons strike other neutral molecules producing more number of electrons. When the saturation point is reached the insulating property of air is destroyed and the air becomes conducting and corona forms.

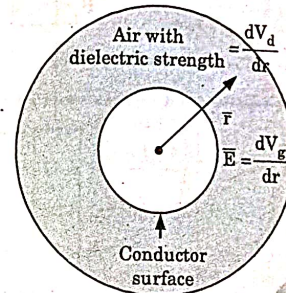


Fig. 2.16.1. Corona formation.

5. Corona occurs if

$$\frac{dV_d}{dr} < \frac{dV_g}{dr}$$

where,

$$\frac{dV_g}{dr} = \text{Electric potential at conductor surface}$$

$$\frac{dV_d}{dr} = \text{Dielectric strength}$$

where r is a radial vector, perpendicular to conductor surface.

If potential gradient (dV_g/dr) exceeds the dielectric strength (dV_d/dr) the corona occurs.

Que 2.17. Deduce expressions for critical disruptive voltage and visual critical voltage.

Answer

Critical disruptive voltage :

1. Let us consider the two-wire line shown in Fig. 2.17.1,

r = Radius of line conductor

d = Distance between their centres

$+q$ = Charge on conductor A

$-q$ = Charge on conductor B

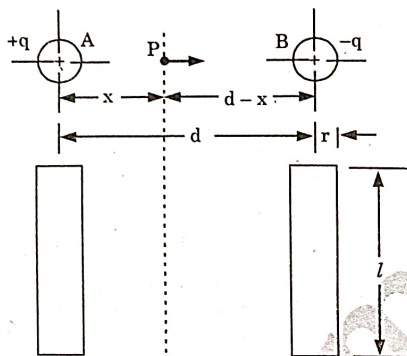


Fig. 2.17.1.

2. Consider point P at a distance of x metres from conductor A .
3. Electric field intensity at point P due to charge on conductor $A = \frac{q}{2\pi\epsilon_0 x}$ acting towards B .
4. Electric field intensity at point P due to induced charge on conductor $B = \frac{q}{2\pi\epsilon_0(d-x)}$ acting towards B .
5. Resultant electric field intensity at point P ,

$$E_x = \frac{q}{2\pi\epsilon_0 x} + \frac{q}{2\pi\epsilon_0(d-x)} = \frac{q}{2\pi\epsilon_0} \left(\frac{1}{x} + \frac{1}{d-x} \right)$$
6. Potential difference between conductors A and B ,

$$V = \int_r^{d-r} E_x dx = \int_r^{d-r} \frac{q}{2\pi\epsilon_0} \left(\frac{1}{x} + \frac{1}{d-x} \right) dx$$

$$= \frac{q}{2\pi\epsilon_0} [\log_e x - \log_e (d-x)]_r^{d-r} = \frac{q}{\pi\epsilon_0} \log_e \frac{d-r}{r}$$
7. Now, since r is very small as compared to d , $d-r \approx d$ and, therefore,

$$V = \frac{q}{\pi\epsilon_0} \log_e \frac{d}{r} \quad \dots(2.17.1)$$
8. Now gradient at any point x from the centre of the conductor A is given by

$$E_x = \frac{q}{2\pi\epsilon_0} \left(\frac{1}{x} + \frac{1}{d-x} \right) = \frac{q}{2\pi\epsilon_0} \frac{d}{x(d-x)} \quad \dots(2.17.2)$$
9. Substituting for q from eq. (2.17.1) in eq. (2.17.2), we have

$$E_x = \frac{\pi\epsilon_0 V}{\log_e \frac{d}{r}} \frac{1}{2\pi\epsilon_0} \frac{d}{x(d-x)} = \frac{V}{2 \log_e \frac{d}{r}} \frac{d}{x(d-x)}$$

and

$$E_x = \frac{V'}{\log_e \frac{d}{r}} \frac{d}{x(d-x)} \quad \dots(2.17.3)$$

where V' is the line to neutral voltage of the system.

10. In case of 3-phase system,

$$V' = \frac{\text{Line-to-Line voltage}}{\sqrt{3}} = \frac{V_L}{\sqrt{3}}$$

11. The potential gradient is maximum when $x = r$, and this value is given by

$$g_{\max} = E_r = E_{\max} = \frac{V'd}{r(d-r) \log_e \frac{d}{r}} = \frac{V'}{r \log_e \frac{d}{r}} \quad \dots(2.17.4)$$

where,

 r = Radius

12. When the disruptive gradient of air is reached at the conductor surface

$$g_0 = \frac{V_{d_0}}{r \log_e \frac{d}{r}}$$

Critical disruptive voltage,

$$V_{d_0} = g_0 r \log_e \frac{d}{r} \quad \dots(2.17.5)$$

The complete formula becomes

$$V_{d_0} = g_0 \delta m_0 r \log_e \frac{d}{r} \quad \dots(2.17.6)$$

where

 δ = Air density factor m_0 = Conductor surface condition factor.

13. The value of V_{d_0} is known as critical disruptive voltage, and is defined as the minimum phase to neutral voltage at which corona occurs.

Visual critical voltage :

1. Visual critical voltage is defined as the minimum phase to neutral voltage at which glow appears all along the line conductors.
2. Thus the visual critical voltage is

$$V_{v_0} = g_0 \delta m_v r \left(1 + \frac{0.3}{\sqrt{\delta r}} \right) \log_e \frac{d}{r} \text{ kV (rms) to neutral} \quad \dots(2.17.7)$$

where m_v = Roughness factor, which is unity for smooth conductors.

Que 2.18. Explain corona loss. Give advantages and disadvantages of corona loss.

Answer**A. Corona loss :**

1. Power wasted due to corona in lines is known as corona power loss.
2. F.W. Peek's formula for the corona loss for the single phase and equilaterally spaced 3 ϕ lines under fair weather conditions is given by, Peek's formula :

$$P_c = \frac{244}{\delta} (f + 25) \sqrt{\frac{r}{D}} (E_n - E_0)^2 \times 10^{-5} \text{ kW/km/phase}$$

where, P_c = Corona power loss

f = Frequency of supply

δ = Air density factor

E_n = Rms phase voltage (line to neutral)

E_0 = Disruptive critical voltage per phase

r = Radius of conductor

D = Spacing or equivalent spacing between conductors

For single phase,

$$E_n = \frac{1}{2} \times \text{line voltage}$$

For three phase,

$$E_n = \frac{1}{\sqrt{3}} \times \text{line voltage}$$

3. Peek's formula is not accurate when losses are low and E_n/E_0 is less than 1.8. In that condition, we use Peterson's formula.

Peterson's formula :

$$P_c = 2.1 f F \frac{E_n^2}{\left(\log_{10} \frac{D}{r}\right)^2} \times 10^{-5} \text{ kW/km/conductor}$$

where, P_c = Corona power loss

f = Supply frequency in hertz

E_n = Voltage per phase (line to neutral) voltage in kV (rms)

r = Radius of conductor in metres

F = Corona loss function

$$E_0 = g_{0\max} m_0 r \delta^{2/3} \ln \frac{D_{eq}}{r} \text{ V/phase (rms)}$$

D = Spacing

B. Advantages of corona loss :

1. Due to corona, the air surrounding the conductor is ionised and becomes conducting. This increases the virtual diameter of the conductor.
2. Corona reduces the effect produced by the surges and conductor is saved from possibility of lightning. It acts as a safety device.

C. Disadvantages of corona loss :

1. It reduces the transmission efficiency.
2. The third harmonic components produced due to corona makes the current non-sinusoidal. This increases the corona loss.
3. The ozone gas formed due to corona chemically reacts with the conductor and can cause corrosion.

Que 2.19. Write short note on the factors affecting the "Corona" losses.

OR

Explain corona effect and the factors affecting the corona. Write its disadvantages.

Answer**Factors affecting corona :**

1. **Effect of frequency :** Corona loss depends on the supply frequency. Higher the supply frequency, higher is the corona loss.
2. **Line voltage :** The line voltage directly affects the corona and the corona loss. For lower line voltage corona may be absent. But for voltages higher than disruptive voltage, corona starts. Higher the line voltage, higher is the corona loss.
3. **Atmospheric conditions :** The pressure and temperature together decide the value of δ which affects the disruptive voltage and the corona loss. Lower the value of δ , higher is the corona and vice-versa.
4. **Size of the conductor :** The corona loss is directly proportional to square root of radius of conductor. Hence, loss is more if size of conductor is more.
5. **Surface conditions :** The corona depends on the surface conditions. For rough and uneven surfaces, the value of disruptive voltage is less and corona effect is dominant. Similarly corona loss is also more for rough and dirty surfaces.
6. **Number of conductors per phase :** For higher voltages a single conductor per phase produces large corona loss. Hence bundled conductors are used due to which self GMD of the conductor δ increases, which increases the disruptive voltage, reducing corona loss.
7. **Spacing between conductors :** If the spacing is made very large, corona can be absent.
8. **Clearance from ground :** The height of the conductors from the ground also affects the corona loss. The smaller the clearance of the conductors from the ground, higher is the corona loss.

Corona effect : Refer Q. 2.16, Page 2-25B, Unit-2.

Disadvantages of corona : Refer Q. 2.18, Page 2-28B, Unit-2.

Que 2.20. What are the methods of reducing corona loss ?

Answer

Methods of reduced corona :

- Voltage of the line :** There is negligible corona loss below disruptive critical voltage. So if voltage is below disruptive critical voltage, there is no corona loss and as the line voltage goes beyond it, corona losses become large.
- Spacing between conductors :** Spacing between the conductors increases disruptive critical voltage. But this method increases overall cost of line as cross arm length got increased. Also there is an increase in voltage drop due to increase in the inductive reactance.
- Increasing diameter of conductor :** Increasing diameter of conductor is widely used to reduce corona loss. Diameter of conductor can be increased either by using Aluminum Conductor Steel Reinforced conductor (ACSR) or by using hollow conductor.
- Bundled conductors :**
 - Presently bundled conductors are used more often to reduce corona loss.
 - It consists of two or more parallel conductors grouped together having spaces between them. Bundle acts as conductor having diameter much larger than component conductors.
 - It reduces the voltage gradient thus reducing corona loss.

Que 2.21. An overhead transmission line operates at 220 kV between phases at 50 Hz. The conductors are arranged in a 5 m delta formation. Calculate the maximum diameter of the conductor that can be used for no corona loss under fair weather conditions. Assume an air density factor of 0.95 and an irregularity factor of 0.85. The critical voltage is 230 kV. Also, find the power loss under stormy weather conditions.

AKTU 2022-23, Marks 10

Answer

Given : Line voltage (V) = 220 kV, Disruptive critical voltage (V_{do}) = 230 kV, Air density factor, (δ) = 0.95, Irregularity factor, $m_o = 0.85$, Frequency, $f = 50$ Hz, Conductor spacing, $D = 5$ m

To Find : Diameter of the conductor and power loss.

- The dielectric strength of air,
$$g_0 = \frac{30}{\sqrt{2}} \text{ kV/cm (max)}$$
- Disruptive critical voltage,

$$V_{do} = g_0 \delta m_o r \log_e \frac{D}{r}$$

$$\frac{230}{\sqrt{3}} = \frac{30}{\sqrt{2}} \times 0.95 \times 0.85 r \ln \frac{500}{r}$$

$$r \ln \frac{500}{r} = 7.752$$

$$r[(\ln 500) - (\ln r)] = 7.752$$

By trial and error method, $r = 1.303$ cm

Therefore, diameter of the conductor, $d = 2.606$ cm

- Under stormy weather conditions the disruptive critical voltage

$$= 0.8 V_{do}$$

$$= 0.8 \times \frac{220}{\sqrt{3}} = 106.23 \text{ kV/phase}$$

- Operating voltage per phase,

$$V = \frac{220}{\sqrt{3}}$$

$$= 127.017 \text{ kV}$$

- The power loss under stormy weather conditions,

$$P = \frac{244}{\delta} (f + 25) \sqrt{\frac{r}{D}} (V_{ph} - 0.8 V_{do})^2 \times 10^{-5} \text{ kW/km/phase}$$

$$= \frac{244}{0.95} (50 + 25) \sqrt{\frac{1.303}{500}} (127.02 - 106.23)^2 \times 10^{-5}$$

$$= 4.25 \text{ kW/km/phase}$$

- Total power loss = 3×4.25

$$= 12.75 \text{ kW/km}$$

PART-7

Performance of Lines : Representation of Lines, Short Transmission Lines, Medium Length Lines, Nominal T and π Representations.

Que 2.22. Derive expression for voltage regulation and efficiency

for short transmission line.

AKTU 2022-23, Marks 10

Answer

- From the equivalent circuit of Fig. 2.22.1,

$$V_r = V_s - IZ \quad (\text{since } I_r = I_s) \quad \dots(2.22.1)$$

where, IZ = Voltage drop along the line.

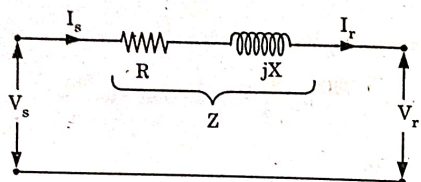


Fig. 2.22.1. Short transmission-line model.

2. From Fig. 2.22.1, we can write

$$\begin{aligned}
 V_s &= OC = \sqrt{(OE)^2 + (EC)^2} \\
 &= \sqrt{(OD + DE)^2 + (EB + BC)^2} \\
 &= \sqrt{(V_r \cos \phi_r + IR)^2 + (V_r \sin \phi_r + IX)^2} \\
 &= \sqrt{V_r^2 + 2V_r IR \cos \phi_r + 2V_r IX \sin \phi_r + I^2(R^2 + X^2)} \\
 &= V_r \sqrt{1 + \frac{2IR}{V_r} \cos \phi_r + \frac{2IX}{V_r} \sin \phi_r + \frac{I^2}{V_r^2}(R^2 + X^2)} \\
 &\approx V_r \sqrt{1 + \frac{2(IR \cos \phi_r + IX \sin \phi_r)}{V_r}}
 \end{aligned}$$

because $\frac{I^2(R^2 + X^2)}{V_r^2}$ is very small when compared with the other terms

$$\therefore V_s = V_r \left(1 + 2 \frac{(IR \cos \phi_r + IX \sin \phi_r + \text{Higher order terms})}{2V_r} \right) \quad \dots(2.22.2)$$

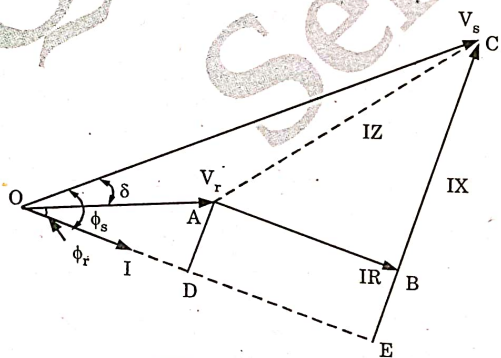


Fig. 2.22.2. Phasor diagram.

3. In practice, the value of higher order terms of eq. (2.22.2) are small and can be neglected, and therefore we get the approximate formula for V_s for

$$V_s \approx V_r + IR \cos \phi_r + IX \sin \phi_r$$

4. From Fig. 2.22.2, the power factor at sending end is given by $\dots(2.22.3)$

$$\cos \phi_s = \frac{OE}{OC} = \frac{V_r \cos \phi_r + IR}{V_s}$$

Regulation :

$$\% \text{ Regulation} = \frac{V_s - V_r}{V_r} \times 100$$

$$= \frac{V_r + IR \cos \phi_r + IX \sin \phi_r - V_r}{V_r} \times 100$$

$$= \frac{IR \cos \phi_r + IX \sin \phi_r}{V_r} \times 100 \quad \dots(2.22.4)$$

Efficiency :

- Power delivered, $P_r = V_r I \cos \phi_r$
Line losses per phase = $I^2 R$
Power supplied per phase, $P_s = V_s I \cos \phi_s + I^2 R$
- The efficiency of a short transmission line,

$$\eta \% = \frac{\text{Power delivered}}{\text{Power supplied}} \times 100 = \frac{P_r}{P_s} \times 100 \quad \dots(2.22.5)$$

Que 2.23. Deduce an expression for transmission efficiency and regulation for medium transmission line using nominal π -method. OR

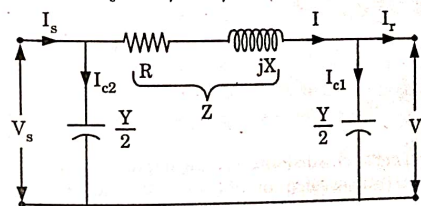
Derive A, B, C and D parameters for nominal π model of a medium transmission line and draw its phasor diagram.

Answer

- The steady-state voltage at the sending and receiving ends are expressed in terms of voltage and current at the receiving end.

$$V_s = AV_r + BI_r \quad \dots(2.23.1)$$

$$I_s = CV_r + DI_r \quad \dots(2.23.2)$$

Fig. 2.23.1. π -equivalent circuit of medium transmission line.

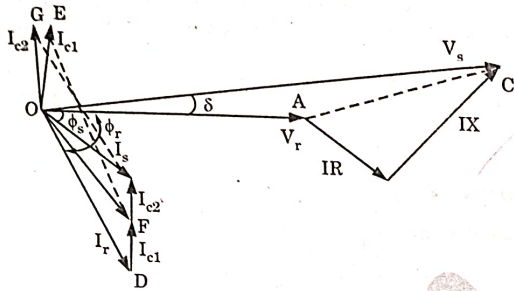


Fig. 2.23.2. Phasor diagram.

2. From Fig. 2.23.1,

$$\begin{aligned}
 V_{c1} &= V_r \\
 I_{c1} &= V_{c1} \frac{Y}{2} = \frac{Y}{2} V_r \\
 I &= I_r + I_{c1} \\
 &= I_r + \frac{Y}{2} V_r \quad \dots(2.23.3) \\
 V_{c2} &= V_{c1} + IZ \\
 &= V_r + \left(I_r + \frac{Y}{2} V_r \right) Z
 \end{aligned}$$

 V_{c2} is also equal to V_s

$$\begin{aligned}
 V_s &= \left(1 + \frac{YZ}{2} \right) V_r + ZI_r \quad \dots(2.23.4)
 \end{aligned}$$

3. The charging current,
The sending-end current,

$$\begin{aligned}
 I_{c2} &= V_s \frac{Y}{2} \\
 I_s &= I_r + I_{c2} \\
 &= I_r + \frac{Y}{2} V_s + \left[\left(1 + \frac{YZ}{2} \right) V_r + ZI_r \right] \frac{Y}{2} \\
 &= \left(\frac{Y}{2} + \frac{Y}{2} + \frac{Y^2 Z}{4} \right) V_r + \left(1 + \frac{YZ}{2} \right) I_r \\
 &= Y \left(1 + \frac{YZ}{4} \right) V_r + \left(1 + \frac{YZ}{2} \right) I_r \quad \dots(2.23.5)
 \end{aligned}$$

4. For general network constants, comparing the eq. (2.23.4) and eq. (2.23.5) with general transmission circuit constants of eq. (2.23.1) and eq. (2.23.2)

$$A = D = 1 + \frac{YZ}{2}; \quad B = Z$$

$$C = Y \left(1 + \frac{YZ}{4} \right)$$

5. The transfer matrix for the network is

$$\begin{bmatrix} 1 + \frac{YZ}{2} & Z \\ Y \left(1 + \frac{YZ}{4} \right) & 1 + \frac{YZ}{2} \end{bmatrix}$$

Regulation :

- To calculate regulation, it is required to calculate the no load receiving-end voltage (V_r') keeping V_s as constant. The voltage at the receiving end at no load V_r' is equivalent to V_{c1} .
- From Fig. 2.23.1, the voltage at the receiving end under no load is

$$V_r' = \frac{V_s \left(-\frac{j2}{\omega C} \right)}{R + jX - \frac{j2}{\omega C}}$$

$$\% \text{ Regulation} = \frac{V_r' - V_r}{V_r} \times 100$$

Efficiency :

$$\eta = \frac{\text{Power delivered at the receiving end } (P_r)}{\text{Power delivered at the receiving end } (P_r) + 3I^2 R}$$

Que 2.24. Analyze the performance of medium transmission line (T model). Draw phasor diagram and derive relation for ABCD parameters.

AKTU 2023-24, Marks 10

OR

Derive the A, B, C, D constants for the transmission line represented by nominal T section and draw its phasor diagram.

AKTU 2021-22, Marks 10

Answer

The steady-state voltage at the sending and receiving ends are expressed in terms of voltage and current at the receiving end

$$V_s = AV_r + BI_r \quad \dots(2.24.1)$$

$$I_s = CV_r + DI_r \quad \dots(2.24.2)$$

Nominal T method :

1. From Fig. 2.24.1,

$$V_c = V_r + \frac{Z}{2} I_r \quad \dots(2.24.3)$$

2. The current through the shunt admittance is

$$I_c = V_c Y$$

$$= \left(V_r + \frac{Z}{2} I_r \right) Y$$

$$I_c = YV_r + \frac{YZ}{2} I_r$$

3. Now the sending-end current is

$$I_s = I_r + I_c$$

$$= I_r + YV_r + \frac{YZ}{2} I_r$$

$$I_s = YV_r + \left(1 + \frac{YZ}{2} \right) I_r \quad \dots(2.24.4)$$

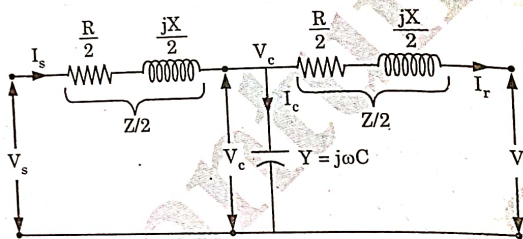


Fig. 2.24.1. T-equivalent circuit of medium transmission line.

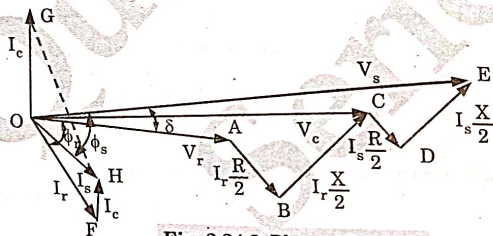


Fig. 2.24.2. Phasor diagram.

and the sending-end voltage is

$$V_s = V_r + \frac{Z}{2} I_s$$

$$= V_r + \frac{Z}{2} I_r + \frac{Z}{2} \left[YV_r + \left(1 + \frac{YZ}{2} \right) I_r \right]$$

$$= \left(1 + \frac{YZ}{2} \right) V_r + \left(\frac{Z}{2} + \frac{Z}{2} + \frac{YZ^2}{4} \right) I_r$$

$$V_s = \left(1 + \frac{YZ}{2} \right) V_r + Z \left(1 + \frac{YZ}{4} \right) I_r \quad \dots(2.24.5)$$

4. For general transmission circuit constants, comparing the eq. (2.24.3) and eq. (2.24.3) with eq. (2.24.4) and eq. (2.24.5) respectively, we get

$$A = 1 + \frac{YZ}{2} = D; \quad B = Z \left(1 + \frac{YZ}{4} \right), \quad C = Y$$

5. The transfer matrix for the network is
- $$\begin{bmatrix} 1 + \frac{YZ}{2} & Z \left(1 + \frac{YZ}{4} \right) \\ Y & 1 + \frac{YZ}{2} \end{bmatrix} \quad \dots(2.24.6)$$

Regulation :

1. Under no load condition, the equivalent circuit of Fig. 2.24.1 is shown in Fig. 2.24.3.

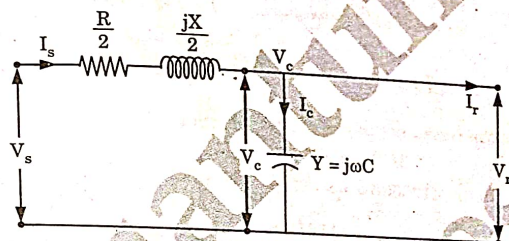


Fig. 2.24.3.

2. At no load, the voltage at the receiving end (V_r') of the transmission line is same as the voltage (V_c) across the admittance, which is located at midpoint of the transmission line.
3. From Fig. 2.24.3, the voltage across the capacitor by using voltage divider rule is

$$V_c = \frac{V_s \left(\frac{-j}{\omega C} \right)}{\frac{R}{2} + j \frac{X}{2} - \frac{j}{\omega C}}$$

When the receiving end is on no load, the no-load voltage, $V_r' = V_c$

$$\% \text{ Regulation} = \frac{V_r' - V_r}{V_r} \times 100$$

Efficiency :

$$\eta = \frac{\text{Power delivered at the receiving end } (P_r)}{\text{Power delivered at the receiving end } (P_r) + 3 \frac{R}{2} (I_r^2 + I_s^2)}$$

Que 2.25. Calculate the distance over which a load of 15 MW at 0.85 pf can be delivered by a three-phase transmission line having conductors each of resistance 0.905 ohm per kilometer. The receiving end voltage is 132 kV and the loss is to be 7.5 % of the load.

AKTU 2020-21, Marks 10

Answer

Given : $P = 15 \text{ MW}$, $pf = 0.85$, loss = 7.5 %, Resistance per kilometer = 0.905 Ω , Voltage = 132 kV

To Find : Length of the line.

- Line current = $\frac{P}{\sqrt{3}V \cos \phi} = \frac{15000}{\sqrt{3} \times 132 \times 0.85} = 77.2 \text{ A}$
- Total loss = $\frac{7.5 \times 15000}{100} = 1125 \text{ kW}$
- If R is the resistance of one conductor, then
 $3I^2R = 3 \times (77.2)^2 \times R$
 $1125000 = 3 \times (77.2)^2 \times R$
 $R = \frac{1125000}{3 \times (77.2)^2}$
 $R = 62.94 \Omega$
- Length of the line = $\frac{62.94}{0.905} = 69.55 \text{ km}$

PART-8

Long Transmission Lines, The Equivalent Circuit Representation of a Long Line, A, B, C, D Constants, Ferranti Effect.

Que 2.26. Deduce the expression for sending end voltage and current in terms of receiving end voltage and current for long transmission lines.

OR

Explain rigorous method for long transmission line.

AKTU 2023-24, Marks 10

Answer

- The steady-state voltage at the sending and receiving ends are expressed in terms of voltage and current at the receiving end

$$V_s = AV_r + BI_r \quad \dots(2.26.1)$$

$$I_s = CV_r + DI_r \quad \dots(2.26.2)$$

- Let
 z = Series impedance per unit length
 y = Shunt admittance per unit length
 l = Length of the line

Then,
 $Z = zl$ = Total series impedance of the line

$Y = yl$ = Total shunt admittance of the line

- Consider a very small element of length Δx at a distance of x from the receiving-end of the line.

- The voltage and current at distance x from the receiving-end are V, I and at distance $x + \Delta x$ are $V + \Delta V$ and $I + \Delta I$, respectively.

So, the change of voltage, $\Delta V = Iz\Delta x$

where, $z\Delta x$ is the impedance of the element considered.

$$\frac{\Delta V}{\Delta x} = Iz$$

$$\lim_{\Delta x \rightarrow 0} \frac{\Delta V}{\Delta x} = \frac{dV}{dx} = Iz \quad \dots(2.26.3)$$

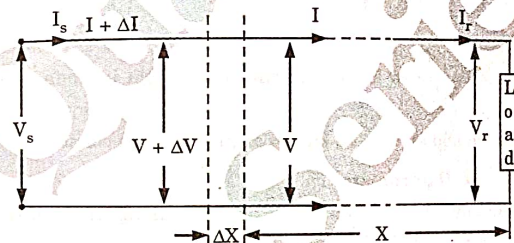


Fig. 2.26.1. Equivalent single-phase representation of a long transmission line.

- Similarly, the change of current, $\Delta I = Vy\Delta x$ where, $y\Delta x$ is the admittance of element considered

$$\frac{\Delta I}{\Delta x} = Vy$$

$$\lim_{\Delta x \rightarrow 0} \frac{\Delta I}{\Delta x} = \frac{dI}{dx} = Vy \quad \dots(2.26.4)$$

- Differentiating the eq. (2.26.3) with respect to x , we get

$$\frac{d^2V}{dx^2} = z \frac{dI}{dx} \quad \dots(2.26.5)$$

7. Substituting the value of $\frac{dI}{dx}$ from eq. (2.26.4) in eq. (2.26.5), we get

$$\frac{d^2V}{dx^2} = zyV \quad \dots(2.26.6)$$

8. Eq. (2.26.6) is a second order differential equation. The solution of this equation is

$$V = Ae^{\sqrt{yz}x} + Be^{-\sqrt{yz}x} \quad \dots(2.26.7)$$

9. Differentiating eq. (2.26.7) with respect to x , we get

$$\frac{dV}{dx} = A\sqrt{yz} e^{\sqrt{yz}x} - B\sqrt{yz} e^{-\sqrt{yz}x} \quad \dots(2.26.8)$$

10. From eq. (2.26.3) and eq. (2.26.8)

$$Iz = A\sqrt{yz} e^{\sqrt{yz}x} - B\sqrt{yz} e^{-\sqrt{yz}x}$$

$$I = A\sqrt{\frac{y}{z}} e^{\sqrt{yz}x} - B\sqrt{\frac{y}{z}} e^{-\sqrt{yz}x} \quad \dots(2.26.9)$$

11. From eq. (2.26.7),

$$V = Ae^{\gamma x} + Be^{-\gamma x} \quad \dots(2.26.10)$$

12. From eq. (2.26.9),

$$I = \frac{A}{Z_c} e^{\gamma x} + \frac{B}{Z_c} e^{-\gamma x} \quad \dots(2.26.11)$$

where, $Z_c = \sqrt{\frac{z}{y}}$ is known as characteristics impedance or surge impedance and $\gamma = \sqrt{yz}$ is known as propagation constant.

A, B, C and D parameter:

1. The constants A and B can be evaluated by using the conditions at the receiving end of the line. The conditions are

at $x = 0$, $V = V_r$ and $I = I_r$

Substitute the above conditions in eq. (2.26.10) and eq. (2.26.11), we get

$$\therefore V_r = A + B \quad \dots(2.26.12)$$

and

$$I_r = \frac{1}{Z_c} (A - B) \quad \dots(2.26.13)$$

2. Solving eq. (2.26.12) and eq. (2.26.13), we get

$$A = \frac{V_r + I_r Z_c}{2} \text{ and } B = \frac{V_r - I_r Z_c}{2}$$

3. Now substituting the values of A and B in eq. (2.26.10) and (2.26.11), V can be expressed as:

$$V = \frac{V_r + I_r Z_c}{2} e^{\gamma x} + \frac{V_r - I_r Z_c}{2} e^{-\gamma x}$$

$$= V_r \left[\frac{e^{\gamma x} + e^{-\gamma x}}{2} \right] + I_r Z_c \left[\frac{e^{\gamma x} - e^{-\gamma x}}{2} \right]$$

$$\therefore V = V_r \cosh \gamma x + I_r Z_c \sinh \gamma x \quad \dots(2.26.14)$$

$$I = \frac{1}{Z_c} \left[\frac{V_r + I_r Z_c}{2} e^{\gamma x} - \frac{V_r - I_r Z_c}{2} e^{-\gamma x} \right]$$

$$= \frac{1}{Z_c} V_r \left(\frac{e^{\gamma x} - e^{-\gamma x}}{2} \right) + I_r \left(\frac{e^{\gamma x} + e^{-\gamma x}}{2} \right)$$

$$= \frac{V_r}{Z_c} \sinh \gamma x + I_r \cosh \gamma x \quad \dots(2.26.15)$$

where, V and I are the voltages and currents at any distance x from the receiving end.

4. At $x = l$, $V = V_s$ and $I = I$

Putting these values in eq. (2.26.14) and eq. (2.26.15), V_s and I_s is expressed as

$$V_s = V_r \cosh \gamma l + I_r Z_c \sinh \gamma l \quad \dots(2.26.16)$$

$$I_s = \frac{V_r}{Z_c} \sinh \gamma l + I_r \cosh \gamma l \quad \dots(2.26.17)$$

5. By comparison of eq. (2.26.16) and eq. (2.26.17) with general transmission circuit constant of eq. (2.26.1) and eq. (2.26.2), we get

$$A = D = \cosh \gamma l,$$

$$B = Z_c \sinh \gamma l \text{ and}$$

$$C = \frac{1}{Z_c} \sinh \gamma l.$$

Que 2.27. Explain Ferranti effect.

Answer

1. When medium or long transmission lines are operated at no-load or light-load, the receiving-end voltage becomes more than the sending-end voltage. The phenomenon of rise in voltage at the receiving-end of a transmission line during no load or light load condition is called the Ferranti effect.

2. The charging current produces a voltage drop in the series reactance of the line. This voltage drop is in phase opposition to the receiving-end voltage, and hence the sending-end voltage becomes smaller than the receiving-end voltage.
3. In order to determine the magnitude of voltage rise, one-half of the total line capacitance will be assumed to be concentrated at the receiving-end as shown in Fig. 2.27.1(a). The phasor diagram is shown in Fig. 2.27.1(b).

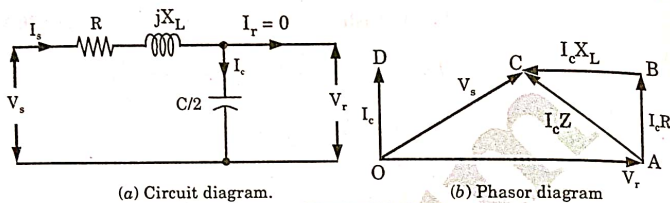


Fig. 2.27.1.

4. Taking receiving-end voltage as reference phasor, we have

$$V_r = V_r \angle 0^\circ$$

and is represented by phasor OA.

5. Charging current

$$I_c = YV_r$$

This is represented by phasor OD.

6. The sending-end voltage

$$\begin{aligned} V_s &= V_r + I_c(R + jX_L) \\ &= V_r + jYV_r(R + jX_L) \\ &= V_r - YX_L V_r + jYRV_r \end{aligned}$$

7. The vector OC represents the sending-end voltage under no-load condition and is less than the receiving-end voltage. The line resistance is usually small as compared to the line inductive reactance. Hence, the resistance is neglected.

8. Neglecting resistive drop of the line, $I_c R$, we get

$$\begin{aligned} \text{Rise in voltage, } V' &= OC - OA \\ &= V_s - V_r \\ &= -YX_L V_r \end{aligned} \quad \dots(2.27.1)$$

The negative sign in eq. (2.27.1) indicates that V_r is more than V_s .

9. If C_0 and L_0 are the capacitance and inductance of the transmission line per meter length, respectively and l is the length of the line in meters, then eq. (2.27.1) becomes,

$$V' = -\frac{\omega C_0 l}{2} \times \omega L_0 l \times V_r$$

$$V' = -\frac{\omega^2 C_0 L_0 l^2 V_r}{2}$$

10. In case of short lines, the effect is negligible, but it increases rapidly with the increase in length of the line. Therefore, this phenomenon is observable only in medium and long lines.
11. For long high voltage and EHV transmission lines, shunt reactors are provided to absorb a part of the charging current or shunt capacitive VAR of the transmission line under no load or light load conditions, in order to prevent the over voltage on the line.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

- Q. 1. Draw and explain single line diagram of power system.

Ans. Refer Q. 2.1.

- Q. 2. What do you understand by "PER UNIT SYSTEM"? What are the significances in power system analysis? And give its advantages.

Ans. Refer Q. 2.5.

- Q. 3. Classify different types of supply system and compare the volume of conductor DC two wire system and 3- ϕ 3-wire system.

Ans. Refer Q. 2.6.

- Q. 4. State and prove Kelvin's law for size of conductor for transmission line. Discuss its limitations.

Ans. Refer Q. 2.12.

- Q. 5. Explain difference between skin effect and proximity effect. What is the percentage saving in copper feeder if the line voltage in a 2-wire DC system is raised from 220 V to 450 V for the same power transmitted over the same distance and having the same power loss?

Ans. Refer Q. 2.15.

Q. 6. What is corona ? Discuss phenomenon of corona and how it is formed.

Ans. Refer Q. 2.16.

Q. 7. Write short note on the factors affecting the "Corona" losses.

Ans. Refer Q. 2.19.

Q. 8. Derive expression for voltage regulation and efficiency for short transmission line.

Ans. Refer Q. 2.22.

Q. 9. Analyze the performance of medium transmission line (T model). Draw phasor diagram and derive relation for ABCD parameters.

Ans. Refer Q. 2.24.

Q. 10. Deduce the expression for sending end voltage and current in terms of receiving end voltage and current for long transmission lines.

Ans. Refer Q. 2.26.

Q. 10. Explain Ferranti effect.

Ans. Refer Q. 2.27.



Transmission and Distribution of Electric Power-II

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PART-1**Mechanical Design of Over Headlines : Catenary Curve, Calculation of Sag and Tension.**

Que 3.1. Explain sag. Also derive expression for sag of a conductor in overhead transmission line when supported at equal levels and at two different levels.

OR

Deduce an expression for sag in overhead transmission lines when
i. Supports are at equal levels
ii. Supports are at unequal levels.

OR

Explain the method of calculating the sag for the same level.

AKTU 2020-21, Marks 10

Answer

A. **Sag:** The difference in levels between point of support and the lowest point on the conductor is called sag. The sag is denoted by S as shown in Fig. 3.1.1.

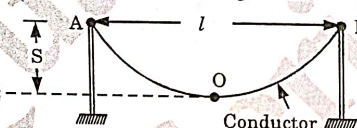


Fig. 3.1.1.

B. **Supports at equal levels:**

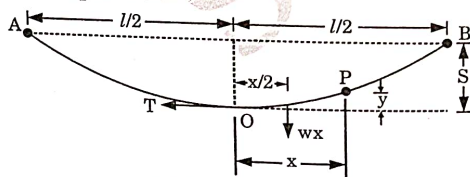


Fig. 3.1.2. Supports at equal level.

1. Let

l = Span length
 w = Weight per unit length of conductor
 T = Tension in the conductor
 S = Sag

2. Consider a point P on the conductor. Its coordinates are x and y , taking O as the origin.
3. If the curvature is considered so small that curved length is equal to its horizontal projection, i.e., $OP = x$, then the forces acting on the portion OP are :
 - i. The weight wx of the conductor acting at a distance $x/2$ from O .
 - ii. The tension T acting at O .
4. Taking moments of these forces about point P , we get

$$T \times y = wx \times x / 2$$

$$y = \frac{wx^2}{2T}$$

The maximum sag (dip) is represented by the value of y at either of the supports A and B .

5. At support A (or B),

$$x = l/2 \text{ and } y = S$$

$$\therefore \text{Sag, } S = \frac{w(l/2)^2}{2T} = \frac{wl^2}{8T}$$

C. **Supports at unequal level:**

1. Let

l = Span length

h = Difference in levels between two supports

x_1 = Distance of support A from O

x_2 = Distance of support B from O

w = Weight per unit length of conductor

T = Tension

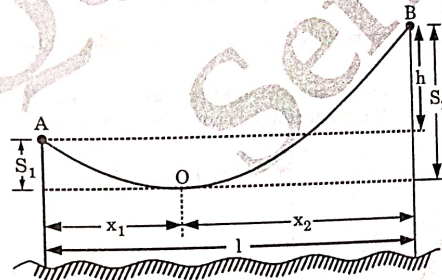


Fig. 3.1.3. Supports at unequal levels.

2. Now,

Also,

3. $\therefore$

$$S_1 = \frac{wx_1^2}{2T}, \text{ and } S_2 = \frac{wx_2^2}{2T}$$

...(3.1.1)

$$x_1 + x_2 = l$$

$$S_2 - S_1 = \frac{wx_2^2}{2T} - \frac{wx_1^2}{2T} = \frac{w}{2T} (x_2^2 - x_1^2)$$

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

$$S_2 - S_1 = \frac{wl}{2T}(x_2 - x_1)$$

4. But,

$$S_2 - S_1 = h$$

 $\therefore$

$$h = \frac{wl}{2T}(x_2 - x_1)$$

$$(x_2 - x_1) = \frac{2Th}{wl}$$

5. Adding eq. (3.1.1) and (3.1.2), we get

$$2x_2 = l + \frac{2Th}{wl}$$

$$x_2 = \frac{l}{2} + \frac{Th}{wl}$$

6. And,

$$x_1 = l - \left[\frac{l}{2} + \frac{Th}{wl} \right] = \frac{l}{2} - \frac{Th}{wl}$$

After finding x_1 and x_2 , the values of S_1 and S_2 can be calculated.**Que 3.2.** Explain catenary method for finding the sag in a transmission line.**AKTU 2023-24, Marks 10****OR**
Explain catenary method for the calculation of sag and tension in transmission line.**Answer**

- When sag is comparable with the span then conductor takes the form of catenary.
- Consider a conductor, supported at the points A and B with O as the lowest point on the conductor, as shown in the Fig. 3.2.1.

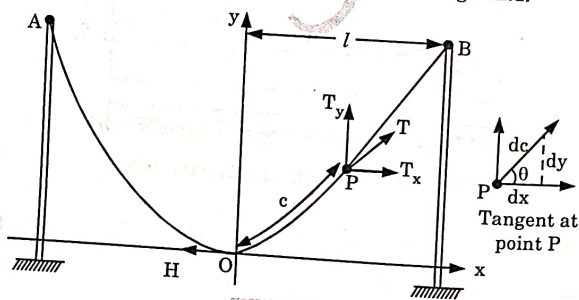


Fig. 3.2.1.

 w = Weight per unit length T = Tension at point P.

3. Let

4. Let P be the point on the conductor such that $OP = c$. The point O is origin and the co-ordinates of point P are (x, y) . The tension T is acting tangentially at point P.

5. The various forces acting on the curve portion OP of the wire are

- Horizontal tension, H acting at O.
- Weight of the portion OP which is wc acting vertically downward through centre of gravity.
- Horizontal and vertical components of tension T in the conductor i.e., T_x and T_y acting at P.

6. In the equilibrium condition, horizontal and vertical components will balance each other.

$$T_x = H$$

 $\therefore$

$$T_y = wc$$

Now

$$\tan \theta = \frac{T_y}{T_x} = \frac{wc}{H}$$

7. $\tan \theta$ can also be written as,

$$\tan \theta = \frac{dy}{dx} = \frac{wc}{H}$$

...(3.2.1)

8. Now

$$(dc)^2 = (dx)^2 + (dy)^2$$

$$\left(\frac{dc}{dx} \right)^2 = 1 + \left(\frac{dy}{dx} \right)^2$$

9. Substituting from equation (3.2.1) we get,

$$\frac{dc}{dx} = \sqrt{1 + \left(\frac{wc}{H} \right)^2}$$

 $\therefore$

$$dx = \frac{dc}{\sqrt{1 + \frac{w^2 c^2}{H^2}}}$$

10. Integrating both sides

$$x = \left(\frac{H}{w} \right) \sinh^{-1} \left(\frac{wc}{H} \right) + A$$

where

A = Constant of integration

11. Now at $x = 0$ i.e., at point O, $c = 0$ hence we get $A = 0$

$$x = \left(\frac{H}{w}\right) \sinh^{-1} \left(\frac{wc}{H}\right) \quad \dots(3.2.2)$$

12. Taking hyperbolic sine of both sides,

$$\sinh \left(\frac{wx}{H}\right) = \frac{wc}{H}$$

$$\therefore c = \frac{H}{w} \sinh \left(\frac{wx}{H}\right) \quad \dots(3.2.3)$$

13. From eq. (3.2.1),

$$\frac{dy}{dx} = \frac{wc}{H}$$

$$\therefore \frac{dy}{dx} = \frac{w}{H} \left[\frac{H}{w} \sinh \left(\frac{wx}{H}\right) \right]$$

$$\therefore dy = \sinh \left(\frac{wx}{H}\right) dx$$

14. Integrating both sides,

$$y = \frac{H}{w} \cosh \left(\frac{wx}{H}\right) + B \quad \dots(3.2.4)$$

where

$B = \text{Constant of integration}$

15. when

$$y = 0, x = 0 \text{ at point } O$$

$$0 = \frac{H}{w} + B$$

$$B = -\frac{H}{w}$$

$$\therefore y = \frac{H}{w} \cosh \left(\frac{wx}{H}\right) - \frac{H}{w}$$

$$\therefore y = \frac{H}{w} \left[\cosh \left(\frac{wx}{H}\right) - 1 \right] \quad \dots(3.2.5)$$

This is the required equation of the catenary form of conductor.

Calculation of sag (S), tension (T) and conductor half span length:

1. The tension T at any point P is,

$$T^2 = T_x^2 + T_y^2 = H^2 + w^2 c^2$$

$$= H^2 + w^2 \frac{H^2}{w^2} \sinh^2 \left(\frac{wx}{H}\right)$$

$$= H^2 \left[1 + \sinh^2 \left(\frac{wx}{H}\right) \right]$$

$$T^2 = H^2 \cosh^2 \left(\frac{wx}{H}\right)$$

$$T = H \cosh \left(\frac{wx}{H}\right)$$

$\therefore l = \text{Half span length}$

2. and the supports A and B are at same level then,

$$c = \frac{H}{w} \sinh \left(\frac{wl}{H}\right)$$

This is length of curved conductor in half span.

3. While the sag S can be obtained by putting $y = S$ in eq. (3.2.5).

$$S = \frac{H}{w} \left[\cosh \left(\frac{wl}{H}\right) - 1 \right]$$

$$= \frac{H}{w} \left[\cosh \left(\frac{wL}{2H}\right) - 1 \right]$$

4. The eq. (3.2.3) giving the arc length c can be expanded as,

$$c = \frac{H}{w} \sinh \left(\frac{wx}{H}\right)$$

$$= \frac{H}{w} \left[\frac{wx}{H} + \frac{w^3 x^3}{3! H^3} + \dots \right] \approx x + \frac{w^2 x^3}{6H^2}$$

5. In such approximation we can assume $H = T$.

$$\therefore c \approx x + \frac{w^2 x^3}{6T^2}$$

6. So half span length can be obtained by substituting $x = l$,

$$\therefore c = l + \frac{w^2 l^3}{6T^2} = l \left[1 + \frac{w^2 l^2}{6T^2} \right]$$

Que 3.3. Write a short note on the factors that affect sag.

AKTU 2023-24, Marks 10

Answer

Several factors influence the amount of sag experienced by power lines:

1. **Conductor material and diameter:** The material and diameter of the conductor affect its weight per unit length. Heavier conductors,

such as those made of aluminum or copper, or conductors with larger diameters, experience greater gravitational forces and, consequently, greater sag.

2. **Temperature :** Temperature fluctuations cause expansion and contraction of the conductor, affecting its length. Higher temperatures cause the conductor to expand, increasing sag, while lower temperatures cause contraction, reducing sag.
3. **Tension :** The tension applied to the conductor affects its sag. Higher tension levels reduce sag by counteracting gravitational forces, while lower tension levels increase sag.
4. **Span length :** The distance between support structures (span length) directly impacts sag. Longer spans result in greater sag, while shorter spans lead to less sag.
5. **Wind and ice loading :** Wind and ice loads exert lateral forces on power lines, affecting sag. Strong winds can push the conductor sideways, altering its position and increasing sag.
6. **Temperature of surrounding environment :** Ambient temperature influences the conductor's temperature and, consequently, its sag. Higher ambient temperatures contribute to thermal expansion and increased sag, while lower temperatures result in contraction and reduced sag.

Que 3.4. An overhead line at a river crossing is supported from two towers of heights 30 meters and 90 meters above water level with a span of 300 meters. The weight of the conductor is 1 kg/meter and the working tension is 2000 kg. Determine the clearance between the conductor and the water level midway between the towers.

AKTU 2021-22, Marks 10

Answer

Given : The working tension, $T = 2000$ kg, Span, $L = 300$ m, Weight of the conductor, $w = 1$ kg/m, $h_1 = 30$ m, $h_2 = 90$ m

To Find : Clearance between the conductor and the water level midway between the towers.

1. The difference in height of tower,
 $h = 90 - 30 = 60$ m
2. Distance between the shorter support and lower point on conductor,
$$x_1 = \frac{L}{2} - \frac{Th}{wL} = \frac{300}{2} - \frac{2000 \times 60}{1 \times 300}$$
$$= 150 - 400$$
$$x_1 = -150 \text{ m}$$

3. Distance between the longer support and lower point on conductor,

$$x_2 = \frac{L}{2} + \frac{Th}{wL} = \frac{300}{2} + \frac{2000 \times 60}{1 \times 300}$$

$$= 150 + 400$$

$$= 550 \text{ m}$$

4. Sag with respect to the lower support,

$$D_1 = \frac{wx_1^2}{2T} = \frac{1 \times (-150)^2}{2 \times 2000}$$

$$= 5.625 \text{ m}$$

5. Clearance between the water level and the lower point of the conductor
 $= 30 - 5.625 = 24.37 \text{ m}$
6. Distance from the midpoint between the two towers and the lower point of the conductor,

$$x = 150 + 150$$

$$x = 300 \text{ m}$$

7. Sag at the mid-point of the supports,

$$D = \frac{wx^2}{2T} = \frac{1 \times (300)^2}{2 \times 2000} = 22.5$$

8. Clearance between the water and conductor at midpoint between two conductors
 $= 24.37 + 22.5$
 $= 46.87 \text{ m}$

Que 3.5. An overhead line has a span of 200 metres, the line conductor weights 0.7 kg per meter. Calculate the maximum sag if allowable tension in the line is 1,400 kg. Prove formula used.

Answer

Given : $l = 200$ m, $w = 0.7$ kg per meter, $T = 1400$ kg

To Find : Maximum sag, S .

$$\text{Maximum sag, } S = \frac{wl^2}{8T} = \frac{0.7 \times 200 \times 200}{8 \times 1400}$$

$$= 2.5 \text{ m}$$

PART-2

Effects of Wind and Ice Loading.

Que 3.6. Discuss the effect of atmospheric condition on transmission line.

Answer

Effect of atmospheric condition on transmission line :

a. Effect of Ice coating :

1. When the transmission line is coated with ice, the thickness and size of the conductor increases. This thickness depends on the weather conditions.
2. This causes increase in weight of the conductor; increase in weight increases the vertical sag.
3. The weight of ice acts vertically downwards, in the same direction as that of the conductor.
4. Consider a conductor with diameter d . It is coated with ice thickness t as shown in Fig. 3.6.1. Hence the overall diameter of the coated conductor is D .

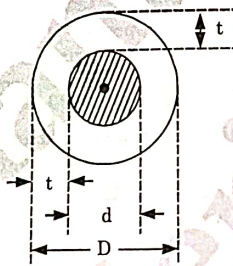


Fig. 3.6.1. Ice coated conductor.

$$D = d + 2t$$

and the area of the coated conductor is

$$= \frac{\pi}{4} D^2$$

5. Area of the ice covering,

$$A_i = \frac{\pi}{4} [D^2 - d^2]$$

6. The density of ice is 915 kg/m^3 . Hence the total weight of ice can be obtained as,

$$w_i = 915 \times \frac{\pi}{4} [D^2 - d^2] \text{ kg/m}$$

= Weight of ice per unit length

$$= 915 \times \frac{\pi}{4} [(d + 2t)^2 - d^2]$$

$$= 915 \times \frac{\pi}{4} [d^2 + 4dt + 4t^2 - d^2]$$

$$= 915 \times \pi [dt + t^2]$$

$$w_i = 915\pi t (d + t) \text{ kg/m}$$

B. Effect of wind pressure :

1. The wind flows horizontally and hence the wind pressure on the conductor is considered to be acting perpendicular to the conductor.
2. Thus force due to wind act at right angles to the projected surface of the conductor as shown in Fig. 3.6.2.

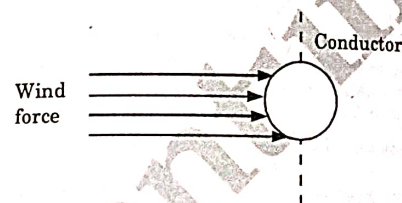


Fig. 3.6.2. Direction of wind force.

3. The wind force w_w can be obtained as,

$$w_w = \text{Wind force per unit length in kg/m}$$

$$= \text{Wind pressure per unit area} \times \text{Projected surface area per unit length}$$

$$= \text{Wind pressure} \times [(d + 2t) \times 1]$$

$$w_w = P[d + 2t]$$

where,

$$P = \text{Wind pressure in kg/m}^2$$

$$d = \text{Diameter of conductor}$$

$$t = \text{Thickness of ice coating if exists}$$

C. Effect of ice and wind :

1. Let

$$w = \text{Weight of conductor itself acting vertically downward}$$

$$w_i = \text{Weight of ice acting vertically downward}$$

$$w_w = \text{Wind force acting horizontally}$$

2. Hence the total force acting on the conductor is vector sum of the horizontal and vertical forces as shown in Fig. 3.6.3.

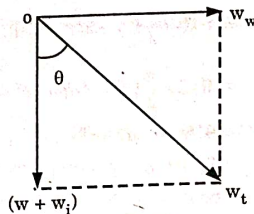


Fig. 3.6.3.

w_t = Total weight acting on conductor

$$= \sqrt{(w + w_t)^2 + (w_w)^2}$$

3. The sag direction is at an angle θ measured with respect to vertical. Hence the sag is called slant sag. This is calculated by the expression considering the total weight w_t .

$$\text{Slant sag, } S = \frac{w_t l^2}{8T}$$

4. The conductor adjusts itself in a plane which is at an angle θ with respect to vertical; the angle is given by,

$$\tan \theta = \frac{w_w}{(w + w_t)}$$

5. As slant sag S is the direction of an angle θ with respect to vertical, the vertical sag is cosine component of slant sag S ,

$$\text{Vertical sag} = S \cos \theta$$

Que 3.7. Explain the calculation procedure of maximum sag of a transmission line at equal supports including wind pressure loading.

AKTU 2022-23, Marks 10

Answer

A. Maximum sag of a transmission line at equal supports : Refer Q. 3.1, Page 3-2B, Unit-3.

B. Effect of wind pressure loading on sag : Refer Q. 3.6, Page 3-10B, Unit-3.

1. The total effective weight,

$$w_t = \sqrt{w^2 + w_w^2}$$

2. So the sag of transmission line at equal supports including wind pressure loading is,

$$S = \frac{w_t l^2}{8T}$$

Que 3.8. An overhead line has the following data :
Span length 160 metres, conductor dia 0.95 cm, weight per unit length of the conductor 0.65 kg/metre. Ultimate stress 4250 kg/cm², wind pressure 40 kg/m² of projected area. Factor of safety 5. Calculate the sag.

AKTU 2022-23, Marks 10

Answer

Given : Span length (l) = 160 m, Diameter (d) = 0.95 cm, Weight per unit length of conductor = 0.65 kg/cm, Ultimate stress = 4250 kg/cm², Wind pressure = 40 kg/m², Factor of safety = 5.
To Find : Sag (S).

- The working stress = $\frac{\text{Ultimate stress}}{\text{Factor of safety}}$
 $= \frac{4250}{5} = 850 \text{ kg/cm}^2$
- The area of section of the conductor = $\frac{\pi d^2}{4}$
 $= \frac{\pi}{4} \times (0.95)^2$
 $= 0.7084 \text{ cm}^2$
- The wind pressure per unit length of conductor
 $= 40 \times 0.95 \times 10^{-2}$
 $= 0.38 \text{ kg/cm}$
- The weight of conductor per unit length = 0.65 kg/m
- The total effective weight,

$$W = \sqrt{(0.65)^2 + (0.38)^2}$$

$$= 0.7529 \text{ kg/m}$$

6. Working tension,

$$T = 850 \times 0.7084$$

$$= 602.5 \text{ kg}$$

- 7.

$$C = \frac{T}{W} = \frac{602.5}{0.7529} = 800 \text{ m}$$

$$S = \frac{l^2}{8C} = \frac{(160)^2}{8 \times 800} = 4 \text{ m}$$

PART-3*Sag Template, Vibration Dampers.*

Que 3.9. Explain sag template and its use.

Answer

1. Sag template is a convenient device used in the design of a transmission line to determine the location and height of tower.
2. For locating the tower positions, for normal spans and for standard towers, the sag and the nature of conductor curve are calculated under expected load condition and plotted on a thin stiff plastic sheet such a graph is called sag template.

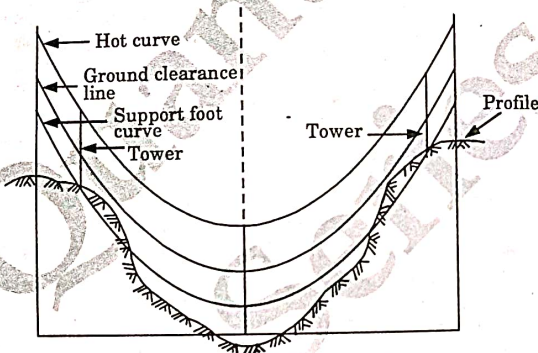


Fig. 3.9.1. Sag template.

3. The curves which are marked on it are :
 - i. **Location of support (tower) or Hot curve :** These curves are obtained by plotting sags at maximum temperature against span lengths. It gives us the location of supports to maintain proper ground clearance.
 - ii. **Ground clearance curve :** This curve is below hot curve. It is drawn parallel to the hot curve and at a vertical distance equal to ground clearance as prescribed by the regulations for the given line.
 - iii. **Support foot curve or tower curve :** It is drawn to locate the position of support for tower lines. It shows height from the base of standard support to the point of attachment of the lowest conductor.

iv. **Uplift curve or cold curve :** These are obtained by plotting the sags at minimum temperature without ice or wind loading against span length. These are drawn to check whether uplift of conductors occurs at any support.

4. **Use of sag template :**

- i. For correct design and economy.
- ii. It is used to allocate the position and height of the support correctly on the profile.

Que 3.10. What do you understand by vibration dampers in overhead transmission line? Describe the different types of dampers used.

AKTU 2021-22, Marks 10

Answer

A. Vibration dampers :

1. Vibration dampers are devices used in overhead transmission lines to control and mitigate the effects of wind-induced vibrations.
2. These vibrations, often caused by the interaction between the conductors and the wind, can lead to fatigue and damage in the conductors and supporting structures.
3. Vibration dampers are designed to absorb, dissipate, or disrupt these vibrations, reducing stress on the components and extending the lifespan of the transmission line.

B. Types of vibration dampers : There are several types of vibration dampers used in overhead transmission lines :

1. **Stockbridge damper :** This is one of the most common types of vibration dampers. It consists of two counterweights connected to a central spacer bar. The damper is attached to the conductor, and its counterweights oscillate out of phase with the conductor's motion, effectively reducing the amplitude of vibrations.
2. **Spacer damper :** Spacer dampers are installed between adjacent conductors to maintain a specific separation distance. They help prevent galloping, a form of conductor vibration where the conductors move in unison due to the wind's force. Spacer dampers offer a more controlled and stable arrangement of conductors.
3. **Anti-galloping damper :** This type of damper is designed to suppress galloping vibrations in bundled conductors. It typically consists of a combination of weights and dampening materials that introduce controlled vibrations that oppose and counteract galloping-induced oscillations.

4. **Twisted spacer damper :** Twisted spacer dampers combine the features of spacer and stockbridge dampers. They are designed to reduce the overall dynamic response of the conductor system to wind-induced vibrations.
5. **Tuned mass damper :** Tuned mass dampers are more complex devices that involve a mass suspended by springs and dampers. They are used for larger spans and higher wind loads, where their dynamic properties can be tuned to match specific frequencies of vibration.

PART-4

Overhead Line Insulators : Type of Insulators and their Applications.

Que 3.11. Explain different type of insulator.

Answer

1. **Pin type insulator :**
 - i. Pin-type insulators are mounted on a pin on the cross-arm of a transmission or distribution pole. They are usually made from materials like porcelain, glass, or composite polymers.
 - ii. They are designed to support conductors on overhead lines and are attached to the pole by a metal pin that runs through the insulator.
 - iii. The shape of the insulator is such that it increases the length of the leakage path to prevent flashover.
2. **Suspension insulator :**
 - i. Suspension insulators consist of a number of insulator discs connected in series by metal fittings, forming a string that "suspends" the conductor below the pole.
 - ii. Each disc is made of glass or porcelain, and the entire string supports high-voltage conductors in overhead transmission lines.
 - iii. Multiple discs are added to increase the voltage rating of the insulator string.
3. **Strain insulator :**
 - i. Strain insulators are used where conductors experience high tension, such as at the ends of transmission lines or at sharp corners.
 - ii. They are typically composed of multiple suspension insulator discs connected in series or may be designed in a specialized form to withstand high mechanical stress.

- iii. The insulator's design ensures that it can handle the tensile forces exerted by the conductors while also providing electrical insulation.
4. **Shackle insulator :**
 - i. Shackle insulators (also known as spool insulators) are used in low-voltage distribution lines. They are either mounted directly on poles or with the help of a cross-arm.
 - ii. Typically made of porcelain or composite materials, they are circular in shape with grooves that hold the conductors.
 - iii. Their design allows them to be mounted in a horizontal or vertical position.
5. **Stay insulator (Guy strain insulator) :**
 - i. Stay insulators are used in the stay (or guy) wires that support utility poles to prevent electrical currents from passing through the metal wire to the ground.
 - ii. These insulators are typically made of porcelain and have a cylindrical shape.
 - iii. Stay insulators ensure that any electrical fault in the stay wire does not reach the ground, thus preventing electrical accidents.

Que 3.12. Write the applications of different types of insulator.

Answer

Applications of different types of insulator :

1. **Pin type insulator :**
 - i. Used in power transmission lines up to 33 kV.
 - ii. Commonly seen in distribution systems where lower voltage levels are used.
2. **Suspension insulator :**
 - i. Widely used in high-voltage transmission lines (above 33 kV).
 - ii. Used in extra high voltage (EHV) and ultra high voltage (UHV) transmission systems where insulation needs are more significant.
3. **Strain insulator :**
 - i. Used at dead-end towers, sharp curves, and river crossings, where the mechanical stress on the conductor is significant.
 - ii. Suitable for high-tension applications where the mechanical forces are higher, such as in high-voltage transmission lines.

4. Shackle insulator :

- i. Used in low-voltage distribution systems (typically less than 11 kV).
- ii. Suitable for use in short-distance power distribution and in areas where the lines require frequent changes in direction.

5. Stay Insulator (Guy strain insulator) :

- i. Found in stay wires of transmission or distribution poles where mechanical support is needed.
- ii. Typically used in low-voltage distribution lines and in telephone or telegraph poles.

Que 3.13. What are the main characteristics of an ideal insulator? Describe the main advantages and disadvantages of glass insulators. Explain rating of an insulator.

Answer**A. Characteristics of ideal insulator :**

1. Mechanically they must be very strong in order to withstand the weight of the conductors.
2. Dielectric strength must be very high.
3. They must have a high ratio of puncture strength to flash over voltage.
4. They should not be porous.
5. They must be free from internal impurities or flaws.

B. Advantages glass insulator :

1. **Durability** : Highly resistant to weathering, UV radiation, and chemical attack, ensuring a long service life.
2. **Transparency** : Allows for easy visual inspection, making it easier to detect defects or contamination.

C. Disadvantages of glass insulators :

1. **Brittleness** : Susceptible to breakage from mechanical impacts and sudden temperature changes.
2. **Weight** : Heavier compared to alternative materials like polymer insulators, potentially increasing installation and handling costs.

D. Rating of insulators :

Insulator	Voltage capacity
Pin insulator	< 11 kV
Suspension insulator	11 kV to 765 kV
Strain insulator	> 33 kV
Shackle insulator	< 33 kV

PART-5

Potential Distribution Over a String of Insulators, Methods of Equalizing the Potential, String Efficiency.

Que 3.14. Explain how the potential is distributed over a string of suspension insulators? Also write about string efficiency.

OR

Derive the expression of voltage distribution in 3 insulator strings.

AKTU 2020-21, Marks 10**OR**

What are the main characteristics of an ideal insulator? Describe the main advantages and disadvantages of glass insulators. Explain rating and string efficiency of an insulator.

AKTU 2021-22, Marks 10**Answer****A. Voltage distributed over a string :**

1. Let

 C = Self capacitance V = Voltage across string $v_1, v_2, v_3 \dots v_n$ = Voltage drop across string from 1, 2, ... n $V_1, V_2, V_3 \dots V_n$ = Voltage between conductors

$$k = \frac{\text{Capacitance to earth}}{\text{Self capacitance}}$$

Capacitance to earth = $k \times$ self capacitance = kC

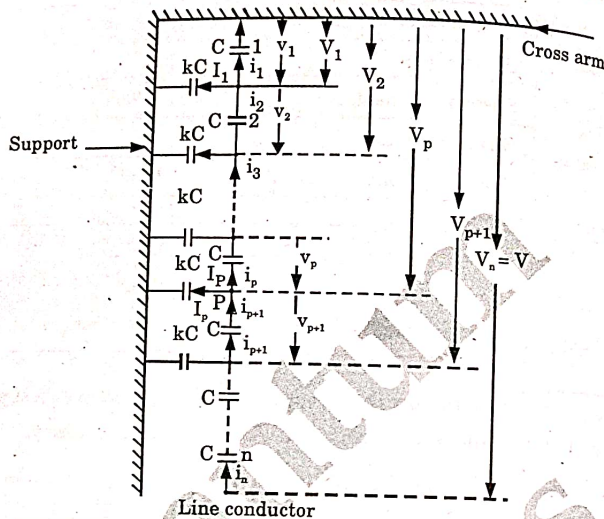


Fig. 3.14.1. Voltage distribution across the units of a string.

2. Applying KCL at node P,

$$i_{p+1} = i_p + I_p$$

$$v_{p+1}(j\omega C) = v_p(j\omega C) + V_p(j\omega kC)$$

$$v_{p+1} = v_p + kV_p \quad \dots(3.14.1)$$

$$v_1 + v_2 + v_3 \dots \dots v_n = V \quad \dots(3.14.2)$$

We can find voltage across any string using eq. (3.14.1) and (3.14.2).

3. Let us find voltage across each insulator of each string i.e., to calculate $v_2, v_3, v_4, \dots \dots v_n$ in terms of v_1 .

4. **Top most insulator or first insulator :**

Voltage across insulator = v_1

5. **Second insulator :**

Using eq. (3.14.1),

$$v_2 = v_1 + kV_1$$

But

$$V_1 = v_1$$

$$v_2 = (1 + k) v_1 \quad \dots(3.14.3)$$

6. **Third insulator :**

$$v_3 = v_2 + kV_2$$

But

$$V_2 = v_1 + v_2$$

$$v_3 = v_2 + k(v_1 + v_2)$$

$$v_3 = kv_1 + (1 + k) v_2 \quad \dots(3.14.4)$$

7. **Fourth insulator :**

$$v_4 = v_3 + kV_3$$

But

$$V_3 = v_1 + v_2 + v_3$$

$$v_4 = v_3 + k(v_1 + v_2 + v_3)$$

$$v_4 = kv_1 + (1 + k)v_2 + (1 + k)v_3 \quad \dots(3.14.5)$$

Similarly, we can calculate for all insulators.

8. It is clear that

$$v_1 < v_2 < v_3 < v_4 \dots \dots \dots < v_n$$

Since mutual capacity of each disc is same and the current through the top most unit is minimum, the voltage drop across that unit will be minimum. Going towards power conductor the current goes on increasing, and will be maximum in the lowest unit. So the voltage drop is maximum there.

- B. **String Efficiency :** String efficiency is measure of the utilization of material in the string and is defined as :

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

where n is number of disc or insulator.

- C. **Characteristics of ideal insulator :** Refer Q. 3.13, Page 3-18B, Unit-3.

- D. **Advantages, disadvantages of glass insulator and rating of insulator :** Refer Q. 3.13, Page 3-18B, Unit-3.

Que 3.15. Explain the methods of increasing string efficiency.

AKTU 2020-21, Marks 10

OR

Discuss different methods of improving string efficiency.

AKTU 2023-24, Marks 10

Answer

Following methods can be employed to enhance string efficiency :

1. **Optimizing conductor size and material :** Using conductors with larger cross-sectional areas and higher conductivity materials reduces the resistance of the line, thereby minimizing power losses and improving string efficiency.
2. **Increasing tension :** Applying higher tension to the conductor reduces sag and increases the clearance between the conductor and ground or nearby objects. This improves string efficiency.
3. **Using composite conductors :** Composite conductors, consisting of a combination of aluminum strands and a core material reduce sag and allows for higher tension levels, improving string efficiency.
4. **Optimizing conductor configuration :** Adjusting the configuration of conductors in a bundle or optimizing the arrangement of conductors in a transmission line can reduce mutual inductance and improve string efficiency.
5. **Installing high-performance insulators :** Using insulators with higher creepage distance, pollution flashover resistance, and mechanical strength enhances the reliability and performance of overhead transmission lines and contribute to higher string efficiency.
6. **Utilizing advanced monitoring and control systems :** Implementing advanced monitoring and control systems, such as systems, enables real-time monitoring of line conditions and allows for dynamic control of parameters to optimize string efficiency.

Que 3.16. Show that the string efficiency of a string of suspension insulators is dependent on number of discs in string.

AKTU 2022-23, Marks 10

Answer

1. Let's consider a string of n suspension insulators connected in series, where each insulator has capacitance C and leakage resistance R .
2. The total capacitance of the string is nC , and the total leakage resistance is nR .
3. Let V be the voltage applied across the whole string, and let V_d be the voltage across a single disc in the string.
4. Using the voltage divider rule, we can express V_d in terms of V as :

$$V_d = V * (C / (nC)) = V / n$$

5. The string efficiency is therefore :

$$\text{String efficiency} = V / (nV_d) = \eta$$

6. As we can see, the string efficiency is dependent on the number of discs in the string.
7. It is equal to the number of insulators in the string.
8. This means that the string efficiency can be increased by increasing the number of insulators in the string.

Que 3.17. An insulator string consists of three units, each having a safe working voltage of 15 kV. The ratio of self-capacitance to shunt capacitance of each unit is 8:1. Find the maximum safe working voltage of the string. Also find the string efficiency.

AKTU 2023-24, Marks 10

Answer

1. The equivalent circuit of string insulators is shown in Fig. 3.17.1.

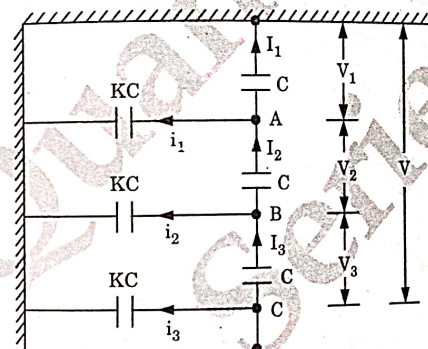


Fig. 3.17.1.

2. The maximum voltage will appear across the lowest unit in the string.

$$V_3 = 15 \text{ kV}, \quad K = \frac{1}{8} = 0.125$$

3. Applying Kirchhoff's current law to junction A, we get

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

or

$$V_1 = V_2 / (1 + K) = V_2 / (1 + 0.125) = 0.89 V_2 \dots (3.17.1)$$

4. Applying Kirchhoff's current law to junction B, we get

$$V_3 = V_2 + (V_1 + V_2)K = V_2 + (0.89 V_2 + V_2) \times 0.125$$

$$V_3 = 1.236 V_2$$

5. Voltage across middle unit, $V_2 = V_3 / 1.236$
 $= 15 / 1.236 = 12.13 \text{ kV}$... (3.17.2)
6. Voltage across top unit, $V_1 = 0.89 V_2 = 0.89 \times 12.13$
 $= 10.79 \text{ kV}$
7. Voltage across the string $= V_1 + V_2 + V_3 = 10.79 + 12.13 + 15$
 $= 37.92 \text{ kV}$
8. String efficiency $= \frac{37.92}{3 \times 15} \times 100 = 84.26 \%$

Que 3.18. A string of 8 suspension insulators is to be fitted with a grading ring. If the pin to earth capacitance is equal to C, find the values of line of pin capacitances that would give a uniform voltage distribution over the string.

Answer

1. The capacitance of the p^{th} link from the top is given by,

$$C_p = \frac{p C_s}{n - p}$$

2. Here $n = 8$, $C_s = C$. Hence the line to pin capacitance from the top are given by,

$$c_1 = \frac{1 \times c}{8 - 1} = \frac{1}{7} c, \quad c_2 = \frac{2c}{8 - 2} = \frac{1}{3} c$$

$$c_3 = \frac{3c}{8 - 3} = \frac{3}{5} c, \quad c_4 = \frac{4c}{8 - 4} = \frac{4}{4} c = c$$

$$c_5 = \frac{5c}{8 - 5} = \frac{5}{3} c, \quad c_6 = \frac{6c}{8 - 6} = 3c$$

$$c_7 = \frac{7c}{8 - 7} = 7c$$

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

- Q. 1.** Explain the method of calculating the sag for the same level.
Ans. Refer Q. 3.1.

- Q. 2.** Explain catenary method for finding the sag in a transmission line.

Ans. Refer Q. 3.2.

- Q. 3.** Write a short note on the factors that affect sag.

Ans. Refer Q. 3.3.

- Q. 4.** Explain the calculation procedure of maximum sag of a transmission line at equal supports including wind pressure loading.

Ans. Refer Q. 3.7.

- Q. 5.** What do you understand by vibration dampers in overhead transmission line? Describe the different types of dampers used.

Ans. Refer Q. 3.10.

- Q. 6.** Explain different type of insulator.

Ans. Refer Q. 3.11.

- Q. 7.** What are the main characteristics of an ideal insulator? Describe the main advantages and disadvantages of glass insulators. Explain rating and string efficiency of an insulator.

Ans. Refer Q. 3.14.

- Q. 8.** Explain the methods of increasing string efficiency.

Ans. Refer Q. 3.15.



4

UNIT

Transmission Line Parameters

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Transmission Line Parameters

PART-1

Inductance and Capacitance Calculations of Transmission Lines : Line Conductors, Inductance and Capacitance of Single Phase and three Phase Lines with Symmetrical and Unsymmetrical Spacing.

Que 4.1. Discuss about line conductors.

Answer

1. Line conductors refer to the wires or cables used to carry electrical current from one point to another in an electrical power system.
2. They are a crucial component of power transmission and distribution systems, used to deliver electricity from power plants to homes, businesses, and other locations.
3. Line conductors are typically made from materials with high electrical conductivity, such as copper or aluminum, to minimize power losses during transmission.

Que 4.2. Derive the expression for inductance of a conductor due to internal and external flux.

Answer

- i. **Inductance due to internal flux :**
 1. Consider a long, cylindrical conductor.
 2. Let us assume that I is the current flowing through it and conductor through which current is returning is so far away that magnetic field due to returning conductor is not affecting the flux lines due to conductor under consideration. Lines of flux are concentric with conductor.

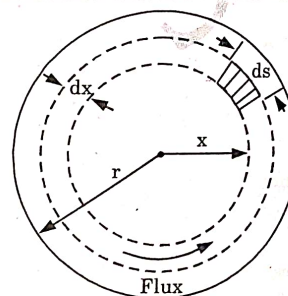


Fig. 4.2.1. Cross-section of a cylindrical conductor.

3. By Ampere's Law, $\oint H_x ds = I_x$

where, H_x = Magnetic field intensity at distance x from centre ... (4.2.1)

s = Distance along path

I_x = Current enclosed

4. Integration of ds along closed circular path = $2\pi x$, eq. (4.2.1) becomes
 $2\pi x H_x = I_x$... (4.2.2)

5. Assuming uniform current density inside conductor.

$$I_x = \frac{\pi x^2}{\pi r^2} I \quad \dots (4.2.3)$$

6. Solving eq. (4.2.2) and (4.2.3), we get

$$\begin{aligned} H_x &= \frac{\pi x^2}{\pi r^2 2\pi x} I \\ &= \frac{x}{2\pi r^2} I \text{ AT/m} \end{aligned} \quad \dots (4.2.4)$$

7. If $\mu = \mu_0 \mu_r$, permeability of conductor

Flux density at distance x from centre of conductor,

$$B_x = \mu H_x = \frac{\mu x I}{2\pi r^2} \text{ Wb/m}^2 \quad \dots (4.2.5)$$

8. Flux enclosed in element of thickness dx per metre axial length of conductor,

$$d\phi = \frac{\mu x I}{2\pi r^2} dx \quad \dots (4.2.6)$$

This flux links with current I_x .

9. Flux linkage per metre length of conductor is given by,

$$d\psi = \frac{\pi x^2}{\pi r^2} \times d\phi = \frac{\mu x^3}{2\pi r^4} I dx \text{ Wb-T} \quad \dots (4.2.7)$$

10. Integrating eq. (4.2.7) from centre to surface for total flux linkage inside conductor.

$$\psi_{\text{int}} = \int_0^r \frac{\mu x^3}{2\pi r^4} I dx = \frac{\mu I}{8\pi} \text{ Wb-T/m} \quad \dots (4.2.8)$$

11. For relative permeability, $\mu_r = 1$

$$\mu = 4\pi \times 10^{-7} \text{ H/m} \quad (\because \mu_0 = 4\pi \times 10^{-7} \text{ H/m})$$

$$\psi_{\text{int}} = \frac{I}{2} \times 10^{-7} \text{ Wb-T/m} \quad \dots (4.2.9)$$

Inductance per unit length

$$L_{\text{int}} = \frac{\psi_{\text{int}}}{I} = \frac{1}{2} \times 10^{-7} \text{ H/m} \quad \dots (4.2.10)$$

ii. Inductance due to external flux :

1. Flux linkage of an isolated conductor due to only that portion of the external flux lies between two points P_1 and P_2 at distance D_1 and D_2 respectively from the centre of conductor.
2. Conductor carries I ampere current. Flux lines are concentric circles.

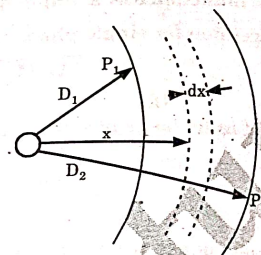


Fig. 4.2.2. A conductor at external points P_1 and P_2 .

3. Taking element dx at distance x from centre of conductor, field intensity is H_x mmf around element

$$\oint H_x dx = I_x = I$$

$$H_x 2\pi x = I$$

$$H_x = \frac{I}{2\pi x} \text{ AT/m} \quad \dots (4.2.11)$$

4. Flux density in element, $B_x = \mu H_x = \frac{\mu I}{2\pi x} \text{ Wb/m}^2 \quad \dots (4.2.12)$

5. Flux in the element dx , $d\phi = \frac{\mu I}{2\pi x} dx \text{ Wb/m} \quad \dots (4.2.13)$

6. Flux linkages $d\psi$ per meter are equal to the flux $d\phi$ since external flux links all the current in the conductor.

$$d\psi = \frac{\mu I}{2\pi x} dx \text{ Wb-T/m} \quad \dots (4.2.14)$$

7. Total flux linkages between point P_1 and P_2 are obtained by integrating $d\psi$ from $x = D_1$ to $x = D_2$

$$\psi_{12} = \int_{D_1}^{D_2} \frac{\mu I}{2\pi x} dx = \frac{\mu I}{2\pi} \ln \frac{D_2}{D_1}$$

8. For relative permeability $\mu_r = 1$, and $\mu = \mu_0 \mu_r$

$$\psi_{12} = 2 \times 10^{-7} I \ln \frac{D_2}{D_1} \text{ Wb-T/m}$$

Inductance due to flux between P_1 and P_2

$$L_{12} = \frac{\psi_{12}}{I} = 2 \times 10^{-7} \ln \left(\frac{D_2}{D_1} \right)$$

Que 4.3. Explain the inductance of a single phase two wire line system. Derive the expression for single phase two wire line.

OR

Derive the expression of inductance of single phase line.

AKTU 2020-21, Marks 10

AKTU 2020-21, Marks 10

Answer

A. Inductance of a single phase two wire line system :

1. The inductance of a single-phase two-wire line system is the property that resists changes in current flow.
2. When an alternating current (AC) flows through the wires, it generates a magnetic field that opposes any change in current.
3. Inductance is determined by the physical arrangement of the wires, such as their length and distance between them.
4. It is measured in Henry (H), and it affects line impedance, voltage drop, power factor, and line regulation in power transmission systems.

B. Expression for single phase two wire line (Single phase line):

1. First conductor carries current. Second conductor is return circuit of other. Both conductors are solid round conductor having radii r_1 and r_2

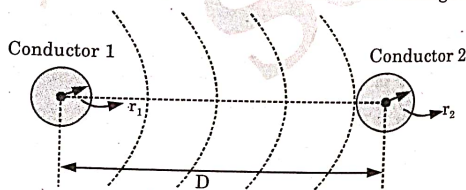


Fig. 4.3.1. Single phase two wire line.

2. For internal flux : $L_{1(int)} = \frac{1}{2} \times 10^{-7}$

$$\text{For external flux : } L_{1(ext)} = 2 \times 10^{-7} \ln \frac{D}{r_1}$$

$$\begin{aligned} 3. \text{ Total Inductance, } L_1 &= 2 \times 10^{-7} \left[\frac{1}{4} + \ln \frac{D}{r_1} \right] \\ &= 2 \times 10^{-7} \left[\ln e^{1/4} + \ln \frac{D}{r_1} \right] \\ &= 2 \times 10^{-7} \ln \frac{D}{e^{-1/4} r_1} \\ &= 2 \times 10^{-7} \ln \frac{D}{0.7788 r_1} \quad [\because e^{-1/4} = 0.778] \\ &= 2 \times 10^{-7} \ln \frac{D}{r_1'} \text{ H/m} \end{aligned}$$

where, r_1' = Geometric mean radius (GMR) of conductor.

4. Similarly, inductance due to current in second conductor

$$L_2 = 2 \times 10^{-7} \ln \frac{D}{r_2'} \text{ H/m}$$

5. If $r_1' = r_2' = r'$
Total inductance of single-phase circuit is given by

$$L = 4 \times 10^{-7} \ln \frac{D}{r'} \text{ H/m}$$

Que 4.4. A double circuit single phase line have conductor a_1 and a_2 which carry the current in one direction. Conductor b_1 and b_2 carry the current in return direction. The diameter of each conductor is 25 mm. Calculate the inductance of the line per km if $D_1 = 1 \text{ mt}$ and $D_2 = 2 \text{ mt}$.

AKTU 2023-24, Marks 10

Answer

Given : $D_1 = 1 \text{ mt}$, $D_2 = 2 \text{ mt}$, $D = 25 \text{ mm}$, $r = \frac{25}{2} = 12.5 \times 10^{-3} \text{ m}$
To Find : Inductance of the line per km

$$L = 2 \times 10^{-7} \ln \frac{D_2(D_1^2 + D_2^2)^{1/2}}{r' D_1}$$

$$L = 2 \times 10^{-7} \ln \frac{2(1+4)^{1/2}}{0.7788 r \times 1} \quad [\because r' = 0.7788r]$$

$$= 2 \times 10^{-7} \ln \frac{2(1+4)^{1/2}}{0.7788 \times 12.5 \times 10^{-3} \times 1}$$

$$\begin{aligned}
 &= 2 \times 10^{-7} \times \ln \frac{4.472}{9.735 \times 10^{-3}} \\
 &= 2 \times 10^{-7} \ln [459.3] \\
 &= 2 \times 10^{-7} \times 6.1298 \text{ H/m} \\
 &= 0.2 \times 6.1298 \text{ mH/km} \\
 &= 1.226 \text{ mH/km}
 \end{aligned}$$

Que 4.5. Derive the expression for the inductance of three phase line with conductors untransposed (unsymmetrical spacing).

Answer

1. Consider a single circuit 3 ϕ system as shown in Fig. 4.5.1. The three conductors are unsymmetrically placed i.e., $D_{12} \neq D_{23} \neq D_{31}$ and each conductor has a radius of r meters.
2. The flux linkage of conductor a due to I_a , I_b and I_c

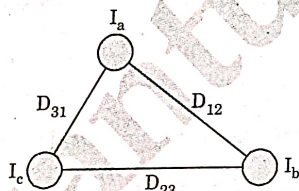


Fig. 4.5.1.

$$\psi_a = 2 \times 10^{-7} \left[I_a \ln \frac{1}{r'} + I_b \ln \frac{1}{D_{12}} + I_c \ln \frac{1}{D_{31}} \right] \quad \dots(4.5.1)$$

$$3. \text{ Similarly, } \psi_b = 2 \times 10^{-7} \left[I_a \ln \frac{1}{D_{12}} + I_b \ln \frac{1}{r'} + I_c \ln \frac{1}{D_{23}} \right] \quad \dots(4.5.2)$$

$$\psi_c = 2 \times 10^{-7} \left[I_a \ln \frac{1}{D_{31}} + I_b \ln \frac{1}{D_{23}} + I_c \ln \frac{1}{r'} \right] \quad \dots(4.5.3)$$

4. Now taking I_a as a reference phasor of unbalanced three phase system

$$I_b = k^2 I_a \text{ and } I_c = k I_a$$

$$\text{where, } k = -0.5 + j0.866$$

$$k^2 = -0.5 - j0.866$$

5. Substituting the values of I_b and I_c in the eq. (4.5.1), we get

$$\psi_a = 2 \times 10^{-7} \left[I_a \ln \frac{1}{r'} + I_a (-0.5 - j0.866) \ln \frac{1}{D_{31}} \right]$$

$$\ln \frac{1}{D_{12}} + I_a (-0.5 + j0.866) \ln \frac{1}{D_{31}}]$$

$$L_a = \frac{\psi_a}{I_a} = 2 \times 10^{-7} \left[\ln \frac{1}{r'} - \ln \frac{1}{\sqrt{D_{31} D_{12}}} - j \frac{\sqrt{3}}{2} \ln \frac{D_{31}}{D_{12}} \right]$$

6. Similarly

$$L_b = 2 \times 10^{-7} \left[\ln \frac{1}{r'} - \ln \frac{1}{\sqrt{D_{23} D_{12}}} - j \frac{\sqrt{3}}{2} \ln \frac{D_{12}}{D_{23}} \right]$$

$$L_c = 2 \times 10^{-7} \left[\ln \frac{1}{r'} - \ln \frac{1}{\sqrt{D_{23} D_{31}}} - j \frac{\sqrt{3}}{2} \ln \frac{D_{23}}{D_{31}} \right]$$

Que 4.6. Deduce an expression for inductance of a three phase transmission line.

OR

Starting from first principles, derive the expression for inductance of a 3-phase unsymmetrical spaced transposed transmission line.

AKTU 2021-22, Marks 10

Answer

Three phase line : Three phase line can be of two types :

- i. Inductance of a three phase transmission with unsymmetrical spacing : Refer Q. 4.5, Page 4-7B, Unit-4.
 - ii. Symmetrical three phase line :
1. As shown in Fig. 4.6.1, in such arrangement conductors are situated at the corners of an equilateral triangle.

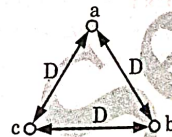


Fig. 4.6.1. Symmetrical 3 ϕ line.

D = Spacing between conductors.

r = Radius of each conductor.

2. Flux linkage of conductor a

$$\psi_a = 2 \times 10^{-7} \left[I_a \ln \frac{1}{D_{aa}} + I_b \ln \frac{1}{D_{ab}} + I_c \ln \frac{1}{D_{ac}} \right]$$

$$D_{ab} = D_{ac} = D$$

$$D_{aa} = r' = re^{-1/4}$$

$$\psi_a = 2 \times 10^{-7} \left[I_a \ln \frac{1}{r'} + I_b \ln \frac{1}{D} + I_c \ln \frac{1}{D} \right]$$

$$= 2 \times 10^{-7} \left[I_a \ln \frac{1}{r'} + (I_b + I_c) \ln \frac{1}{D} \right]$$

3. For three wire system algebraic sum of current in conductor is zero

$$I_a + I_b + I_c = 0$$

$$I_b + I_c = -I_a$$

$$\psi_a = 2 \times 10^{-7} \left[I_a \ln \frac{1}{r'} - I_a \ln \frac{1}{D} \right] = 2 \times 10^{-7} \times I_a \left[\ln \frac{1}{r'} - \ln \frac{1}{D} \right]$$

$$= 2 \times 10^{-7} \times I_a \ln \frac{D}{r'} \text{ Wb-T/m}$$

4. Inductance of conductors a is

$$L_a = \frac{\psi_a}{I_a} = 2 \times 10^{-7} \ln \frac{D}{r'} \text{ H/m}$$

5. The inductance of conductors b and c will also be the same as that of a , because of symmetry

$$L_b = L_c = 2 \times 10^{-7} \ln \frac{D}{r'} \text{ H/m}$$

iii. Unsymmetrical spacing but transposed :

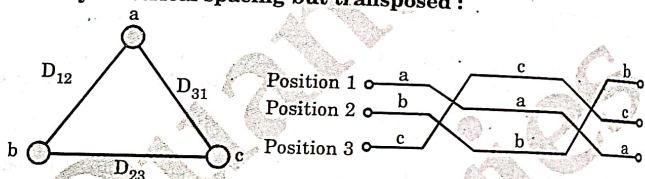


Fig. 4.6.2. Transposition cycle of unequally spaced three phase line conductors.

1. Flux linkage of conductor a ; when a is in the position 1, b in position 2 and c in position 3

$$\psi_{a1} = 2 \times 10^{-7} \left[I_a \ln \frac{1}{r'} + I_b \ln \frac{1}{D_{12}} + I_c \ln \frac{1}{D_{31}} \right]$$

2. When conductor a is in position 2, b in position 3 and c in position 1

$$\psi_{a2} = 2 \times 10^{-7} \left[I_a \ln \frac{1}{r'} + I_b \ln \frac{1}{D_{23}} + I_c \ln \frac{1}{D_{12}} \right]$$

3. When conductor a is in position 3, b in position 1 and c in position 2

$$\psi_{a3} = 2 \times 10^{-7} \left[I_a \ln \frac{1}{r'} + I_b \ln \frac{1}{D_{31}} + I_c \ln \frac{1}{D_{23}} \right]$$

4. Average value of flux linkages of a is

$$\psi_a = \frac{1}{3} \times [\psi_{a1} + \psi_{a2} + \psi_{a3}]$$

$$= \frac{1}{3} \times 2 \times 10^{-7} \left[\left(I_a \ln \frac{1}{r'} + I_b \ln \frac{1}{D_{12}} + I_c \ln \frac{1}{D_{31}} \right) \right.$$

$$\left. + \left(I_a \ln \frac{1}{r'} + I_b \ln \frac{1}{D_{23}} + I_c \ln \frac{1}{D_{12}} \right) + \left(I_a \ln \frac{1}{r'} + I_b \ln \frac{1}{D_{31}} + I_c \ln \frac{1}{D_{23}} \right) \right]$$

$$= \frac{2}{3} \times 10^{-7} \left[\left(3I_a \ln \frac{1}{r'} + I_b \ln \frac{1}{D_{12}D_{23}D_{31}} + I_c \ln \frac{1}{D_{12}D_{23}D_{31}} \right) \right]$$

$$= \frac{2}{3} \times 10^{-7} \left[\left(3I_a \ln \frac{1}{r'} + (I_b + I_c) \ln \frac{1}{D_{12}D_{23}D_{31}} \right) \right]$$

5. For balanced condition $I_a + I_b + I_c = 0$
 $I_b + I_c = -I_a$

$$\psi_a = 2 \times 10^{-7} \left[I_a \ln \frac{1}{r'} - \frac{1}{3} I_a \ln \frac{1}{D_{12}D_{23}D_{31}} \right]$$

$$= 2 \times 10^{-7} \times I_a \ln \frac{(D_{12}D_{23}D_{31})^{1/3}}{r'}$$

6. Average inductance of phase a

$$L_a = \frac{\psi_a}{I_a} = 2 \times 10^{-7} \ln \frac{(D_{12}D_{23}D_{31})^{1/3}}{r'} \text{ H/m}$$

7. Similarly,

$$L_b = L_c = 2 \times 10^{-7} \ln \frac{(D_{12}D_{23}D_{31})^{1/3}}{r'} \text{ H/m}$$

Que 4.7. The three conductors of a 3-phase line are arranged at the corners of a triangle of sides 2 m, 2.5 m and 4.5 m. Calculate the inductance per km of the line when the conductors are regularly transposed. The diameter of each conductor is 1.24 cm.

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Answer

$$\text{Given : } r = \frac{d}{2} = \frac{1.24}{2} = 0.62 \text{ cm, } D_{12} = 2 \text{ m, } D_{23} = 2.5 \text{ m, } D_{31} = 4.5 \text{ m}$$

To Find : L

1. $r' = 0.778 r = 0.482 \text{ cm}$

2.
$$L = 2 \times 10^{-7} \ln \frac{(D_{12} D_{23} D_{31})^{1/3}}{r'}$$

$$= 2 \times 10^{-7} \ln \frac{(2 \times 2.5 \times 4.5)^{1/3}}{0.482 \times 10^{-2}} \text{ H/m}$$

$$= 12.74 \times 10^{-7} \times 1000 \text{ k/m}$$

$$= 12.74 \times 10^{-4} \text{ H/km.}$$

Que 4.8. Discuss the concept of self GMD and mutual GMD with the help of suitable example.

Answer

A. Self-GMD (D_s):

1. It is also called geometrical mean radius (GMR).
2. Inductance per conductor per meter length is given by,

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

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

$$L = 2 \times 10^{-7} \ln \frac{D}{D_s}$$

where,

D_s = Self-GMD or GMR = $0.7788r$

Sometimes GMR is denoted by r' .

3. Self-GMD of a conductor depends upon the size and shape of the conductor and is independent of the spacing between the conductors.

B. Mutual-GMD (D_m): The mutual-GMD is the geometrical mean of the distance from one conductor to the other. It simply represents the equivalent geometrical spacing.

C. Example of self GMD and mutual GMD :

1. The conductor arrangement of the double circuit is shown in Fig. 4.8.1. Let the radius of each conductor be r .

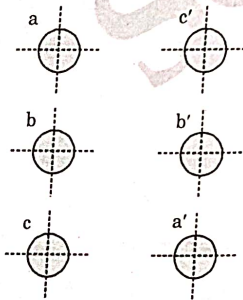


Fig. 4.8.1.

2. Self-GMD of conductor = $0.7788r$

4-12 B (EN-Sem-5)

3. Self-GMD of combination aa' ,

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

4. Self-GMD of combination bb' ,

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

5. Self-GMD of combination cc' ,

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

6. Equivalent self-GMD of one phase,

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

7. Since each conductor has the same radius, therefore the value of D_s is same for the all phases.

8. Mutual-GMD between phases A and B,

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

Mutual-GMD Between phases B and C,

$$D_{BC} = (D_{bc} \times D_{bc'} \times D_{b'c} \times D_{b'c'})^{1/4}$$

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

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

10. Mutual-GMD is independent of exact size, shape and orientation of the conductor and depends only upon the spacing.

Que 4.9. Find the inductance per phase of symmetrically spaced double circuit 3-phase line.

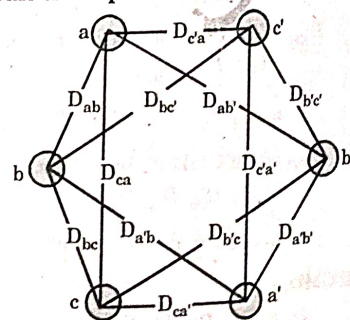
OR

Describe the inductance calculation procedure of three-phase double-circuit line with symmetrical spacing (hexagonal).

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Answer

Double circuit three phase lines with transposition :



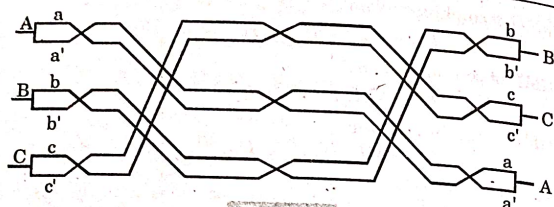


Fig. 4.9.1.

1. Formula for inductance of a 3 ϕ unsymmetrical line

$$L = 2 \times 10^{-7} \ln \left(\frac{\text{Mutual GMD}}{\text{Self GMD}} \right) \dots (4.9.1)$$

2. For double circuit line

D_{AB} = Mutual GMD between phase A & B i.e., between a, a' and b, b'

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

D_{BC} = Mutual GMD between phases B and C i.e., between b, b' and c, c'

$$= (D_{bc} D_{bc'} D_{b'c} D_{b'c'})^{1/4}$$

D_{CA} = Mutual GMD between phases C and A i.e., between c, c' and a, a'

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

3. Mutual GMD of line

$$D_m = (D_{AB} D_{BC} D_{CA})^{1/3} \\ = (D_{ab} D_{bc} D_{ca} D_{ab'} D_{bc'} D_{ca'} D_{a'b} D_{b'c} D_{c'a} D_{a'b'} D_{b'c'} D_{c'a'})^{1/12}$$

D_{SA} = Self GMD of phase A i.e., a, a'

$$= (D_{aa} D_{a'a'} D_{a'a} D_{a'a'})^{1/4} \\ = (r' r' D_{aa}^2)^{1/4} = (r' D_{aa})^{1/2}$$

D_{SB} = Self GMD of phase B i.e., b, b'

$$= (D_{bb} D_{b'b'} D_{b'b} D_{b'b'})^{1/4} \\ = (r' r' D_{bb}^2)^{1/4} = (r' D_{bb})^{1/2}$$

D_{SC} = Self GMD of phase C i.e., c, c'

$$= (D_{cc} D_{c'c'} D_{c'c} D_{cc'})^{1/4} \\ = (r' r' D_{cc}^2)^{1/4} = (r' D_{cc})^{1/2}$$

4. Equivalent self GMD,

$$D_s = (D_{SA} D_{SB} D_{SC})^{1/3}$$

$$= (r' D_{aa'} \cdot r' D_{bb'} \cdot r' D_{cc'})^{1/6}$$

$$= (r'^3 D_{aa'} D_{bb'} D_{cc'})^{1/6}$$

5. Inductance of double circuit line per phase

$$L = 2 \times 10^{-7} \ln \frac{D_m}{D_s}$$

$$= 2 \times 10^{-7} \ln \frac{(D_{ab} D_{bc} D_{ca} D_{ab'} D_{bc'} D_{ca'} D_{a'b} D_{b'c} D_{c'a} D_{a'b'} D_{b'c'} D_{c'a'})^{1/12}}{(r'^3 D_{aa'} D_{bb'} D_{cc'})^{1/6}}$$

Case I:

Inductance of 3 ϕ double circuit line with hexagonal spacing as shown in Fig. 4.9.2.

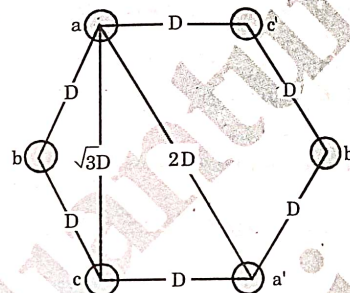


Fig. 4.9.2. Double circuit three phase line with hexagonal spacing.

1. $D_{ab} = D_{bc} = D_{ca} = D_{c'a} = D_{a'b'} = D_{b'b'} = D$
 $D_{ca} = D_{ab'} = D_{bc'} = D_{a'b} = D_{b'c} = D_{c'a'} = \sqrt{3}D$
 $D_{aa'} = D_{bb'} = D_{cc'} = 2D$

2. Inductance per phase

$$L = 2 \times 10^{-7} \ln \frac{[D^6 (\sqrt{3}D)^6]^{1/12}}{[2r'(2D)^3]^{1/6}}$$

$$= 2 \times 10^{-7} \ln \frac{(\sqrt{3}D^2)^{1/2}}{[r' 2D]^{1/2}}$$

$$= 10^{-7} \ln \left(\frac{\sqrt{3}D}{2r'} \right) \text{ H/m}$$

Case II :

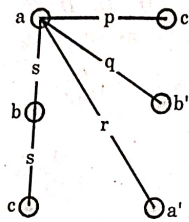


Fig. 4.9.3. Double circuit three phase line with flat vertical spacing.

1. Conductors are placed flat and vertically spaced.

$$D_{ab} = D_{bc} = D_{a'b'} = D_{b'c'} = D_{c'a'} = s$$

$$D_{ac} = D_{a'c'} = 2s$$

$$D_{ac'} = D_{bb'} = D_{ca'} = p$$

$$D_{ab'} = D_{ba'} = D_{bc'} = D_{cb'} = q$$

$$D_{aa'} = D_{cc'} = r$$

2. Inductance per phase using eq. (4.9.1)

$$L = 2 \times 10^{-7} \ln \frac{(s.s.2s.q.q.p.q.q.p.s.s.2s)^{1/2}}{(r^{13}.r.p.r.)^{1/6}} \text{ H/m}$$

$$= 2 \times 10^{-7} \ln \left[2^{1/6} \left(\frac{s}{r} \right)^{1/2} \left(\frac{q}{r} \right)^{1/3} \right] \text{ H/m}$$

Que 4.10. A three phase 50 Hz transmission line consists of three equal conductors of radii π , placed in a horizontal plane, with a spacing of 6 m between the middle and each outer conductor. Determine the inductive reactance per phase per km of the transposed line if the radius of each conductor is 12.5 mm.

Answer

Given : $f = 50 \text{ Hz}$, $r = 12.5 \text{ mm}$

To Find : Inductive reactance per phase per km.

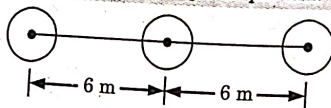


Fig. 4.10.1.

$$D_{eq} = (D.D.2D)^{1/3}$$

$$= (6 \times 6 \times 12)^{1/3} = 7.558$$

1. Inductance/phase/m

$$L = \left(0.5 + 2 \ln \frac{D_{eq}}{r} \right) \times 10^{-7}$$

$$= \left(0.5 + 2 \ln \left(\frac{7.558 \times 10^3}{12.5} \right) \right) \times 10^{-7}$$

$$= 13.31 \times 10^{-7} \text{ H/m}$$

$$= 13.31 \times 10^{-7} \times 1000 \text{ H/km}$$

$$= 13.31 \times 10^{-4} \text{ H/km}$$

Que 4.11. Derive expressions for the line-to-neutral capacitance and line-to-line capacitance of a single phase line.

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OR

Derive an expression for the capacitance of a single phase overhead transmission line.

Answer

Capacitance of single phase line :

1. Voltage between two points,

$$V_{12} = \frac{q}{2\pi\epsilon} \ln \left(\frac{D_2}{D_1} \right) \text{ V} \quad \dots(4.11.1)$$

2. Potential due to q_a using eq. (4.11.1)

$$V_{ab}' = \frac{q_a}{2\pi\epsilon} \ln \frac{D}{r_a} \quad \dots(4.11.2)$$

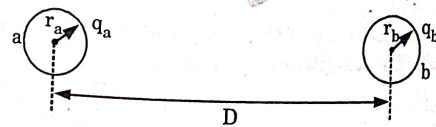


Fig. 4.11.1. Single phase line.

3. Potential due to q_b using eq. (4.11.1)

$$V_{ab}'' = \frac{q_b}{2\pi\epsilon} \ln \frac{r_b}{D} \quad \dots(4.11.3)$$

4. Net potential from a to b,

$$V_{ab} = V_{ab}' + V_{ab}'' = \frac{1}{2\pi\epsilon} \left\{ q_a \ln \frac{D}{r_a} + q_b \ln \frac{r_b}{D} \right\} \quad \dots(4.11.4)$$

5. Since b is return conductor,

$$q_a = -q_b$$

6. On putting $q_a = -q_b$, eq. (4.11.4) becomes

$$\begin{aligned} V_{ab} &= \frac{1}{2\pi\epsilon} q_a \ln \left(\frac{D^2}{r_a r_b} \right) \\ &= \frac{1}{\pi\epsilon} q_a \ln \frac{D}{\sqrt{r_a r_b}} \quad \dots(4.11.5) \end{aligned}$$

7. Now capacitance of line,

$$C_{ab} = \frac{q_a}{V_{ab}} = \frac{\pi\epsilon}{\ln(D/\sqrt{r_a r_b})} \text{ F/m} \quad \dots(4.11.6)$$

8. If

$$r_a = r_b = r \text{ then eq. (4.11.5) becomes}$$

$$C_{ab} = \frac{\pi\epsilon}{\ln(D/r)} \text{ F/m} \quad \dots(4.11.7)$$

9. The potential difference between each conductor and neutral is half the potential difference between the two conductors. This means capacitance of one of the conductor with respect to the neutral point will be two times the capacitance of single phase line.

$$C_{an} = C_{bn} = 2 C_{ab} = \frac{2\pi\epsilon}{\ln \frac{D}{r}} \text{ F/m}$$

C_{an} = Capacitance of conductor with respect to neutral point N .

Que 4.12. Find the capacitance of single-phase line 40 km long consisting of two parallel wires each 5 mm in diameter and 1.5 m apart.

Determine the capacitance of the same line taking into account the effect of ground. The height of the conductor above the ground is 7 meters.

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Answer

Given: Diameter of the conductor, $d = 5$ mm, Effective radius of conductor, $r = 2.5$ mm, Spacing between the conductors, $D = 1.5$ m, $h = 7$ meter.

To Find: Capacitance of single phase line (C), C_L .

1. Capacitance of one conductor

$$C_1 = \frac{2\pi\epsilon}{\ln \frac{D}{r}} = \frac{10^{-9}}{18 \ln \frac{1.5}{2.5 \times 10^{-3}}} = 8.68 \text{ nF/km}$$

2. The capacitance between the two conductors,

$$C' = \frac{C_1}{2} = \frac{8.68}{2} = 4.34 \text{ nF/km}$$

3. Capacitance between the two conductors for 40 km

$$C = 4.34 \times 10^{-3} \times 40 \times 10^3 = 0.173 \mu\text{F}$$

- ii. When the effect of ground is taken into account, the line to neutral capacitance is given by

$$C_n = \frac{1}{18 \times 10^9 \left(\ln \frac{D}{r} - \ln \frac{H_m}{H_s} \right)}$$

$$h = 7, H_1 = H_2 = 2h = 2 \times 7 = 14 \text{ m}$$

$$H_{12} = H_{21} = (D^2 + 4h^2)^{1/2} = (1.5^2 + 4 \times 14^2)^{1/2} = \sqrt{786}$$

$$H_m = (H_{12} H_{21})^{1/2} = H_{12} = \sqrt{786}$$

$$H_s = (H_1 H_2)^{1/2} = (2h \cdot 2h)^{1/2} = 2h = 14 \text{ m}$$

$$C_n = \frac{1}{18 \times 10^9 \left(\ln \frac{1.5}{2.5 \times 10^{-3}} - \ln \frac{\sqrt{786}}{14} \right)}$$

$$= \frac{1}{18 \times 10^9 \left(\ln \frac{1.5}{2.5 \times 10^{-3}} \times \frac{14}{\sqrt{786}} \right)}$$

$$= 9.74 \mu\text{F/m}$$

2. Line to line capacitance

$$C_L = \frac{1}{2} C_n$$

$$= \frac{1}{2} \times 9.74$$

$$= 4.87 \mu\text{F/m}$$

Que 4.13. Derive expression for capacitance of three phase line.
OR
Derive the expression for capacitance of unsymmetrically and symmetrically spaced three phase lines.
OR
Derive an expression for the capacitance per unit length of a 3-phase line completely transposed.

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Answer

A. 3-φ line symmetrically spaced or equilateral spacing:

1. Taking conductor *a*

Voltage between conductor *a* and *b*

$$V_{ab} = \frac{1}{2\pi\epsilon} \left\{ q_a \ln \frac{D}{r} + q_b \ln \frac{r}{D} \right\} \quad \dots(4.13.1)$$

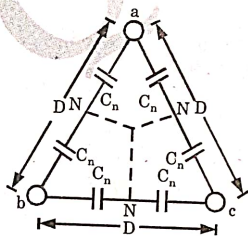
2. Voltage between conductor *a* and *c*

$$V_{ac} = \frac{1}{2\pi\epsilon} \left\{ q_a \ln \frac{D}{r} + q_c \ln \frac{r}{D} \right\} \quad \dots(4.13.2)$$

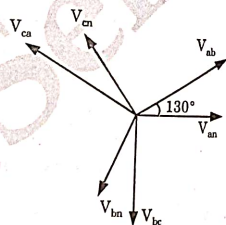
3. Adding eq. (4.13.1) and (4.13.2)

$$V_{ab} + V_{ac} = \frac{1}{2\pi\epsilon} \left\{ 2q_a \ln \frac{D}{r} + (q_b + q_c) \ln \frac{r}{D} \right\} \quad \dots(4.13.3)$$

4. Also,
 $q_a + q_b + q_c = 0$
 $q_b + q_c = -q_a$



(a) Three phase line with equilateral spacing.



(b) Phasor diagram of voltages.

Fig. 4.13.1.

5. Substituting value of $q_b + q_c$ in eq. (4.13.3)

$$V_{ab} + V_{ac} = \frac{1}{2\pi\epsilon} \left\{ 2q_a \ln \frac{D}{r} - q_a \ln \frac{r}{D} \right\}$$

$$= \frac{1}{2\pi\epsilon} \left\{ 2q_a \ln \frac{D}{r} + q_a \ln \frac{D}{r} \right\}$$

$$V_{ab} + V_{ac} = \frac{3q_a}{2\pi\epsilon} \ln \frac{D}{r} \quad \dots(4.13.4)$$

$$V_{ab} = \sqrt{3} V_{an} \angle 30^\circ$$

$$V_{ac} = -V_{ca}$$

$$= \sqrt{3} V_{an} \angle -30^\circ$$

$$V_{ab} + V_{ac} = 3V_{an} \quad \dots(4.13.5)$$

7. From eq. (4.13.4) and (4.13.5)

$$3V_{an} = \frac{3q_a}{2\pi\epsilon} \ln \frac{D}{r}$$

$$V_{an} = \frac{q_a}{2\pi\epsilon} \ln \frac{D}{r} \quad \dots(4.13.6)$$

8. Line to neutral capacitance,

$$C_n = \frac{q_a}{V_{an}} = \frac{2\pi\epsilon}{\ln D/r} \text{ F/m} \quad \dots(4.13.7)$$

For air, $\epsilon_r = 1$

Since $\epsilon = \epsilon_0 \epsilon_r$

$$C_n = \frac{2\pi\epsilon_0}{\ln D/r} \text{ F/m} \quad \dots(4.13.8)$$

B. 3-φ line unsymmetrically spaced but transposed:

1. When phase *a* is in position 1, *b* in position 2 and *c* in position 3.

$$V_{ab} = \frac{1}{2\pi\epsilon} \left\{ q_a \ln \frac{D_{12}}{r} + q_b \ln \frac{r}{D_{12}} \right\} \quad \dots(4.13.9)$$

2. When *a* in position 2, *b* in position 3 and *c* in position 1

$$V_{ab} = \frac{1}{2\pi\epsilon} \left\{ q_a \ln \frac{D_{23}}{r} + q_b \ln \frac{r}{D_{23}} \right\} \quad \dots(4.13.10)$$

3. When *a* in position 3, *b* in position 1 and *c* in position 2

$$V_{ab} = \frac{1}{2\pi\epsilon} \left\{ q_a \ln \frac{D_{31}}{r} + q_b \ln \frac{r}{D_{31}} \right\} \quad \dots(4.13.11)$$

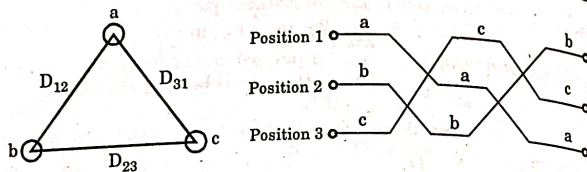


Fig. 4.13.2. Transposition cycle of unequally spaced three phase line conductors.

4. Average voltage between conductor a and b :

$$V_{ab} = \frac{1}{3} \times \frac{1}{2\pi\epsilon} \left\{ q_a \ln \frac{D_{12} D_{23} D_{31}}{r^3} + q_b \ln \frac{r^3}{D_{12} D_{23} D_{31}} \right\} \quad \dots(4.13.12)$$

$$V_{ab} = \frac{1}{6\pi\epsilon} \times \left\{ q_a \ln \left(\frac{D_m}{r} \right)^3 + q_b \ln \left(\frac{r}{D_m} \right)^3 \right\}$$

$$V_{ab} = \frac{1}{2\pi\epsilon} \times \left\{ q_a \ln \frac{D_m}{r} + q_b \ln \frac{r}{D_m} \right\} \quad \dots(4.13.13)$$

where $D_m = (D_{12} D_{23} D_{31})^{1/3}$
is mutual geometric mean distance between phase

5. Similarly, average voltage between conductor a and c

$$V_{ac} = \frac{1}{2\pi\epsilon} \left\{ q_a \ln \frac{D_m}{r} + q_c \ln \frac{r}{D_m} \right\} \quad \dots(4.13.14)$$

6. Similarly, average voltage between conductor b and c

$$V_{bc} = \frac{1}{2\pi\epsilon} \left\{ q_b \ln \frac{D_m}{r} + q_c \ln \frac{r}{D_m} \right\} \quad \dots(4.13.15)$$

7. Let line to neutral voltage of conductor a is V_{an}

$$\begin{aligned} 3V_{an} &= V_{ab} + V_{ac} \\ &= \frac{1}{2\pi\epsilon} \left\{ 2q_a \ln \frac{D_m}{r} + q_b \ln \frac{r}{D_m} + q_c \ln \frac{r}{D_m} \right\} \end{aligned} \quad \dots(4.13.16)$$

8. Here, $q_a + q_b + q_c = 0$

$$q_b + q_c = -q_a$$

Eq. (4.13.16) becomes

$$3V_{an} = \frac{3}{2\pi\epsilon} q_a \ln \left(\frac{D_m}{r} \right) \quad \dots(4.13.17)$$

9. Capacitance of line a to neutral

$$C_{an} = \frac{q_a}{V_{an}} = \frac{2\pi\epsilon}{\ln(D_m/r)} \text{ F/m} \quad \dots(4.13.18)$$

Que 4.14. Derive expression of capacitance of three phase untransposed line.

Answer

1. A three-phase single circuit untransposed line is shown in Fig. 4.14.1.

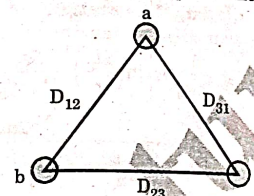


Fig. 4.14.1. Three-phase single-circuit untransposed line.

2. The potential difference between a and b is given by

$$V_{ab} = \frac{1}{2\pi\epsilon_0} \left(q_a \ln \frac{D_{12}}{r} + q_b \ln \frac{r}{D_{12}} + q_c \ln \frac{D_{23}}{D_{31}} \right)$$

3. The potential difference between a and c is given by

$$V_{ac} = \frac{1}{2\pi\epsilon_0} \left(q_a \ln \frac{D_{31}}{r} + q_b \ln \frac{D_{23}}{D_{12}} + q_c \ln \frac{r}{D_{31}} \right)$$

4. But $V_{ab} + V_{ac} = 3V_{an}$

Therefore,

$$\begin{aligned} 3V_{an} &= \frac{1}{2\pi\epsilon_0} \left[q_a \left(\ln \frac{D_{12}}{r} + \ln \frac{D_{31}}{r} \right) \right. \\ &\quad \left. + q_b \left(\ln \frac{r}{D_{12}} + \ln \frac{D_{23}}{D_{31}} \right) + q_c \left(\ln \frac{D_{23}}{D_{12}} + \ln \frac{r}{D_{31}} \right) \right] \end{aligned}$$

5. Since for a three-phase three-wire circuit

$$q_a + q_b + q_c = 0$$

$$q_c = -q_a - q_b$$

$\therefore$

$$\begin{aligned} 3V_{an} &= \frac{1}{2\pi\epsilon_0} \left[q_a \left(\ln \frac{D_{12}}{r} + \ln \frac{D_{31}}{r} \right) \right. \\ &\quad \left. + q_b \left(\ln \frac{r}{D_{12}} + \ln \frac{D_{23}}{D_{31}} \right) - q_a \ln \frac{D_{23}}{D_{12}} - \ln \frac{r D_{23}}{D_{31}^2} \right] \end{aligned}$$

$$= \frac{1}{2\pi\epsilon_0} \left(q_a \ln \frac{D_{12} D_{31} D_{31}^2}{r^2 r D_{23}} + q_b \ln \frac{r D_{23} D_{31}^2}{D_{12}^2 r D_{23}} \right)$$

6. But

$$q_b = q_a \angle -120^\circ = q_a \left(-\frac{1}{2} - j\frac{\sqrt{3}}{2} \right)$$

$$\therefore 3V_{an} = \frac{1}{2\pi\epsilon_0} \left(q_a \ln \frac{D_{12} D_{31}^3}{r^3 D_{23}} - \frac{1}{2} q_a \ln \frac{D_{31}^2}{D_{12}^2} - j\frac{\sqrt{3}}{2} q_a \ln \frac{D_{31}^2}{D_{12}^2} \right)$$

$$= \frac{1}{2\pi\epsilon_0} q_a \left(\ln \frac{D_{12} D_{31}^3 D_{12}}{r^3 D_{23} D_{31}} + j\sqrt{3} \ln \frac{D_{12}}{D_{31}} \right)$$

$$= \frac{1}{2\pi\epsilon_0} q_a \left[\ln \left(\frac{D_{31}}{r} \right)^3 \frac{D_{12}^2}{D_{23} D_{31}} + j\sqrt{3} \ln \frac{D_{12}}{D_{31}} \right]$$

$$C_{an} = \frac{q_a}{V_{an}} = \frac{2\pi\epsilon_0}{\frac{1}{3} \left[\ln \left(\frac{D_{31}}{r} \right)^3 \left(\frac{D_{12}^2}{D_{23} D_{31}} \right) + j\sqrt{3} \ln \frac{D_{12}}{D_{31}} \right]}$$

$$= \frac{2\pi\epsilon_0}{\frac{1}{3} \left[\ln \left(\frac{D_{31}}{r} \right)^3 \left(\frac{D_{12}^2 D_{12}}{D_{12} D_{23} D_{31}} \right) + j\sqrt{3} \ln \frac{D_{12}}{D_{31}} \right]}$$

$$= \frac{2\pi\epsilon_0}{\frac{1}{3} \left[\ln \left(\frac{D_{31}}{r} \right)^3 \frac{D_{12}^3}{D_m^3} + j\sqrt{3} \ln \frac{D_{12}}{D_{31}} \right]}$$

$$C_{an} = \frac{2\pi\epsilon_0}{\left(\ln \frac{D_{31} D_{12}}{r D_m} + j \frac{1}{\sqrt{3}} \ln \frac{D_{12}}{D_{31}} \right)} \text{ F/m}$$

7. Similarly,

$$C_{ab} = \frac{2\pi\epsilon_0}{\left(\ln \frac{D_{12} D_{23}}{r D_m} + j \frac{1}{\sqrt{3}} \ln \frac{D_{23}}{D_{12}} \right)}$$

$$C_{cn} = \frac{2\pi\epsilon_0}{\left(\ln \frac{D_{31} D_{23}}{r D_m} + j \frac{1}{\sqrt{3}} \ln \frac{D_{31}}{D_{23}} \right)} \text{ F/m}$$

It is found that the phase capacitances are complex numbers.

PART-2

Composite Conductors-Transposition, Bundled Conductors, and Effect of Earth on Capacitance.

Que 4.15. Calculate inductance of a single-phase system (with composite conductors).

OR

Show that the inductance of a bundle conductor line is less than that of the line with one conductor per phase with mathematical expression.

AKTU 2022-23, Marks 10

Answer

1. Consider a single-phase system consisting of two composite conductors A and B, each having m and n number of strands, respectively as shown in Fig. 4.15.1.

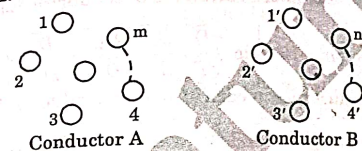


Fig. 4.15.1.

2. The current is assumed to be equally divided amongst all the strands of 'A' conductor and is equal to $\frac{I}{m}$ (acts as "go" conductor for the single-phase line) and current in all the strands of 'B' conductor is $\frac{-I}{n}$ (acts as "return" conductor for the single-phase line).

3. Using eq. $\psi_1 = 2 \times 10^{-7} \left(I_1 \ln \frac{1}{D_{11}} + I_2 \ln \frac{1}{D_{12}} + \dots + I_n \ln \frac{1}{D_{1n}} \right)$ Wb-T/m the flux linkages of strand 1 due to currents in all conductors is given by,

$$\psi_1 = 2 \times 10^{-7} \frac{I}{m} \left(\ln \frac{1}{D_{11}} + \ln \frac{1}{D_{12}} + \dots + \ln \frac{1}{D_{1m}} \right) - 2 \times 10^{-7} \frac{I}{n} \left(\ln \frac{1}{D_{11'}} + \ln \frac{1}{D_{12'}} + \dots + \ln \frac{1}{D_{1n'}} \right) \quad \dots (4.15.1)$$

$$\psi_1 = 2 \times 10^{-7} \frac{I}{m} \left(\ln \frac{1}{D_{11} D_{12} \dots D_{1m}} \right) - 2 \times 10^{-7} \frac{I}{n} \left(\ln \frac{1}{D_{11'} D_{12'} \dots D_{1n'}} \right)$$

$$\psi_1 = 2 \times 10^{-7} I \left(\ln \frac{1}{\sqrt[m]{D_{11} D_{12} \dots D_{1m}}} - \ln \frac{1}{\sqrt[n]{D_{11'} D_{12'} \dots D_{1n'}}} \right)$$

$$= 2 \times 10^{-7} I \left(\ln \frac{\sqrt{D_{11'} D_{12'} \dots D_{1n'}}}{\sqrt{D_{11} D_{12} \dots D_{1m}}} \right) \dots (4.15.2)$$

4. Inductance of strand 1 of conductor A is

$$L_1 = \frac{\Psi_1}{I/m} = 2m \times 10^{-7} \ln \frac{\sqrt{D_{11'} D_{12'} \dots D_{1n'}}}{\sqrt{D_{11} D_{12} \dots D_{1m}}} H/m \dots (4.15.3)$$

5. Inductance of strand 2 of conductor A is

$$L_2 = \frac{\Psi_2}{I/m} = 2m \times 10^{-7} \ln \frac{\sqrt{D_{21'} D_{22'} \dots D_{2n'}}}{\sqrt{D_{21} D_{22} \dots D_{2m}}} H/m \dots (4.15.4)$$

6. Similarly, the inductance of strand m of conductor A is

$$\therefore L_m = \frac{\Psi_m}{I/m} = 2m \times 10^{-7} \ln \frac{\sqrt{D_{m1'} D_{m2'} \dots D_{mn'}}}{\sqrt{D_{m1} D_{m2} \dots D_{mm}}} H/m \dots (4.15.5)$$

The average inductance of each strand in conductor A is

$$L_{av} = \frac{L_1 + L_2 + \dots + L_m}{m} \dots (4.15.6)$$

8. Since conductor A is composed of m subconductors electrically in parallel. Thus the inductance of conductor A is

$$L_A = \frac{L_{av}}{m} = \frac{L_1 + L_2 + \dots + L_m}{m^2} \dots (4.15.7)$$

9. Substituting the logarithmic expression for inductance of each strand in eq. (4.15.7) and combining terms, we get

$$L_A = 2 \times 10^{-7} \ln \left(\frac{\sqrt{mn} \sqrt{(D_{11'} D_{12'} \dots D_{1n'}) (D_{21'} D_{22'} \dots D_{2n'}) \dots (D_{n1'} D_{n2'} \dots D_{nn'})}}{\sqrt{m^2 \sqrt{(D_{11} D_{12} \dots D_{1m}) (D_{21} D_{22} \dots D_{2m}) \dots (D_{m1} D_{m2} \dots D_{mm})}}} \right) \dots (4.15.8)$$

10. In eq. (4.15.8), the numerator is known as Geometric Mean Distance (GMD or mutual GMD) and is denoted as D_m and is equal to

$$D_m = \sqrt[mn]{(D_{11'} D_{12'} \dots D_{1n'}) (D_{21'} D_{22'} \dots D_{2n'}) \dots (D_{n1'} D_{n2'} \dots D_{nn'})} \dots (4.15.9)$$

11. It is the mn^{th} root of the product of the mn distances between m strands of conductor A and n strands of conductor B.

12. The denominator is known as GMR or self GMD, denoted as D_s and is equal to

$$D_s = \sqrt[m^2]{(D_{11} D_{12} \dots D_{1m}) (D_{21} D_{22} \dots D_{2m}) \dots (D_{m1} D_{m2} \dots D_{mm})}$$

13. It is the m^2 root of the product of m^2 distances within the conductor A.

14. Now eq. (4.15.8) can be written as,

$$L_A = 2 \times 10^{-7} \ln \frac{D_m}{D_{sA}} H/m \dots (4.15.10)$$

15. Similarly, the inductance of composite conductor B is

$$L_B = 2 \times 10^{-7} \ln \frac{D_m}{D_{sB}} H/m \dots (4.15.11)$$

16. Therefore, the total inductance of a single-phase system of composite conductor is

$$L = L_A + L_B \dots (4.15.12)$$

17. If conductors A and B are identical i.e., $D_{sA} = D_{sB} = D_s$, then the inductance is

$$L = 4 \times 10^{-7} \ln \frac{D_m}{D_s} H/m$$

or

$$L = 0.4 \ln \frac{D_m}{D_s} \text{ mH/km} \dots (4.15.13)$$

18. **Twin conductor bundle:** In this group, a two sub-conductor arrangement is shown in Fig. 4.15.1(a).

$$D_{sb} = \sqrt{(r'D)^2} = \sqrt{r'D} \dots (4.15.14)$$

19. **Triple bundle:** A three sub-conductor arrangement is shown in Fig. 4.15.1(b).

$$D_{sb} = \sqrt[3]{(r'D^2)^3} = \sqrt[3]{r'D^2} \dots (4.15.15)$$

20. **Quadruple bundle:** A four sub-conductor arrangement is shown in Fig. 4.15.1(c).

$$D_{sb} = \sqrt[4]{(\sqrt{2} r'D^3)^4} = 1.09 \sqrt[4]{r'D^3} \dots (4.15.16)$$

where,

D_{sb} = GMR of bundled conductor

D_s = GMR of each sub-conductor of bundle

D = Spacing between the sub-conductor of a bundle

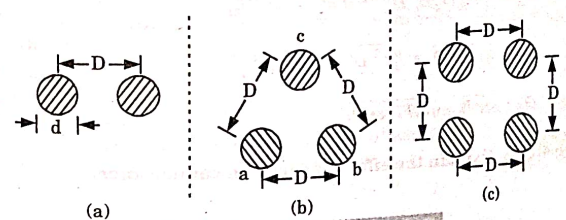


Fig. 4.15.1. Bundled conductors.

21. The GMD of a bundled conductor line can be found by taking the root of the product of distances from each conductor of a bundle to every other conductor of the other bundles.
22. It can be observed from eq. (4.15.14) to (4.15.16) that the GMR of a bundled conductor increases. For the calculation of inductances, the GMR is a denominating factor.
23. Therefore, the inductance of a bundled conductor line is less than the inductances of the line with one conductor per phase.

Que 4.16. What are bundled conductors ? How to calculate self GMR of bundled conductor ?

Answer

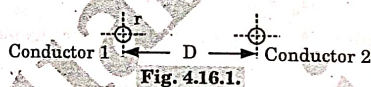
A. Bundle conductors : Refer Q. 2.10, Page 2-19B, Unit-2.

B. Calculation of GMR :

1. Let r be the radius of each subconductor in a bundle and r' is GMR, of any one of the subconductor.

$$r' = 0.7788 r$$

2. Consider the bundle of two subconductors.



3. Let D be the spacing between two conductors in a bundle.

D_S = Self GMR of bundled conductor

$$D_S = \sqrt[2x]{(D_{aa} D_{ab} \dots D_{ax})(D_{ba} D_{bb} \dots D_{bx}) \dots (D_{xa} D_{xb} \dots D_{xx})}$$

Here x is number of subconductors in each bundle.

4. In case of two conductor bundle $x = 2$

$$\therefore D_S = \sqrt[4]{D_{aa} D_{ab} D_{ba} D_{bb}} = \sqrt[4]{D_{11} D_{12} D_{22} D_{21}}$$

$$= \sqrt{r' d r' D} = \sqrt{r'^2 D} = [(r' D)^2]^{1/2}$$

$$\therefore D_S = \sqrt{r' D} = \sqrt{0.7788 r D}$$

Que 4.17. Explain the effect of earth on capacitance.

Answer

1. The earth significantly affects the capacitance of conductors, particularly in high-voltage transmission systems.
2. For overhead transmission lines, the earth acts as one plate of a capacitor, with conductors as the other. This increases capacitance, especially as the conductor is closer to the ground.
3. For underground cables, the earth's proximity and the insulation around conductors lead to much higher capacitance compared to overhead lines. The insulation acts as a dielectric between the conductor and ground.
4. In transmission systems, this earth-induced capacitance influences voltage distribution and can lead to the Ferranti effect in long, lightly loaded lines.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q.1. Explain the inductance of a single phase two wire line system. Derive the expression for single phase two wire line.

Ans. Refer Q. 4.3.

Q.2. Starting from first principles, derive the expression for inductance of a 3-phase unsymmetrical spaced transposed transmission line.

Ans. Refer Q. 4.6.

Q.3. Describe the inductance calculation procedure of three-phase double-circuit line with symmetrical spacing (hexagonal).

Ans. Refer Q. 4.9.

Q.4. Derive expressions for the line-to-neutral capacitance and line-to-line capacitance of a single phase line.

Ans. Refer Q. 4.11.

Q. 5. Derive an expression for the capacitance per unit length of a 3-phase line completely transposed.

Ans: Refer Q. 4.13.

Q. 6. Show that the inductance of a bundle conductor line is less than that of the line with one conductor per phase with mathematical expression.

Ans: Refer Q. 4.15.

Q. 7. Explain the effect of earth on capacitance.

Ans: Refer Q. 4.17.



Quantum Series



Insulated Cables

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PART-1

Insulated Cables : Introduction, Insulation, Insulating Materials.

Que 5.1. What are insulated cables ?

Answer

1. Insulated cables are electrical cables with a non-conductive protective layer, known as insulation, which surrounds the conductive wires.
2. This insulation helps prevent electrical current leakage, reduces the risk of short circuits, shocks, and fires, and ensures safe transmission of electricity. Common insulation materials include PVC, rubber, and XLPE.
3. Insulated cables are widely used in power distribution, telecommunications, and industrial wiring to provide safe and efficient electrical connections.

Que 5.2. What should be the desirable characteristics of insulating materials used in cables ? Also discuss general construction of cable.

Answer

A. Characteristics of insulating materials :

1. It should be flexible.
2. It should be non-inflammable.
3. It should be non-hygroscopic so that it will not absorb the moisture from the surrounding.
4. It should be unaffected by acid and alkalis.
5. It should be capable of withstanding high breakdown voltage.
6. It should have high temperature withstanding capability.

B. General construction of cable :

The Fig. 5.2.1 shows the general construction of a cable. Its various parts are :

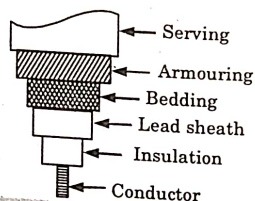


Fig. 5.2.1. General construction of a cable.

Conductor or core :

1. This section consists of single conductor or more than one conductor. The conductors are also called cores.
2. The conductors used are aluminium or annealed copper. The conductors are stranded in order to provide flexibility to the cable.
3. **Insulation :** Each conductor or core is covered by insulation of proper thickness. The commonly used insulating materials are varnished cambric, vulcanized bitumen and impregnated paper.
3. **Metallic sheath :** The insulated conductors are covered by lead sheath or aluminium sheath. This provides the mechanical protection but mainly restricts moisture and other gases to reach to the insulation.
4. **Bedding :**
 - i. The metallic sheath is covered by another layer called bedding. The bedding consists of paper tape compounded with a fibrous material like jute strands or hessian tape.
 - ii. The purpose of bedding is to protect the metallic sheath from corrosion and from mechanical injury resulting due to armouring.
5. **Armouring :** This layer consists of the layers of galvanized steel which provide protection to the cable from the mechanical injury.
6. **Serving :** The last layer above the armouring is serving. It is a layer of fibrous material like jute cloth which protects the armouring from the atmospheric conductions.

Que 5.3. Discuss different types of insulating materials used in power system.

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Answer

Following types of insulating materials are used in power systems :

1. **Polyvinyl Chloride (PVC) :** PVC is a widely used thermoplastic polymer known for its flexibility, chemical resistance, and low cost. It is commonly used as insulation for electrical cables in low-voltage applications.
2. **Cross-linked Polyethylene (XLPE) :** XLPE is a thermosetting polymer with excellent electrical and thermal properties. It is suitable for medium and high-voltage cable insulation in power distribution networks.
3. **Ethylene Propylene Rubber (EPR) :** EPR is a synthetic elastomer known for its flexibility, durability, and resistance to heat, ozone, and weathering. It is often used as insulation for medium-voltage cables.
4. **Mineral insulating oil :** Mineral oil is commonly used as an insulating fluid in power transformers and switchgear. It offers good electrical insulation properties and excellent cooling capabilities.

5. **Sulfur hexafluoride (SF₆)** : SF₆ is a gas known for its high dielectric strength and excellent insulating properties. It is used as an insulating and arc-quenching medium.
6. **Silicone rubber** : Silicone rubber is a synthetic elastomer known for its flexibility, high temperature resistance, and weathering resistance. It is used as insulation for high-temperature applications.
7. **Glass and ceramic insulators** : Glass and ceramic materials are used to manufacture insulators for overhead power transmission lines and substations.

PART-2*Extra High Voltage Cables.*

Que 5.4. Discuss about Extra high voltage (EHV) cables.

Answer

1. Extra high voltage (EHV) cables are used for transmitting electricity at voltages typically above 220 kV, often up to 765 kV or more.
2. They are essential for long-distance power transmission in large-scale electrical grids.
3. These cables are designed to handle extremely high voltages, offering low energy losses and higher transmission efficiency.
4. EHV cables are insulated with materials like cross-linked polyethylene (XLPE) or paper-oil for reliability and safety.
5. Their construction also includes multiple protective layers to prevent electrical breakdown, overheating, and environmental damage.
6. They are commonly used in power plants, substations, and major industrial projects.

PART-3*Grading of Cables.*

Que 5.5. What is grading of cable ? Why is it necessary ? Explain capacitance grading with suitable circuit diagram.

OR

Explain the grading method of underground cables with mathematical expressions.

AKTU 2022-23, Marks 10

Answer

A. Grading of cables : The process of obtaining uniform distribution of stress in insulation of cables is called grading of cables.

B. Necessity : Grading of cables is done because the unequal distribution has following two unwanted effects :

1. Greater insulation thickness is required, which increases the cost and size.
2. It may lead to the breakdown of insulation.

C. Capacitance grading or dielectric grading :

1. The grading done by using the layers of dielectric having different permittivities between core and sheath is called capacitive grading.

2. Let

r = Radius of conductor
 r_1, r_2, R = Radius of dielectrics
 $\epsilon_1, \epsilon_2, \epsilon_3$ = Permittivity of dielectrics

$$\epsilon_1 > \epsilon_2 > \epsilon_3$$

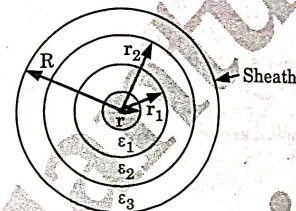


Fig. 5.5.1. Dielectric grading.

3. Dielectric stress is given by,

$$g_x = \frac{q}{2\pi \epsilon_0 \epsilon_1 x}$$

4. Potential difference across inner layer,

$$V_1 = \int_r^{r_1} g_x dx = \int_r^{r_1} \frac{q}{2\pi \epsilon_0 \epsilon_1 x} dx = \frac{q}{2\pi \epsilon_0 \epsilon_1} \ln \frac{r_1}{r}$$

$$= \frac{q}{2\pi \epsilon_0 \epsilon_1 r} \times r \ln \frac{r_1}{r} = g_{\max 1} r \ln \frac{r_1}{r}$$

5. Similarly, the potential difference between r_1 and r_2 , $V_2 = g_{\max 2} r_1 \ln \frac{r_2}{r_1}$

6. Potential difference between r_2 and R , $V_3 = g_{\max 3} r_2 \ln \frac{R}{r_2}$

7. Total potential difference between core and earthed sheath

$$V = V_1 + V_2 + V_3$$

$$= g_{\max 1} r \ln \frac{r_1}{r} + g_{\max 2} r_1 \ln \frac{r_2}{r_1} + g_{\max 3} r_2 \ln \frac{R}{r_2}$$

8. Capacitance of cable, $C = \frac{q}{V}$

$$= \frac{q}{\left[\frac{q}{2\pi\epsilon_0} \left(\frac{1}{\epsilon_1} \ln \frac{r_1}{r} + \frac{1}{\epsilon_2} \ln \frac{r_2}{r_1} + \frac{1}{\epsilon_3} \ln \frac{R}{r_2} \right) \right]}$$

$$= \frac{2\pi\epsilon_0}{\frac{1}{\epsilon_1} \ln \frac{r_1}{r} + \frac{1}{\epsilon_2} \ln \frac{r_2}{r_1} + \frac{1}{\epsilon_3} \ln \frac{R}{r_2}}$$

9. Maximum stresses,

$$g_{\max 1} = \frac{q}{2\pi\epsilon_0\epsilon_1 r}$$

$$g_{\max 2} = \frac{q}{2\pi\epsilon_0\epsilon_2 r_1}$$

$$g_{\max 3} = \frac{q}{2\pi\epsilon_0\epsilon_3 R}$$

10. If maximum stress is same in each layer,

$$g_{\max 1} = g_{\max 2} = g_{\max 3} = g_{\max} \text{ (say)}$$

$$\epsilon_1 r = \epsilon_2 r_1 = \epsilon_3 R$$

11. Total voltage applied across the cable,

$$V = g_{\max} \left(r \ln \frac{r_1}{r} + r_1 \ln \frac{r_2}{r_1} + r_2 \ln \frac{R}{r_2} \right)$$

Que 5.6. Discuss the inter-sheath grading of cables. What are practical difficulties in the grading of cable?

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Answer

A. Inter-sheath grading of cable :

1. In intersheath grading, a homogeneous dielectric is used, but it is divided into various layers by placing metallic intersheaths between the core and lead sheath. The intersheaths are held at suitable potentials, which are in between the core potential and earth potential.
2. Consider a cable of core radius r and outer lead sheath of radius R . Suppose that two intersheaths of radius r_1 and r_2 are inserted into the homogeneous dielectric and maintained at some fixed potentials. Let V_1 , V_2 and V_3 respectively be the voltage between core and intersheath 1, between intersheath 1 and 2 and between intersheath 2 and outer sheath.

3. Since there is a definite potential difference between the inner and outer layers of each intersheath, therefore, each sheath can be treated as a homogeneous single core cable.

4. Maximum stress between core and the intersheath 1 is,

$$g_{1\max} = \frac{V_1}{r \log_e \frac{r_1}{r}}$$

5. Similarly,

$$g_{2\max} = \frac{V_2}{r_2 \log_e \frac{r_2}{r_1}}$$

$$g_{3\max} = \frac{V_3}{R \log_e \frac{R}{r_2}}$$

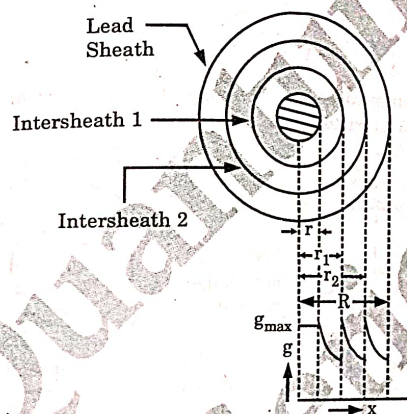


Fig. 5.6.1.

6. The dielectric is homogeneous, the maximum stress in each layer is the same i.e., $g_{1\max} = g_{2\max} = g_{3\max}$

$$\frac{V_1}{r \log_e \frac{r_1}{r}} = \frac{V_2}{r_2 \log_e \frac{r_2}{r_1}} = \frac{V_3}{R \log_e \frac{R}{r_2}}$$

7. As the cable behaves like three capacitors in series, therefore, all the potentials are in phase i.e., voltage between conductor and earthed lead sheath is

$$V = V_1 + V_2 + V_3$$

- B. Practical difficulties in the grading of cables :

1. **Complexity of cable design :** Modern high-voltage cables often have complex designs with multiple layers of insulation and shielding. Designing effective grading systems for such cables can be challenging.

- Material selection :** Finding materials that offer both adequate electrical properties and compatibility with the cable's construction materials is difficult.
- Cost and resource constraints :** Advanced materials and manufacturing techniques necessary for grading are costly. Budget limitations and resource availability can impede the adoption of inter-sheath grading.

PART-4*Insulation Resistance of a Cable.*

Que 5.7. Derive the expression for insulation resistance of a single core cable.

Answer

- The resistance offered by cable to path of the leakage current is called an insulation resistance.

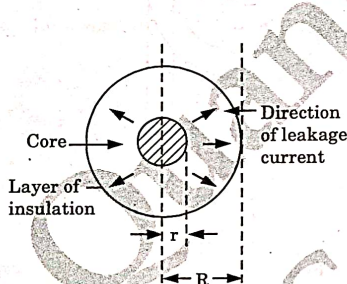


Fig. 5.7.1. Single cable.

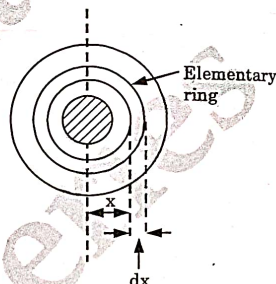


Fig. 5.7.2. Elementary Ring.

- Load current flows through the core of cable while some leakage current flows radially from the conductor to the sheath through the dielectric material.
- Resistance of any material is given by,

$$R = \rho \frac{l}{A}$$

where,

ρ = Specific resistance of material.

l = Length of material.

A = Area of cross-section of material.

- Resistance of elemental circular ring at distance x ,

$$dR = \rho \frac{dx}{2\pi x} \text{ (unit length of cable)}$$

dR = Differential leakage resistance,

$$R = \frac{\rho}{2\pi} \int_r^R \frac{dx}{x}$$

$$= \frac{\rho}{2\pi} \ln \frac{R}{r} \text{ ohms/metre}$$

If length of cable is l units.

$$\text{Leakage resistance, } R = \frac{\rho}{2\pi l} \ln \frac{R}{r} \text{ ohms}$$

PART-5*Capacitance of a Single Core and Three Core Cables.*

Que 5.8. Derive the expression for capacitance of single core cable.

Answer

- Let,

d = Conductor diameter

D = Total diameter with sheath

Q = Charge per meter length of conductor in coulombs

ϵ = Permittivity of a material between core and sheath

ϵ_0 = Permittivity of free space = 8.854×10^{-12} F/m

ϵ_r = Relative permittivity of the medium

- Consider an elementary cylinder with radius x and axial length of 1 m. The thickness of the cylinder is dx .

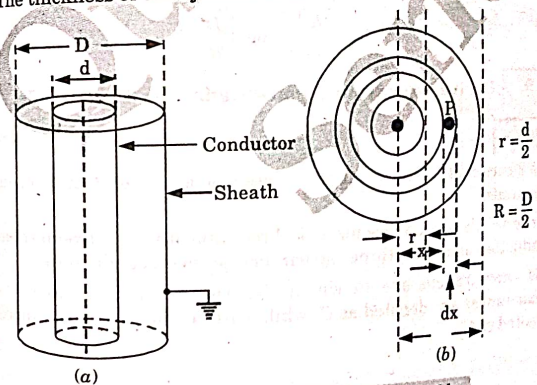


Fig. 5.8.1. Capacitance of a single-core-cable.

- Flux density $D_x = \frac{Q}{\text{Surface area}} = \frac{Q}{2\pi x}$

The electric field intensity at any point P on the elementary cylinder is

$$g_x = \frac{D_x}{\epsilon} = \frac{Q}{2\pi x \epsilon} = \frac{Q}{2\pi x \epsilon_0 \epsilon_r} \text{ V/m}$$

4. Hence the work done in moving a unit charge a distance dx in the direction of an electric field is $g_x dx$.
5. The work done in moving a unit charge from the conductor to sheath is the potential difference between the conductor and the sheath given by,

$$\begin{aligned} V &= \int_{d/2}^{D/2} g_x dx = \int_{d/2}^{D/2} \frac{Q}{2\pi x \epsilon_0 \epsilon_r} dx \\ &= \frac{Q}{2\pi \epsilon_0 \epsilon_r} \int_{d/2}^{D/2} \frac{dx}{x} = \frac{Q}{2\pi \epsilon_0 \epsilon_r} [\log x]_{d/2}^{D/2} \\ &= \frac{Q}{2\pi \epsilon_0 \epsilon_r} \left[\log \frac{D}{2} - \log \frac{d}{2} \right] \\ \therefore V &= \frac{Q}{2\pi \epsilon_0 \epsilon_r} \log \left[\frac{D}{d} \right] = \frac{Q}{2\pi \epsilon_0 \epsilon_r} \log \left[\frac{R}{r} \right] \end{aligned}$$

6. The capacitance of a cable is given by,

$$\begin{aligned} C &= \frac{Q}{V} = \frac{Q}{\frac{Q}{2\pi \epsilon_0 \epsilon_r} \log \left(\frac{R}{r} \right)} \\ C &= \frac{2\pi \epsilon_0 \epsilon_r}{\log_e \left(\frac{R}{r} \right)} = \frac{2\pi \epsilon_0 \epsilon_r}{\log_e \left(\frac{D}{d} \right)} \text{ F/m} \end{aligned}$$

Que 5.9. Derive expression of capacitance for 3-core cable.

Answer

1. In a 3-core cable, sheath is at earth potential and 3 conductors at supply potentials.
2. There are six capacitance formed, three capacitance between sheathed conductors and other three capacitance between conductors.
3. The capacitances are shown in the Fig. 5.9.1. The core to core capacitances are denoted as C_c while core to sheath capacitances are denoted as C_s .

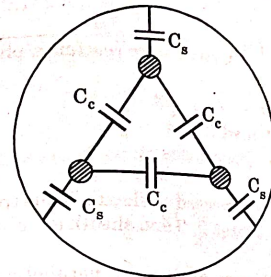


Fig. 5.9.1.

4. The core to core capacitances C_c are in delta and can be presented in the equivalent star as shown in the Fig. 5.9.2.

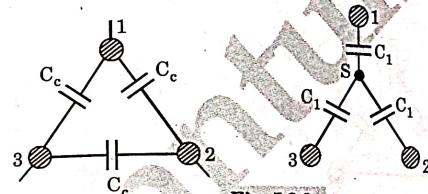


Fig. 5.9.2.

5. The impedance between core 1 and the star point Z_1 can be obtained as,

$$Z_1 = \frac{Z_{12} Z_{13}}{Z_{12} + Z_{13} + Z_{23}} \quad [\text{from delta-star conversion}]$$

Now

$$Z_{12} = Z_{13} = Z_{23} = \frac{1}{\omega C_c}$$

$\therefore$

$$Z_1 = \frac{\frac{1}{\omega C_c} \times \frac{1}{\omega C_c}}{\frac{3}{\omega C_c}} = \frac{1}{3 \omega C_c}$$

And

$$Z_1 = \frac{1}{\omega C_1}$$

$$\frac{1}{\omega C_1} = \frac{1}{3 \omega C_c}$$

$\therefore$

$$C_1 = 3C_c$$

6. If star point is assumed to be at earth potential and if sheath is also earthed then the capacitance of each conductor to neutral is,

$$C_N = C_s + C_1 = C_s + 3C_c$$

7. If V_{ph} is phase voltage then charging current per phase is,

$$I = \frac{V_{ph}}{\text{Capacitance reactance/phase}} = \frac{V_{ph}}{X_{CN}} = \frac{V_{ph}}{\frac{1}{\omega C_N}}$$

$$I = \omega C_N V_{ph} \text{ A}$$

Measurement of C_s and C_c :

1. Measurement involves two cases.

Case I:

- The core 2 and core 3 connected to sheath. Thus the C_c between cores 2 and 3 and C_s between cores 2, 3 and sheath get eliminated as shown in the Fig. 5.9.3.
- All the three capacitances are now in parallel across core 1 and the sheath.
- The capacitance of core 1 with sheath is measured practically and denoted by C_a .

$$C_a = C_s + 2C_c \quad \dots(5.9.1)$$

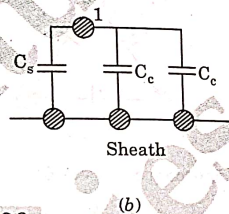
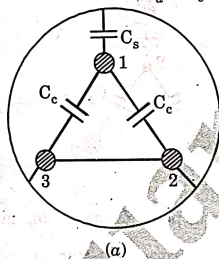


Fig. 5.9.3.

Case II:

- All the three cores are bundled together. This eliminates all the core-core capacitances. This is shown in the Fig. 5.9.4.
- The capacitances C_s are in parallel between the common core and sheath. This capacitance is practically measured and denoted by C_b .

$$C_b = 3C_s \quad \dots(5.9.2)$$

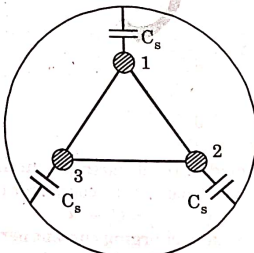


Fig. 5.9.4.

2. Solving eq. (5.9.1) and (5.9.2),

$$C_a = \frac{C_b}{3} + 2C_c$$

$$C_c = \frac{C_a}{2} - \frac{C_b}{6} \text{ and } C_s = \frac{C_b}{3}$$

3. Thus both the capacitances can be determined

$$C_N = C_s + 3C_c$$

$$= \frac{C_b}{3} + 3 \left[\frac{C_a}{2} - \frac{C_b}{6} \right]$$

$$C_N = \frac{3C_a}{2} - \frac{C_b}{6} \quad \dots(5.9.3)$$

4. Capacitance can also be calculated by empirical formula given by Simon. The formula is given as

$$C_N = \frac{0.0299 \epsilon_r}{\log \left[1 + \frac{T+t}{d} \left\{ 3.84 - 1.7 \frac{T}{T} + 0.52 \frac{t^2}{T^2} \right\} \right]} \mu\text{F/km}$$

where,

ϵ_r = Relative permittivity of the dielectric
 d = Conductor diameter
 t = Belt insulation thickness
 T = Conductor insulation thickness.

Que 5.10. Show that the most economical size of conductor in a single core cable is obtained when radius of cable sheath (R) equals e.r. where e is the base of radius of conductor. Explain dielectric loss.

AKTU 2021-22, Marks 10

Answer**A. Most economical size of conductor:**

- Let
 - r = Radius of conductor or inner radius of insulation.
 - R = Internal radius of sheath or outer radius of insulation.
 - ϵ_0 = Permittivity of free space.
 - ϵ_r = Relative permittivity of the dielectric.
 - q = Charge on the conductor per unit length
 - V = Operating phase-to-neutral voltage
- The electric flux density at a distance x from the center is,

$$D_x = \frac{q}{2\pi x}$$

and the electric stress is given by,

$$E_x = \frac{D_x}{\epsilon_r \epsilon_0} = \frac{q}{(2\pi \epsilon_r \epsilon_0) x}$$

...(5.10.1)

- The potential difference between the conductor and the sheath is equal to the work done to move a unit charge from the conductor to sheath.

Thus,
$$V = \int_r^R g_x dx = \int_r^R \frac{q}{(2\pi \epsilon_0 \epsilon_r)x} dx$$

$$= \frac{q}{2\pi \epsilon_0 \epsilon_r} \ln \frac{R}{r} \quad \dots(5.10.2)$$

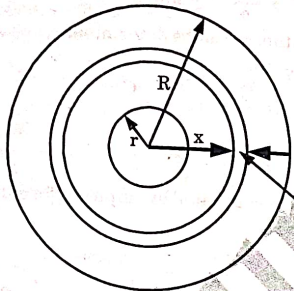


Fig. 5.10.1. Single-core cable.

4. Combining eq. (5.10.1) and (5.10.2), we get

$$g_x = \frac{V}{x \ln \left(\frac{R}{r} \right)}$$

5. The maximum stress will occur at $x = r$, $g_{\max} = \frac{V}{r \ln \left(\frac{R}{r} \right)} \quad \dots(5.10.3)$

6. The minimum stress occurs at $x = R$, $g_{\min} = \frac{V}{R \ln \left(\frac{R}{r} \right)}$

7. Ratio of maximum and minimum stress is,

$$\frac{g_{\max}}{g_{\min}} = \frac{V/r \ln(R/r)}{V/R \ln(R/r)} = \frac{R}{r} = \frac{D}{d} = \frac{\text{Outer diameter}}{\text{Inner diameter}}$$

8. The value of $g_{\max}$ will be minimum when $\frac{\partial g_{\max}}{\partial d} = 0$

9. Putting $r = \frac{d}{2}$ and $R = \frac{D}{2}$ in eq. (5.10.3), we get

$$g_{\max} = \frac{2V}{d \ln \left[\frac{D}{d} \right]}$$

$$\begin{aligned} \frac{\partial g_{\max}}{\partial d} &= \frac{d \ln \left[\frac{D}{d} \right] \frac{\partial}{\partial d} (2V) - 2V \frac{\partial}{\partial d} \left[d \ln \left(\frac{D}{d} \right) \right]}{\left[d \ln \left(\frac{D}{d} \right) \right]^2} \\ &= \frac{0 - 2V \frac{\partial}{\partial d} \left[d \ln \left(\frac{D}{d} \right) \right]}{\left[d \ln \left(\frac{D}{d} \right) \right]^2} \\ &= \frac{-2V}{\left[d \ln \left(\frac{D}{d} \right) \right]^2} \left\{ \ln \left(\frac{D}{d} \right) + d \frac{1}{\left(\frac{D}{d} \right)} \left(\frac{-D}{d^2} \right) \right\} \\ \therefore \frac{\partial g_{\max}}{\partial d} &= \frac{-2V}{\left[d \ln \left(\frac{D}{d} \right) \right]^2} \left\{ \ln \left(\frac{D}{d} \right) - 1 \right\} \quad \dots(5.10.4) \end{aligned}$$

10. Now the value of $\frac{\partial g_{\max}}{\partial d}$ must be zero to get minimum $g_{\max}$

$$\ln \left(\frac{D}{d} \right) - 1 = 0$$

$$\ln \left(\frac{D}{d} \right) = 1$$

$$\frac{D}{d} = e = 2.718$$

$$\frac{R}{r} = e$$

$$R = er$$

$$d = \frac{D}{2.718}$$

11. Hence, the core diameter must be $1/2.718$ times the sheath diameter D so as to give the minimum value of $g_{\max}$.

12. The value of minimum $g_{\max}$ is,

$$\text{Minimum } g_{\max} = \frac{2V}{d}$$

$$\therefore \text{Minimum } g_{\max} = \frac{V}{r}$$

B. Dielectric loss :

1. Dielectric loss is the energy loss that occurs when an alternating current (AC) flows through a dielectric material.
2. This loss is caused by the friction of the electrons as they move through the material.

5-16 B (EN-Sem-5)

Insulated Cables

- The amount of dielectric loss is proportional to the frequency of the AC current and the dielectric constant of the material.
- When dielectric loss occurs, it generates heat. This heat can cause the cable to overheat, which can damage the cable and shorten its lifespan.

Que 5.11. Find the most economical diameter of a single core cable to be used on 66 kV, 3 phase system. If the peak permissible stress is not to exceed 50 kV/m. Also find overall diameter.

AKTU 2021-22, Marks 10

AKTU 2023-24, Marks 10

Answer

- RMS value of phase voltage = $\frac{66}{\sqrt{3}} = 38.15 \text{ kV}$
- Peak value = $38.15 \times \sqrt{2} = 53.94 \text{ kV}$
- For economical size of cable, $\frac{R}{r} = e = \frac{D}{d}$

$$g_{\max} = \frac{V}{r \ln(R/r)} = \frac{V}{r}$$

$$50 = \frac{53.94}{r}$$

$$r = 1.078 \text{ mm}$$
- Economical diameter, $d = 2 \times r$
 $2 \times 1.078 = 2.157 \text{ mm}$
- Overall diameter, $D = e \times d$ $[\because e = 2.71]$
 $= 2.71 \times 2.157$
 $= 5.845 \text{ mm}$

PART-6

Overhead Lines Versus Underground Cables, Types of Cables.

Que 5.12. Compare the overhead lines and the underground cables.

AKTU 2020-21, Marks 10

OR

Explain the comparisons between overhead lines versus underground cables.

AKTU 2022-23, Marks 10

5-17 B (EN-Sem-5)

Power System - I

Answer

S.No.	Aspect	Overhead line	Underground cable
1.	Installation	Above ground on towers/poles.	Buried underground.
2.	Maintenance	Easier to access and repair.	More challenging to access and repair.
3.	Capital cost	Lower initial cost.	Higher initial cost.
4.	Efficiency	Slightly lower efficiency	Higher efficiency.
5.	Voltage capacity	Suitable for high voltage transmission	Suitable for medium to low voltage transmission.
6.	Visual impact	Can be visually intrusive	Less visually intrusive.

Que 5.13. Describe the selection of the cables and the capacitance grading.

AKTU 2020-21, Marks 10

Answer

- A. Selection of cable :** The factors considered for selecting the cable:
- Rated voltage :** It is necessary to select a power cable capable of supporting a particular system voltage.
 - Current carrying capacity :** Each power cable is designed to operate under certain temperature conditions. Current carrying capacity of power cable is dependent on conductor material (Copper / Aluminium) and insulation type.
 - Voltage drop :** The voltage drop per unit length of cable should be minimum.
 - Short circuit withstand :** A power cable in case of short circuit event should be able to withstand the high current values without any damage to the cable and insulation.
- B. Capacitance grading :** Refer Q. 5.5, Page 5-4B, Unit-5.

Que 5.14. Discuss in brief about the different types of cables.

OR

Explain with a neat sketch, the construction of a 3-core belted type cable.

AKTU 2022-23, Marks 10

Answer

The type of a cable basically decided based on the voltage level for which it is manufactured and the material used for the insulation such as paper cotton, rubber etc.

Types of cable :**A. Low tension cable (L. T. cable) :**

1. These are used for the voltage levels upto 6.6 kV.
2. The paper is used as insulation in these cables. Some time resin is also used which increases the viscosity and helps to prevent drainage.
3. The Fig. 5.14.1 shows the cross-section of a single core L.T. cable. It consists of a circular core of stranded copper or aluminium.

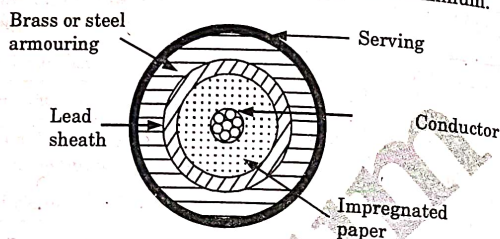


Fig. 5.14.1. Single core L.T. cable.

4. The conductor is insulated by impregnated paper over the paper insulation, the lead sheath is provided then a layer of compounded fibrous material is provided. Then armouring is provided and finally covered again with a layer of fibrous compounded material.

B. Medium and high tension cables :

1. The three phase medium and H.T. cables are three core cable. For voltage upto 66 kV the three core cable i.e., multicore cable are used.
2. These cables are classified as :

a. Belted cables :

1. These are used for the voltage level upto 11 kV. The construction of belted cable is shown in Fig. 5.14.2.

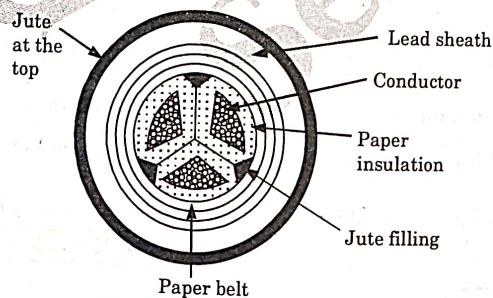


Fig. 5.14.2. Belted 3-core cable.

2. The cores are not circular in shape. The cores are insulated from each other by use of impregnated paper.

3. The three cores are grouped together and belted with the help of a paper belt.
4. The gaps are filled with fibrous material like jute. This gives circular cross-sectional shape to the cable.
5. The belt is covered with lead sheath which protects cable from moisture and also gives mechanical strength.
6. The lead sheath is finally covered by jute like fibrous compounded material.

- Screened type cables :** These cables are used for the voltage levels of 22 kV and 33 kV. The two types of screened cables are :

i. H-type cable :

1. There is no paper belt in this type of cable. Each conductor in this cable is insulated with a paper, covered with a metallic screen which is generally an aluminium foil. The construction is shown in Fig. 5.14.3.

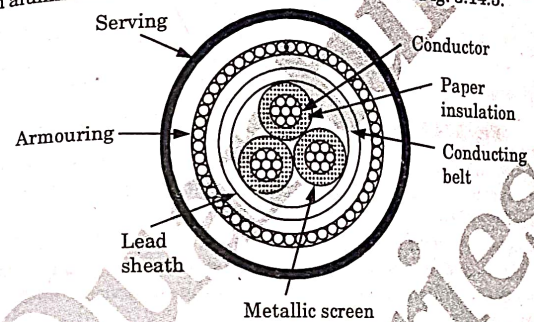


Fig. 5.14.3. H-type cable.

ii. S.L type cable (Separate lead screened cable) :

1. In this cable each core is insulated with an impregnated paper and each one is then covered by separate lead sheath.

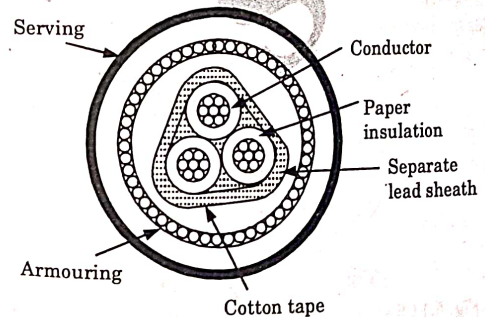


Fig. 5.14.4. S.L. type cable.

2. Then there is a cotton tape covering the three cores together using a proper filter material.
- C. Super tension (S.T.) cables :**
1. The S.T. cables are used for 132 kV to 275 kV voltage level.
 2. Such cables using oil or gas under pressure are called pressure cables and are of two types :
- a. Oil filled cables :**
1. In case of oil filled cables, the channels or ducts are provided within or adjacent to the cores, through which oil under pressure is circulated.

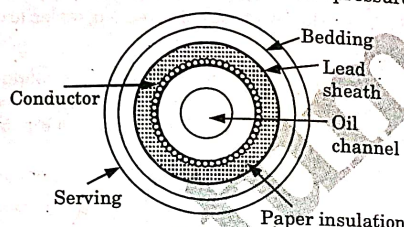


Fig. 5.14.5. Conductor channel single core oil filled cable.

2. Fig. 5.14.5 shows the construction of single core oil filled cable. It consists of concentric stranded conductor but built around a hollow cylindrical steel spiral core.
 3. This hollow core acts as a channel for the oil. The oil channel is filled in a factory and the pressure is maintained in the oil by connecting the oil channel to the tanks which are placed at the suitable distances along the path of the cable.
- b. Gas pressure cables :**
1. In case of gas pressure cables an inert gas like nitrogen at high pressure is introduced. The pressure is about 12 to 15 atmospheres.
 2. Due to such a high pressure there is a radial compression due to which the ionization is totally eliminated. The working power factor of such cables is also high.

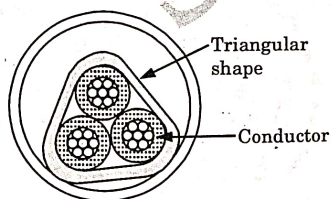


Fig. 5.14.6. Gas pressure cable.

3. The Fig. 5.14.6 shows the section of a gas pressure cable. The cable is triangular in shape and installed in the steel pipe.

4. The pipe is filled with the nitrogen at 12 to 15 atmospheric pressure. There is no bedding and serving.

Que 5.15. Explain the cables for high voltage DC transmission and the operating problems with cables.

AKTU 2020-21, Marks 10

Answer

A. High Voltage Direct Current (HVDC) transmission cables :

1. High Voltage Direct Current (HVDC) transmission cables are designed to transmit electricity over long distances with minimal power losses.
 2. These cables typically consist of a conductor (usually aluminum or copper), an insulation layer (such as cross-linked polyethylene), and protective layers to shield the conductor from environmental damage and electrical faults.
- B. Operating problems with HVDC cables :** The main operating problems with HVDC cables include :
1. **Thermal stress :** Due to high currents, heat can accumulate, leading to insulation breakdown and reduced lifespan.
 2. **Electrical stress :** Prolonged high voltage causes dielectric stress on the insulation, leading to partial discharge and failure.
 3. **Cable joints and terminations :** These are weak points in the cable system and prone to faults.
 4. **Electromagnetic interference :** The strong DC fields can induce interference in nearby systems.
 5. **Environmental factors :** Water ingress, chemical corrosion, and mechanical damage can compromise cable integrity, especially in submarine applications.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

- Q. 1.** What should be the desirable characteristics of insulating materials used in cables? Also discuss general construction of cable.

Ans. Refer Q. 5.2.

Q. 2. Discuss different types of insulating materials used in power system.

Ans. Refer Q. 5.3.

Q. 3. What is grading of cable ? Why is it necessary ? Explain capacitance grading with suitable circuit diagram.

Ans. Refer Q. 5.5.

Q. 4. Discuss the inter-sheath grading of cables. What are practical difficulties in the grading of cable ?

Ans. Refer Q. 5.6.

Q. 5. Show that the most economical size of conductor in a single core cable is obtained when radius of cable sheath (R) equals $e.r$ where e is the base of radius of conductor. Explain dielectric loss.

Ans. Refer Q. 5.10.

Q. 6. Compare the overhead lines and the underground cables.

Ans. Refer Q. 5.12.

Q. 7. Discuss in brief about the different types of cables.

Ans. Refer Q. 5.14.



1

UNIT

Power Generation (2 Marks Questions)

1.1. Write the conventional and non-conventional source of energy.

AKTU 2020-21, Marks 02

Ans.

A. Conventional source of energy : Fossil fuels (coal, oil, natural gas) and biomass.

B. Non-conventional source of energy : Solar energy and wind energy.

1.2. Differentiate between renewable and non-renewable energy.

AKTU 2023-24, Marks 02

Ans.

S.No.	Aspect	Renewable energy	Non-renewable energy
1.	Sources	Solar and wind.	Coal and petroleum.
2.	Availability	Inexhaustible.	Finite.

1.3. List the key features of primary and secondary distribution systems in the power system.

AKTU 2022-23, Marks 02

Ans.

A. Features of primary distribution system :

1. It is carried out by 3-phase, 3-wire system.
2. Primary distribution handles large consumers such as factories and industries.

B. Features of secondary distribution system :

1. It is carried out by 3-phase, 4-wire system.
2. This system directly supplies to the residential end consumers.

1.4. What are the problems associated in development of hydropower ?

Ans:

1. Huge financial requirements.
2. Land acquisition.
3. Technical problems.
4. Skilled manpower and labour problems.

1.5. Write the advantages of hydro electric power plant.

Ans:

1. No fuel charges.
2. Highly reliable.
3. Low maintenance and operation charges.
4. Low running cost.
5. No standby losses.

1.6. Define load duration curve.

AKTU 2020-21, Marks 02

Ans: A load duration curve (LDC) is a graphical representation of the variation of load demand over a period of time. The LDC is plotted with the load demand on the y-axis and the time on the x-axis. The LDC is used to illustrate the relationship between generating capacity requirements and capacity utilization.

1.7. What is demand factor? Why is it important?

AKTU 2021-22, Marks 02

Ans:

A. **Demand factor**: The demand factor is the ratio of the actual maximum demand of the system to the total connected load of the system.

$$DF = \frac{\text{Maximum demand}}{\text{Total connected load}}$$

B. **Reason**: It is important in determining the capacity of the plant equipment.

1.8. For the same maximum demand, if load factor is decreased, then what will be the cost of energy?

AKTU 2021-22, Marks 02

Ans: If the load factor is decreased for the same maximum demand, the cost of energy will increase.

1.9. Explain diversity factor in power systems.

AKTU 2022-23, Marks 02

OR

What is a diversity factor?

AKTU 2023-24, Marks 02

Ans: Diversity factor is the ratio of the sum of the individual maximum demands of the various subdivisions of a system to the maximum demand of the whole system.

1.10. What is load diversity?

Ans: Load diversity in a power system refers to the variation in electricity demand across different consumers and sectors over time. It plays a crucial role in optimizing the economic efficiency of power systems.

1.11. What are the roles of load diversity in power system economy?

Ans: Following are the roles of load diversity:

1. Reduces the need for expensive peak power plants
2. Improves overall system efficiency
3. Lowers operational and infrastructure costs

1.12. Define base load and peak load.

Ans: **Base load**: Base load refers to the continuous, stable demand met by base-load plants (e.g., coal, nuclear) that operate efficiently at a steady output.

Peak load: Peak load denotes temporary, high demand during specific periods, addressed by peaking plants (e.g., gas turbines) that can quickly adjust output.

☺☺☺

2

UNIT

Transmission and Distribution of Electric Power-I (2 Marks Questions)

2.1. What do you mean by single line diagram of power system ?

AKTU 2020-21, Marks 02

Ans: The single line diagram is the simplified representation of power system components where each component is represented by its symbol.

2.2. Draw and explain 3-wire DC system.

Ans: In a 3-wire DC system, there are two outers and a middle or neutral wire which is earthed at the generator end as shown in Fig. 2.2.1. If the load is balanced, the current in the neutral wire is zero.

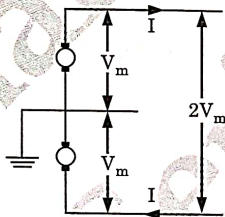


Fig. 2.2.1.

2.3. What is skin effect ?

AKTU 2023-24, Marks 02

Ans: The tendency of alternating current to concentrate near the surface of a conductor is known as skin effect.

2.4. What is proximity effect ?

Ans: The distribution of current in a conductor is affected by the presence of other conductor in its vicinity due to inductance is known as proximity effect.

2.5. Write Kelvin's law of power system.

AKTU 2020-21, Marks 02

Ans: Kelvin's law of power system states that the most economical area of cross-section of a conductor is that for which the variable part of annual charges is equal to the cost of energy wasted per year.

2.6. What are the limitations of Kelvin law ?

AKTU 2021-22, Marks 02

Ans:

1. It is difficult to estimate the energy loss in the line without actual load curves.
2. The conductor size determined by Kelvin's law may not always be practicable one since it may be too small for the safe carrying of necessary current.

2.7. Define term corona.

Ans: The phenomenon of violet glow, hissing noise and production of ozone gas in an overhead transmission line is known as corona.

2.8. Define critical disruptive voltage and visual critical voltage.

Ans:

- A. **Critical disruptive voltage :** It is defined as the minimum phase to neutral voltage at which corona occurs. It is denoted by V_c or V_{dc} .
- B. **Visual critical voltage :** It is the minimum phase to neutral voltage at which corona glow appears all along the line. It is denoted by V_{vo} .

2.9. Which factors affect corona ?

Ans:

1. Conductor surface gradient.
2. Condition of conductor surface.
3. Atmospheric conditions.

2.10. What is a Ferranti effect ?

AKTU 2020-21, Marks 02

OR

What is Ferranti effect ?

AKTU 2021-22, Marks 02

Ans: The phenomenon of rise in voltage at the receiving end of the open-circuited or lightly loaded line is called the Ferranti effect.

2.11. Is corona more in AC or DC ?

AKTU 2023-24, Marks 02

Ans: Corona effect is more prominent in AC systems compared to DC systems.

2.12. What will be the effect of line capacitance for lagging load in the medium transmission line ?

AKTU 2022-23, Marks 02

Ans: On lagging load, the effect of line capacitance is to reduce voltage drop along the line and also to reduce the copper losses of the line.

2.13. Why the line capacitance is neglected in short transmission lines ?

AKTU 2022-23, Marks 02

Ans: 1. In the analysis of short transmission lines the capacitive reactance is given by :

$$X_c = \frac{1}{2\pi fCl}$$

2. Since the value of length (l) is small in the short transmission lines, therefore the reactance becomes very high. High reactance means an open circuit; hence effect of capacitance is neglected in the short transmission lines.



Transmission and Distribution of Electric Power-II

(2 Marks Questions)

3.1. Define the term 'Sag'.

AKTU 2020-21, Marks 02

Ans: The difference in levels between point of support and lowest point on the conductor is called sag.

AKTU 2023-24, Marks 02

3.2. What is the importance of sag in transmission line ?

AKTU 2021-22, Marks 02

Ans: It protects the conductor from excessive tension. In order to permit a safe level of tension in the conductor, conductors are not fully stretched, rather they are allowed to have sagged.

3.3. Explain the factors affecting sag of an overhead transmission line.

AKTU 2022-23, Marks 02

Ans:

1. Weight of conductor
2. Span length (distance between the poles)
3. Working tensile strength
4. Ice coating
5. Wind pressure and temperature.

3.4. Explain the effect on sag of transmission line if the height of tower is increased.

AKTU 2022-23, Marks 02

Ans: The formula for sag is,

$$S = \frac{WL^2}{8T}$$

where,

W = Weight of the conductor

L = Span length of the conductor

T = Working tension on the conductor

Now, according to the given formula sag is independent of height of tower, i.e., there is no effect on sag due increase or decrease of height of tower. Hence these will be no change in sag.

3.5. How are voltage distribution and the string efficiency affected by rain ?

AKTU 2021-22, Marks 02

Ans: In the rainy season, insulators are wet and the mutual capacitance value increases. Thus the ratio of shunt to mutual capacitance i.e., k decreases. This increases the uniformity of the voltage distribution. Hence in rainy season, string efficiency is higher.

3.6. Define string efficiency.

AKTU 2020-21, Marks 02

Ans: String efficiency is the ratio of voltage across the whole string and the product of the number of units and voltage across the unit nearest to the line conductor.

$$\text{String efficiency} = \frac{\text{Voltage across string}}{n \times \text{Voltage across the lowermost unit}}$$

where, n = Number of units.

3.7. What do you mean by sag template ?

AKTU 2023-24, Marks 02

Ans:

1. Sag template is a convenient device used in the design of a transmission line to determine the location and height of tower.
2. For locating the tower positions, for normal spans and for standard towers, the sag and the nature of conductor curve are calculated under expected load condition and plotted on a thin stiff plastic sheet such a graph is called sag template.

3.8. What are the types of insulators used in transmission and distribution ?

Ans:

1. Pin type
2. Suspension type
3. Strain insulator
4. Shackle insulator
5. Stay insulator.

3.9. How are the causes of failure of insulators ?

Ans:

1. Cracking of porcelain
2. Porosity
3. Puncture
4. Mechanical stresses
5. Flash-over.

3.10. What are the methods used for equalizing the potential across the insulator string in transmission lines ?

Ans:

1. Use of long cross arms.
2. Capacitance grading or grading of units.
3. Use of guard rings.

3.11. What are uses of sag template ?

Ans:

- Following are the uses of sag template :
1. For correct design and economy.
 2. It is used to allocate the position and height of the support correctly on the profile.

3.12. What are the different types of dampers used ?

Ans:

- Following are the types of dampers used :
1. Stockbridge damper
 2. Spacer damper
 3. Anti-galloping damper
 4. Twisted spacer damper
 5. Tuned mass damper.

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Quantum Series

4

UNIT

Transmission Line Parameters (2 Marks Questions)

4.1. Define transposition.

AKTU 2020-21, Marks 02

Ans: Transposition refers to periodically switching the positions of conductors to balance inductance and capacitance, reducing interference, and minimizing unbalanced voltages in long-distance power lines.

4.2. Explain symmetrical and unsymmetrical spacing of conductors.

AKTU 2020-21, Marks 02

- Ans:**
- A. **Symmetrical spacing:** If the three conductors A, B, C are placed symmetrically at the corners of an equilateral triangle of side d , then the spacing is said to be symmetrical.
- B. **Asymmetrical spacing:** When 3-phase line conductors are not equidistant from each other, the conductor spacing is said to be unsymmetrical.

4.3. Differentiate between GMD and GMR.

AKTU 2021-22, Marks 02

Ans:

S.No.	Aspect	GMD	GMR
1.	Definition	Average distance between conductors in a system.	Equivalent radius of a conductor.
2.	Uses	Transmission line calculations.	Self-inductance and capacitance calculations.

4.4. Why the effect of ground on the line capacitance can be neglected?

AKTU 2021-22, Marks 02

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

4.5. Classify various type of supports used in power transmission lines.

AKTU 2022-23, Marks 02

- Ans:**
1. Wooden poles.
 2. Steel poles.
 3. RCC poles.
 4. Lattice steel towers.

4.6. Describe the uses and advantages of bundled conductors.

AKTU 2022-23, Marks 02

Ans:

A. **Uses of bundled conductors:**

1. Overhead power transmission lines.
2. Underground cables.

B. **Advantages of bundled conductors:**

1. Reduced corona loss due to larger cross-sectional area.
2. Improved voltage regulation.

4.7. What do you mean by self GMD and mutual GMD?

AKTU 2023-24, Marks 02

Ans:

A. **Self GMD:**

1. Self Geometrical Mean Distance (GMD) typically refers to the distance between conductors in a transmission line configuration, specifically in overhead transmission lines.
2. The self-GMD is calculated by considering the geometric arrangement of the conductors in relation to each other. It takes into account the spacing between conductors and their positions relative to each other within the same phase or bundle.

B. **Mutual GMD:** The mutual-GMD is the geometrical mean of the distance from one conductor to the other. It simply represents the equivalent geometrical spacing.

4.8. What is the need of transposition of transmission lines?

Ans: Transposition of transmission lines is needed because:

1. It reduces the electrostatic unbalance among the three phases.
2. It is also used to stabilize voltage unbalance.
3. It helps to reduce the system power loss.

4.9. Why is leakage conductance negligible in overhead lines?

Ans: The leakage conductance is due to leakage currents flowing across insulators and air. As leakage current is considerably small compared to nominal current, it is usually neglected, and therefore, leakage conductance is negligible in overhead lines.

4.10. What are the factors which govern the performance of a transmission line ?

Ans: Series resistance R , inductance L , shunt capacitance C and conductance G .



Insulated Cables (2 Marks Questions)

5.1. What is general construction of cable ?

Ans:

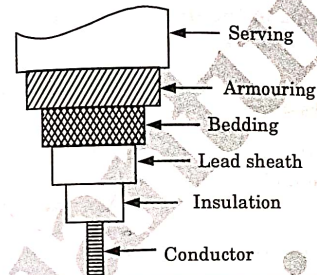


Fig. 5.1.1. General construction of a cable.

5.2. Summarize why metallic sheath is provided in underground cables.

AKTU 2022-23, Marks 02

Ans: The metallic sheath is provided in underground cables for mechanical protection, electromagnetic shielding, and grounding.

5.3. List the different types of insulating materials used in underground cables.

AKTU 2022-23, Marks 02

Ans:

1. Paper insulation.
2. Polyethylene (PE).
3. Cross-Linked Polyethylene (XLPE).
4. Polyvinyl Chloride (PVC).

5.4. Write the main causes of insulation failure.

AKTU 2023-24, Marks 02

Ans. Main causes of insulation failure include :

1. **Electrical stress** : Overvoltage or voltage surges can exceed the insulation's breakdown strength, leading to dielectric breakdown and insulation failure.
2. **Thermal stress** : Excessive heat can degrade insulation materials, reducing their dielectric properties and causing insulation breakdown.

5.5. Why single core cables are usually not provided with armouring ?

AKTU 2021-22, Marks 02

Ans. Single-core cables are not usually armoured in order to avoid excessive sheath losses.

5.6. How do voids in the insulation cause breakdown of the cable ?

AKTU 2021-22, Marks 02

Ans. The breakdown strength of the void is lower than the insulation because of the lower permittivity of the void so the presence of void leads to insulation breakdown.

5.7. Discuss the underground cable losses.

AKTU 2023-24, Marks 02

Ans. Underground cable losses primarily stem from resistive losses due to the conductor material and length, as well as dielectric losses from the insulating materials. These losses are influenced by factors such as conductor size, cable length, operating voltage, ambient temperature, and frequency.

5.8. Differentiate between overhead lines and underground cables.

AKTU 2023-24, Marks 02

Ans.

S.No.	Criteria	Overhead lines	Underground cables
1.	Maintenance	Generally easier to inspect and repair.	More difficult to access for maintenance, requiring specialized equipment.
2.	Cost	Typically lower initial installation costs.	Generally higher initial installation costs due to excavation and materials.

5.9. Give classification of underground cables.

- Ans.**
1. Low voltage (LT) cables.
 2. High voltage (HT) cables.
 3. Super-tension (ST) cables.
 4. Extra high tension (EHT) cables.
 5. Extra super-voltage cables.

5.10. What should be the desirable characteristics of insulating materials used in cables ?

- Ans.**
1. It should be flexible.
 2. It should be non-inflammable.
 3. It should be non-hygroscopic so that it will not absorb the moisture from the surrounding.
 4. It should be unaffected by acid and alkalis.

5.11. Mention important factors to be considered while selecting a cable.

Ans. The factors to be considered in selection of a cable are continuous current rating, voltage grade, permissible voltage drop and short-circuit rating (in case of HT cables only) and operating cost.

5.12. What is grading of cable ? Why is it necessary ?

OR

Define the grading of cable.

AKTU 2020-21, Marks 02

Ans.

A. **Grading of cables** : The process of obtaining uniform distribution of stress in insulation of cables is called grading of cables.

B. **Necessity** : Grading of cables is done because the unequal distribution has following two unwanted effects :

- i. Greater insulation thickness is required, which increases the cost and size.
- ii. It may lead to the breakdown of insulation.

5.13. Write the expression of insulation resistance of a single-core cable.

Ans. Insulation resistance of a single-core cable is given by

$$R_{ins} = \frac{\rho}{2\pi l} \log_e \frac{r_2}{r_1}$$

where, ρ = Resistivity of the insulating material
 l = Length of cables
 r_1, r_2 = Radii of cable conductor and internal sheath respectively.

5.14. Name the sources of heat generation in cables.

Ans.

1. I^2R losses in the conductor.
2. Dielectric losses in the cable insulation.
3. Losses in the metallic sheath and armourings.



B. Tech.
(SEM. V) ODD SEMESTER THEORY
EXAMINATION, 2020-21
POWER SYSTEM-I

Time : 3 Hours

Max. Marks : 100

Notes : Attempt all sections. If require any missing data; then choose suitably.

SECTION-A

1. Attempt all questions in brief. (2 × 10 = 20)
 a. Write the conventional and non-conventional source of energy.

Ans. Refer Q. 1.1, Page SQ-1B, Unit-1, 2 Marks Questions.

- b. Define load duration curve.

Ans. Refer Q. 1.6, Page SQ-2B, Unit-1, 2 Marks Questions.

- c. What do you mean by single line diagram of power system ?

Ans. Refer Q. 2.1, Page SQ-4B, Unit-2, 2 Marks Questions.

- d. Write Kelvin's law of power system.

Ans. Refer Q. 2.5, Page SQ-4B, Unit-2, 2 Marks Questions.

- e. What is a Ferranti effect ?

Ans. Refer Q. 2.10, Page SQ-5B, Unit-2, 2 Marks Questions.

- f. Define the term 'Sag'.

Ans. Refer Q. 3.1, Page SQ-7B, Unit-3, 2 Marks Questions.

- g. Define string efficiency.

Ans. Refer Q. 3.6, Page SQ-8B, Unit-3, 2 Marks Questions.

- h. Define transposition.

Ans. Refer Q. 4.1, Page SQ-10B, Unit-4, 2 Marks Questions.

- i. Explain symmetrical and unsymmetrical spacing of conductors.

Ans. Refer Q. 4.2, Page SQ-10B, Unit-4, 2 Marks Questions.

- j. Define the grading of cable.

Ans. Refer Q. 5.12, Page SQ-15B, Unit-5, 2 Marks Questions.

SECTION-B

2. Attempt any three of the following :

- a. With neat sketch, describe the nuclear power plant. (10 × 3 = 30)

Ans. Refer Q. 1.7, Page 1-8B, Unit-1.

- b. Explain corona effect and the factors affecting the corona. Write its disadvantages.

Ans. Refer Q. 2.19, Page 2-30B, Unit-2.

- c. Explain the method of calculating the sag for the same level.

Ans. Refer Q. 3.1, Page 3-2B, Unit-3.

- d. Derive the expression of inductance of single phase line.

Ans. Refer Q. 4.3, Page 4-5B, Unit-4.

- e. Compare the overhead lines and the underground cables.

Ans. Refer Q. 5.12, Page 5-16B, Unit-5.

3. Attempt any one part of the following :

- a. With a neat sketch explain the function of main parts of thermal power plant. (10 × 1 = 10)

Ans. Refer Q. 1.6, Page 1-7B, Unit-1.

- b. A generating station has a connected load of 450 MW and a maximum demand of 250 MW; the unit generated being 615×10^6 per annum. Calculate the demand factor and load factor.

Ans. Refer Q. 1.16, Page 1-16B, Unit-1.

4. Attempt any one part of the following :

- a. What is the single line diagram of power system from generating station to utilization level ? Obtain reactance diagram for any arbitrary chosen power system. (10 × 1 = 10)

Ans. Refer Q. 2.4, Page 2-4B, Unit-2.

- b. Calculate the distance over which a load of 15 MW at 0.85 pf can be delivered by a three-phase transmission line having conductors each of resistance 0.905 ohm per kilometer. The receiving end voltage is 132 kV and the loss is to be 7.5 % of the load.

Ans. Refer Q. 2.25, Page 2-39B, Unit-2.

5. Attempt any one part of the following :

- a. Explain the methods of increasing string efficiency. (10 × 1 = 10)

Ans. Refer Q. 3.15, Page 3-21B, Unit-3.

- b. Derive the expression of voltage distribution in 3 insulator strings.

Ans. Refer Q. 3.14, Page 3-19B, Unit-3.

6. Attempt any one part of the following : (10 × 1 = 10)

- a. Explain the inductance of a single phase two wire line system. Derive the expression for single phase two wire line.

Ans. Refer Q. 4.3, Page 4-5B, Unit-4.

- b. Find the capacitance of single-phase line 40 km long consisting of two parallel wires each 5 mm in diameter and 1.5 m apart.

Determine the capacitance of the same line taking into account the effect of ground. The height of the conductor above the ground is 7 meters.

Ans. Refer Q. 4.12, Page 4-17B, Unit-4.

7. Attempt any one part of the following :

(10 × 1 = 10)

- a. Describe the selection of the cables and the capacitance grading.

Ans. Refer Q. 5.13, Page 5-17B, Unit-5.

- b. Explain the cables for high voltage DC transmission and the operating problems with cables.

Ans. Refer Q. 5.15, Page 5-21B, Unit-5.

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B. Tech.
(SEM. V) ODD SEMESTER THEORY
EXAMINATION, 2021-22
POWER SYSTEM-I

Time : 3 Hours

Max. Marks : 100

Notes : Attempt all sections. If require any missing data; then choose suitably.

SECTION-A

1. Attempt all questions in brief.

a. What is demand factor ? Why is it important ? (2 × 10 = 20)

Ans. Refer Q. 1.7, Page SQ-2B, Unit-1, 2 Marks Questions.

b. For the same maximum demand, if load factor is decreased, then what will be the cost of energy ?

Ans. Refer Q. 1.8, Page SQ-2B, Unit-1, 2 Marks Questions.

c. What are the limitations of Kelvin law ?

Ans. Refer Q. 2.6, Page SQ-5B, Unit-2, 2 Marks Questions.

d. What is Ferranti effect ?

Ans. Refer Q. 2.10, Page SQ-5B, Unit-2, 2 Marks Questions.

e. How are voltage distribution and the string efficiency affected by rain ?

Ans. Refer Q. 3.5, Page SQ-8B, Unit-3, 2 Marks Questions.

f. What is the importance of sag in transmission line ?

Ans. Refer Q. 3.2, Page SQ-7B, Unit-3, 2 Marks Questions.

g. Differentiate between GMD and GMR.

Ans. Refer Q. 4.3, Page SQ-10B, Unit-4, 2 Marks Questions.

h. Why the effect of ground on the line capacitance can be neglected ?

Ans. Refer Q. 4.4, Page SQ-10B, Unit-4, 2 Marks Questions.

i. Why single core cables are usually not provided with armouring ?

Ans. Refer Q. 5.5, Page SQ-14B, Unit-5, 2 Marks Questions.

j. How do voids in the insulation cause breakdown of the cable ?

Ans. Refer Q. 5.6, Page SQ-14B, Unit-5, 2 Marks Questions.

SECTION-B

2. Attempt any three of the following :

(10 × 3 = 30)

a. What are the conventional and non conventional sources of energy ? Explain with examples.

Ans. Refer Q. 1.3, Page 1-3B, Unit-1.

b. Draw single line diagram of a four-bus system having generator G_1 connected to bus-1 through transformer T_1 , generator G_2 connected to bus-2 through transformer T_2 , load A and load B connected to bus-3 through transformer T_3 , four synchronous motors M_1 to M_4 connected to bus-4 through transformer T_4 , transmission lines TL_1 , TL_2 , TL_3 and TL_4 connected between bus 1-2, 2-3, 3-4 and 4-1 respectively.

Ans. Refer Q. 2.2, Page 2-3B, Unit-2.

c. What are the main characteristics of an ideal insulator ? Describe the main advantages and disadvantages of glass insulators. Explain rating and string efficiency of an insulator.

Ans. Refer Q. 3.14, Page 3-19B, Unit-3.

d. Derive expressions for the line-to-neutral capacitance and line-to-line capacitance of a single phase line.

Ans. Refer Q. 4.11, Page 4-16B, Unit-4.

e. Discuss the inter-sheath grading of cables. What are practical difficulties in the grading of cable ?

Ans. Refer Q. 5.6, Page 5-6B, Unit-5.

SECTION-C

3. Attempt any one part of the following :

(10 × 1 = 10)

a. A generating station has a maximum demand of 35 MW, a load factor of 50 %, a plant capacity factor of 80 % and a plant use factor of 62 %. Find (i) the reserve capacity of the plant (ii) the daily energy produced and (iii) Maximum energy that could be produced daily if the plant while running as per schedule, were fully loaded.

Ans. Refer Q. 1.17, Page 1-16B, Unit-1.

- b. Define and explain the importance of the following terms in generation: (i) Connected load (ii) Maximum demand (iii) Diversity factor (iv) Average load.

Ans. Refer Q. 1.15, Page 1-15B, Unit-1.

4. Attempt any one part of the following :

(10 × 1 = 10)

- a. Explain difference between skin effect and proximity effect. What is the percentage saving in copper feeder if the line voltage in a 2-wire DC system is raised from 220 V to 450 V for the same power transmitted over the same distance and having the same power loss ?

Ans. Refer Q. 2.15, Page 2-24B, Unit-2.

- b. Derive the A , B , C , D constants for the transmission line represented by nominal T section and draw its phasor diagram.

Ans. Refer Q. 2.24, Page 2-36B, Unit-2.

5. Attempt any one part of the following :

(10 × 1 = 10)

- a. What do you understand by vibration dampers in overhead transmission line ? Describe the different types of dampers used.

Ans. Refer Q. 3.10, Page 3-15B, Unit-3.

- b. An overhead line at a river crossing is supported from two towers of heights 30 meters and 90 meters above water level with a span of 300 meters. The weight of the conductor is 1 kg/meter and the working tension is 2000 kg. Determine the clearance between the conductor and the water level midway between the towers.

Ans. Refer Q. 3.4, Page 3-8B, Unit-3.

6. Attempt any one part of the following :

(10 × 1 = 10)

- a. Starting from first principles, derive the expression for inductance of a 3-phase unsymmetrical spaced transposed transmission line.

Ans. Refer Q. 4.6, Page 4-8B, Unit-4.

- b. The three conductors of a 3-phase line are arranged at the corners of a triangle of sides 2 m, 2.5 m and 4.5 m. Calculate the inductance per km of the line when the conductors are regularly transposed. The diameter of each conductor is 1.24 cm.

Ans. Refer Q. 4.7, Page 4-10B, Unit-4.

7. Attempt any one part of the following :

(10 × 1 = 10)

- a. Show that the most economical size of conductor in a single core cable is obtained when radius of cable sheath (R) equals $e.r$ where e is the base of radius of conductor. Explain dielectric loss.

Ans. Refer Q. 5.10, Page 5-13B, Unit-5.

- b. Find the most economical diameter of a single core cable to be used on 66 kV, 3 phase system. If the peak permissible stress is not to exceed 50 kV/m. Also find overall diameter.

Ans. Refer Q. 5.11, Page 5-16B, Unit-5.



B. Tech.
(SEM. V) ODD SEMESTER THEORY
EXAMINATION, 2022-23
POWER SYSTEM-I

Time : 3 Hours

Max. Marks : 100

Notes : Attempt all Sections. If require any missing data, then choose suitably.

SECTION-A

1. Attempt all questions in brief. (2 × 10 = 20)
- a. List the key features of primary and secondary distribution systems in the power system.
Ans. Refer Q. 1.3, Page SQ-1B, Unit-1, 2 Marks Questions.
- b. Explain diversity factor in power systems.
Ans. Refer Q. 1.9, Page SQ-2B, Unit-1, 2 Marks Questions.
- c. What will be the effect of line capacitance for lagging load in the medium transmission line ?
Ans. Refer Q. 2.12, Page SQ-6B, Unit-2, 2 Marks Questions.
- d. Why the line capacitance is neglected in short transmission lines ?
Ans. Refer Q. 2.13, Page SQ-6B, Unit-2, 2 Marks Questions.
- e. Explain the effect on sag of transmission line if the height of tower is increased.
Ans. Refer Q. 3.4, Page SQ-7B, Unit-3, 2 Marks Questions.
- f. Explain the factors affecting sag of an overhead transmission line.
Ans. Refer Q. 3.3, Page SQ-7B, Unit-3, 2 Marks Questions.
- g. Classify various type of supports used in power transmission lines.
Ans. Refer Q. 4.5, Page SQ-11B, Unit-4, 2 Marks Questions.
- h. Describe the uses and advantages of bundled conductors.
Ans. Refer Q. 4.6, Page SQ-11B, Unit-4, 2 Marks Questions.

- i. Summarize why metallic sheath is provided in underground cables.
Ans. Refer Q. 5.2, Page SQ-13B, Unit-5, 2 Marks Questions.
- j. List the different types of insulating materials used in underground cables.
Ans. Refer Q. 5.3, Page SQ-13B, Unit-5, 2 Marks Questions.

SECTION-B

2. Attempt any three of the following : (10 × 3 = 30)
- a. A plant having daily energy production and plant factor is 1296 MWhr and 50 % respectively. Calculate the maximum rating of the power plant.
Ans. Refer Q. 1.18, Page 1-17B, Unit-1.
- b. Write short note on the factors affecting the "Corona" losses.
Ans. Refer Q. 2.19, Page 2-30B, Unit-2.
- c. Show that the string efficiency of a string of suspension insulators is dependent on number of discs in string.
Ans. Refer Q. 3.16, Page 3-22B, Unit-3.
- d. Show that the inductance of a bundle conductor line is less than that of the line with one conductor per phase with mathematical expression.
Ans. Refer Q. 4.15, Page 4-24B, Unit-4.
- e. Explain the comparisons between overhead lines versus underground cables.
Ans. Refer Q. 5.12, Page 5-16B, Unit-5.

SECTION-C

3. Attempt any one part of the following : (10 × 1 = 10)
- a. Explain in detail the nuclear reaction theory and working principle of a nuclear power station with plant layout.
Ans. Refer Q. 1.8, Page 1-9B, Unit-1.
- b. A hydro-electric power station has a reservoir of area 2.4 square kilometres and capacity $5 \times 10^6 \text{ m}^3$. The effective head of water is 100 metres. The penstock, turbine and generation efficiencies are respectively 95 %, 90 % and 85 % :
 i. Calculate the total electrical energy that can be generated from the power station.

- ii. If a load of 15,000 kW has been supplied for 3 hours, find the fall in reservoir level.

Ans: Refer Q. 1.5, Page 1-6B, Unit-1.

4. Attempt any one part of the following :

- a. An overhead transmission line operates at 220 kV between phases at 50 Hz. The conductors are arranged in a 5 m delta formation. Calculate the maximum diameter of the conductor that can be used for no corona loss under fair weather conditions. Assume an air density factor of 0.95 and an irregularity factor of 0.85. The critical voltage is 230 kV. Also, find the power loss under stormy weather conditions. (10 × 1 = 10)

Ans: Refer Q. 2.21, Page 2-31B, Unit-2.

- b. Derive expression for voltage regulation and efficiency for short transmission line.

Ans: Refer Q. 2.22, Page 2-32B, Unit-2.

5. Attempt any one part of the following :

- a. Explain the calculation procedure of maximum sag of a transmission line at equal supports including wind pressure loading. (10 × 1 = 10)

Ans: Refer Q. 3.7, Page 3-12B, Unit-3.

- b. An overhead line has the following data :

Span length 160 metres, conductor dia 0.95 cm, weight per unit length of the conductor 0.65 kg/metre. Ultimate stress 4250 kg/cm², wind pressure 40 kg/m² of projected area. Factor of safety 5. Calculate the sag.

Ans: Refer Q. 3.8, Page 3-13B, Unit-3.

6. Attempt any one part of the following :

- a. Derive an expression for the capacitance per unit length of a 3-phase line completely transposed. (10 × 1 = 10)

Ans: Refer Q. 4.13, Page 4-19B, Unit-4.

- b. Describe the inductance calculation procedure of three-phase double-circuit line with symmetrical spacing (hexagonal).

Ans: Refer Q. 4.9, Page 4-12B, Unit-4.

7. Attempt any one part of the following :

- a. Explain the grading method of underground cables with mathematical expressions. (10 × 1 = 10)

Ans: Refer Q. 5.5, Page 5-4B, Unit-5.

- b. Explain with a neat sketch, the construction of a 3-core belted type cable.

Ans: Refer Q. 5.14, Page 5-17B, Unit-5.



Quantum Series

B. Tech.
(SEM. V) ODD SEMESTER THEORY
EXAMINATION, 2023-24
POWER SYSTEM-I

Time : 3 Hours

Max. Marks : 100

Note: 1. Attempt all sections. If require any missing data; then choose suitably.

Section-A

1. Attempt all questions in brief. (2 × 10 = 20)
- a. Differentiate between renewable and non-renewable energy.
Ans: Refer Q. 1.2, Page SQ-1B, Unit-1, 2 Marks Questions.
- b. What is a diversity factor ?
Ans: Refer Q. 1.9, Page SQ-2B, Unit-1, 2 Marks Questions.
- c. What is skin effect ?
Ans: Refer Q. 2.3, Page SQ-4B, Unit-2, 2 Marks Questions.
- d. Is corona more in AC or DC ?
Ans: Refer Q. 2.11, Page SQ-5B, Unit-2, 2 Marks Questions.
- e. What do you mean by sag template ?
Ans: Refer Q. 3.7, Page SQ-8B, Unit-3, 2 Marks Questions.
- f. Define the term sag.
Ans: Refer Q. 3.1, Page SQ-7B, Unit-3, 2 Marks Questions.
- g. What do you mean by self GMD and mutual GMD ?
Ans: Refer Q. 4.7, Page SQ-11B, Unit-4, 2 Marks Questions.
- h. Write the main causes of insulation failure.
Ans: Refer Q. 5.4, Page SQ-13B, Unit-5, 2 Marks Questions.
- i. Discuss the underground cable losses.
Ans: Refer Q. 5.7, Page SQ-14B, Unit-5, 2 Marks Questions.
- j. Differentiate between overhead lines and underground cables.
Ans: Refer Q. 5.8, Page SQ-14B, Unit-5, 2 Marks Questions.

Section-B

2. Attempt any three of the following : (10 × 3 = 30)
- a. What are the equipments used in sub-station ? Discuss them.
Ans: Refer Q. 1.2, Page 1-3B, Unit-1.
- b. State and prove Kelvin's law for size of conductor for transmission line. Discuss its limitations.
Ans: Refer Q. 2.12, Page 2-21B, Unit-2.
- c. Write a short note on the factors that affect sag.
Ans: Refer Q. 3.3, Page 3-7B, Unit-3.
- d. A double circuit single phase line have conductor a_1 and a_2 which carry the current in one direction. Conductor b_1 and b_2 carry the current in return direction. The diameter of each conductor is 25 mm. Calculate the inductance of the line per km if $D_1 = 1$ mt and $D_2 = 2$ mt.
Ans: Refer Q. 4.4, Page 4-6B, Unit-4.
- e. Discuss different types of insulating materials used in power system.
Ans: Refer Q. 5.3, Page 5-3B, Unit-5.

Section-C

3. Attempt any one part of the following : (10 × 1 = 10)
- a. A generating station has the following daily load cycle :

Time (Hours)	0-6	6-10	10-12	12-16	16-20	20-24
Load (MW)	40	50	60	50	70	40

 Draw the load curve and find
 - i. Maximum demand
 - ii. Units generated per day
 - iii. Average load
 - iv. Load factor.**Ans:** Refer Q. 1.19, Page 1-18B, Unit-1.
- b. Give the layout of thermal power plant and explain its components in details.
Ans: Refer Q. 1.6, Page 1-7B, Unit-1.
4. Attempt any one part of the following : (10 × 1 = 10)
- a. Classify different types of supply system and compare the volume of conductor DC two wire system and 3- ϕ 3-wire system.
Ans: Refer Q. 2.6, Page 2-6B, Unit-2.

- b. Analyze the performance of medium transmission line (T model). Draw phasor diagram and derive relation for $ABCD$ parameters.

Ans. Refer Q. 2.24, Page 2-36B, Unit-2.

5. Attempt any one part of the following :

(10 × 1 = 10)

- a. An insulator string consists of three units, each having a safe working voltage of 15 kV. The ratio of self-capacitance to shunt capacitance of each unit is 8:1. Find the maximum safe working voltage of the string. Also find the string efficiency.

Ans. Refer Q. 3.17, Page 3-23B, Unit-3.

- b. Discuss different methods of improving string efficiency.

Ans. Refer Q. 3.15, Page 3-21B, Unit-3.

6. Attempt any one part of the following :

(10 × 1 = 10)

- a. Explain catenary method for finding the sag in a transmission line.

Ans. Refer Q. 3.2, Page 3-4B, Unit-3.

- b. Explain rigorous method for long transmission line.

Ans. Refer Q. 2.26, Page 2-39B, Unit-2.

7. Attempt any one part of the following :

(10 × 1 = 10)

- a. Discuss the inter-sheath grading of cables. What are practical difficulties in the grading of cables ?

Ans. Refer Q. 5.6, Page 5-6B, Unit-5.

- b. Find the most economical diameter of a single core cable to be used on 66 kV, 3-phase system. If the peak permissible stress is not to exceed 50 kV/m. Also find overall diameter.

Ans. Refer Q. 5.11, Page 5-16B, Unit-5.



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