POWER SYSTEM-I

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BASIC CONCEPTS

Multiple Choice Type Questions

1. The surge impedance of a 50 miles long underground cable is 25 Ω. For a 25 miles length it will be [WBUT 2019]
   a) 50 Ω b) 100 Ω c) 25 Ω d) 200 Ω

Answer: (a)

2. In an interconnected grid system, the diversity factor of the whole system [MODEL QUESTION]
   a) increases b) decreases
   c) remains constant d) None of these

Answer: (a)

3. In inter connected grid system the connection of several generating stations are made in [MODEL QUESTION]
   a) series b) parallel c) series-parallel d) delta-star

Answer: (a)

4. In interconnected stations [MODEL QUESTION]
   a) the maximum demand on the system is much reduced
   b) the diversity factor of the system is improved
   c) there is overall increase of the effective capacity of the system
   d) all of these

Answer: (d)

5. Diversity factor is always [MODEL QUESTION]
   a) 1 b) 0 c) greater than 1 d) ∞

Answer: (c)

6. A reversible turbine-pump operation is used [MODEL QUESTION]
   a) pumped storage plant b) thermal power plant
   c) nuclear power plant d) None of these

Answer: (a)

7. A modern power system comprises [MODEL QUESTION]
   a) large number of element any system interconnected by tie lines.
   b) complex electrical network grid spread-over a large geographical region
   c) synchronous machines to run in synchronism
   d) All of these

Answer: (d)

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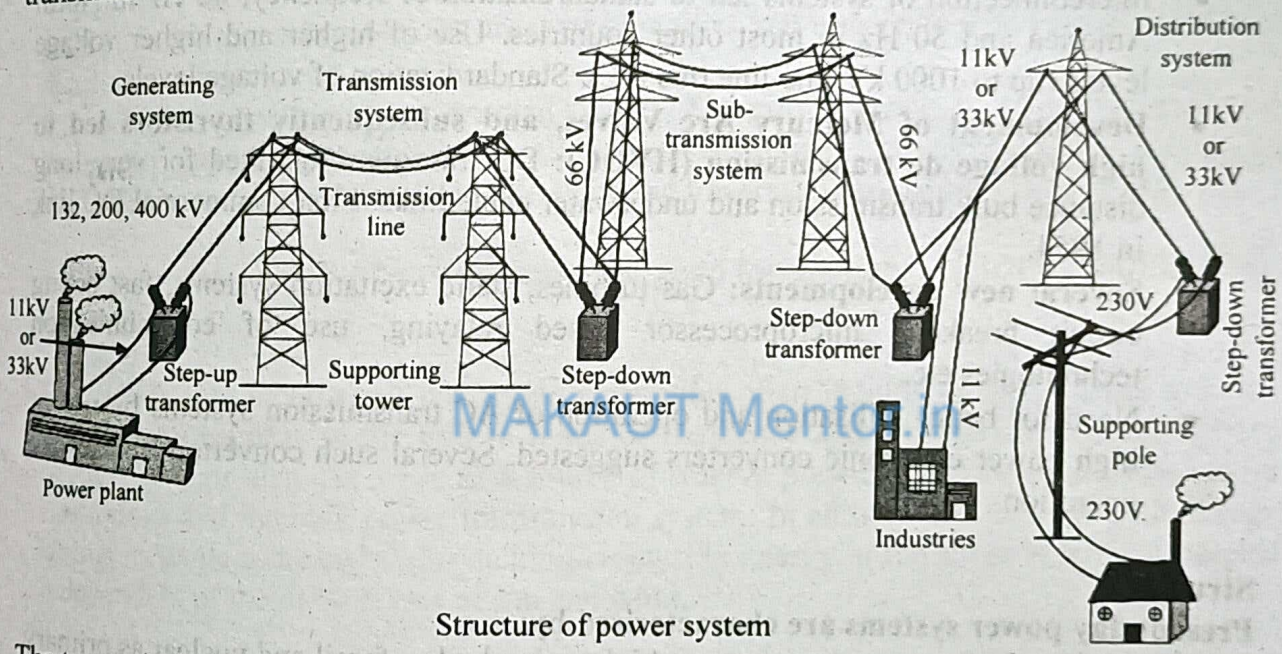
Long Answer Type Questions

1. What is the definition of power system? **[MODEL QUESTION]**

Answer:

The power system is a network which consists generation, distribution and transmission system. It uses the form of energy (like coal and diesel) and converts it into electrical energy. The power system includes the devices connected to the system like the synchronous generator, motor, transformer, circuit breaker, conductor, etc.

The power plant, transformer, transmission line, substations, distribution line, and distribution transformer are the six main components of the power system. The power plant generates the power which is step-up or step-down through the transformer for transmission.



Structure of power system

The transmission line transfers the power to the various substations. Through substation, the power is transferred to the distribution transformer which step-down the power to the appropriate value which is suitable for the consumers.

2. Describe the evolution of power system and present day scenario. **[MODEL QUESTION]**

Answer:

Evolution:

Electrical Technology was founded on the remarkable discovery by Faraday that a changing magnetic flux creates an electric field. Out of that discovery, grew the largest and most complex engineering achievement of man: the electric power system. Indeed, life without electricity is now unimaginable. Electric power systems form the basic infrastructure of a country. Even as we read this, electrical energy is being produced at rates in excess of hundreds of giga-watts (1 GW = 1,000,000,000 W). Giant rotors spinning at speeds up to 3000 rotations per minute bring us the energy stored in the

potential energy of water, or in fossil fuels. Yet we notice electricity only when the lights go out!

While the basic features of the electrical power system have remained practically unchanged in the past century, there are some significant milestones in the evolution of electrical power systems:

- **First complete DC power system built by Edison (1882):** Incandescent lamps supplied by steam driven DC generators (electrical cable system at 110V). 59 customers spread over an approximate area with 1.5 km radius.
- Development of transformers led to supersession of DC systems by AC systems.
- **Nikola Tesla - polyphase induction motors:** led to development of AC 3 phase systems.
- Interconnection of systems led to standardization of frequency, 60 Hz in North America and 50 Hz in most other countries. Use of higher and higher voltage levels (up to 1000 kV line-line rms AC). Standardization of voltage levels.
- **Development of Mercury Arc Valves, and subsequently thyristors led to high voltage dc transmission (HVDC):** DC transmission suited for very long distance bulk transmission and underwater cable links. First commercial DC link in 1954.
- **Several new developments:** Gas turbines, static excitation systems, fast acting circuit breakers, microprocessor based relaying, use of communication technologies etc.
- Need for better utilisation and operation of AC transmission systems by use of high power electronic converters suggested. Several such converters are now in operation.

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Structure:

Present day power systems are characterised by:

AC generation (3 phase synchronous machines using hydro, fossil and nuclear as primary energy sources) AC transmission (a limited number of DC transmission links are present in some systems) 3 phase AC utilization (some loads are single phase, but they are usually distributed equally in all phases to obtain a balanced system).

The transmission network consists of an extra high voltage (220 kV and above) lines interconnecting large generators to major load centers. These lines are capable of transmitting large amounts of power over large distances (1000 km is not unusual!).

For example, several 400 kV lines may be required to transmit, say, 2000 MW from a large thermal power plant to a distant load center.

Note: high voltage dc lines are suitable if distances are very large (we shall see why later in the course). Generators, typically having terminal voltages of around 15 kV and are connected to these EHV lines via transformers. Interconnecting transformers connect EHV lines at different voltage levels (they are usually auto-transformers).

A sub-transmission network, consisting of transmission lines at 66 kV and 132 kV are used to deliver power received from EHV network to various distribution substations.

Finally, a distribution network consisting of lines at less than 66 kV are used to transfer power to each consumer.

A large power system may also be connected to neighbouring power systems via ac transmission lines or dc links. The power exchange between such neighbours is usually regulated.

3. What is Bulk Power Grid? **[MODEL QUESTION]**

Answer:

A **bulk power system** (BPS) is a large interconnected electrical system made up of generation and transmission facilities and their control systems. A BPS does not include facilities used in the local distribution of electric energy. If a **bulk power** system is disrupted, the effects are felt in more than one location.

The **power grid** is a network for delivering **electricity** to consumers. The **power grid** includes generator stations, transmission lines and towers, and individual consumer distribution lines.

It is a highly-complex interconnected system. The critical strategic assets that make up the **power grid** include rotating machinery, transformers, circuit breakers, protective devices, transmission and distribution lines and towers, control centers, and substations.

4. What is Microgrid? Why microgrids are good for utilities? **[MODEL QUESTION]**

Answer:

1st Part:

Microgrids that incorporate renewable generation often include energy storage systems that provide benefits to the grid in terms of frequency and voltage stabilization. These storage systems also can serve as a source of reserve power to reduce peak demands on substations and the bulk power transmission system. In addition, microgrids with energy storage provide a means of dispatching renewable energy at the times it is most needed independent of the daily cycles of sun and wind.

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2nd Part:

There are two main reasons microgrids can work for utilities and not against them. First, to be economically feasible, a microgrid's generation must provide savings over current retail energy tariffs. Increased reliability and resiliency come at a cost, however, and someone must pay that cost. To justify passing costs along to consumers, those costs must be offset by improved power quality and a substantial reduction in unplanned customer outages. What generally clinches the economic incentives for constructing a microgrid are the efficiencies created by energy storage, CHP systems, and, in places with abundant wind and solar potential and renewable energy incentives, lower generation costs.

When it comes to an undertaking as complex as designing, installing and maintaining a microgrid, many customers will be just as eager to turn those tasks over to a large, capable utility as they are to turn over payroll, office information technology and telecommunications services to large, capable providers in those fields. Most customers, even large industrial ones, don't want to be in the power business, and they shouldn't be.

They simply want to lower their energy costs while improving reliability. Utility ownership of microgrids allow customers to accomplish these goals in a way that incorporates new technology while maintaining the traditional utility model as a distributor of energy to the customer.

Secondly, microgrids are also proving to be helpful for utilities to reduce the costs of maintaining reliable service.

As microgrid technology, reliability and costs improve, utilities and regulators see that microgrids can be a cost-effective alternative to transmission upgrades or redundancy. In addition, they can deliver utility-scale benefits, such as supporting smart grid deployments and lowering line loss in challenging service areas.

In years to come, we can see customized deployments of microgrids becoming an increasingly popular, proven alternative to conventional transmission and distribution upgrades. In states that have restructured utilities to separate power generation from energy delivery, laws must be amended to clarify how much generation, in the context of a microgrid, a restructured utility is allowed to own, and when utilities are allowed to install microgrids outside their home service territories, such as to serve a multi-location customer. These changes are simply negotiations, however, not deal-killers.

At the highest level, utility business models are already evolving, as they must. A process of redefining what "utility," "grid" and "generation" mean in the context of 2017 energy delivery is already underway thanks to thousands of residential customers installing rooftop PV. Microgrids are simply the next wave of that redefinition. The distribution system, once a linear one-way pipeline from substation to customer is being transformed into a bidirectional system connecting a network of energy customers and producers much in the way the bulk power transmission system presently works. Utilities must revise their business model to reflect these foundational changes and extract revenue based on providing the capacity to transmit power as opposed to a flat cost of energy to consumers. Time of day rates are key to this business model both for utilities and the microgrid customers. Utilities and regulators are well into working through how to price the value those customers will place on maintaining a connection to the utility grid.

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The opportunity to deploy projects that serve customers and rationalize network reliability make the upgrade costs associated microgrids worth the mega-opportunity they provide electric utilities.

Microgrids that incorporate renewable generation often include energy storage systems that provide benefits to the grid in terms of frequency and voltage stabilization.

GENERATION OF ELECTRIC POWER

Multiple Choice Type Questions

1. In a hydroelectric plant, spillways are used [MODEL QUESTION]
   a) to reduce the pressure swings in the conduit leading water to turbine
   b) to avoid sharp corners and abrupt contractions at the head of an intake in head works
   c) to discharge the surplus water from the storage reservoir into the river on the down-stream side of the dam
   d) None of these

Answer: (c)

2. For high head hydroelectric plants, the turbine used is [MODEL QUESTION]
   a) reaction turbine b) Pelton wheel
   c) Francis turbine d) Kaplan turbine

Answer: (b)

3. Concrete penstocks are suitable for [MODEL QUESTION]
   a) high heads b) medium heads c) low heads (<30m)

Answer: (c)

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4. The cheapest plant in operation and maintenance is [MODEL QUESTION]
   a) diesel power b) steam power
   c) hydroelectric power d) nuclear power

Answer: (c)

5. Surge tank is provided for the protection of [MODEL QUESTION]
   a) Penstock b) Governor c) Ecomiser d) None of these

Answer: (a)

6. A hydroelectric generating station is supplied for a reservoir of capacity 5×10^6 cubic metres at a head of 200 meters. The total energy available in kWh if the overall efficiency is 75% will be [MODEL QUESTION]
   a) 1.05×10^4 kWh b) 3.01×10^4 kWh
   c) 2.044×10^6 kWh d) 1.95×10^5 kWh

Answer: (c)

7. First nuclear power plant in India was started at [MODEL QUESTION]
   a) Kota b) Tarapur c) Kalpakkam d) Narora

Answer: (b)

8. Nuclear power station is normally used for [MODEL QUESTION]
a) peak load b) base load c) average load d) any load
Answer: (b)

9. Of all the plants, minimum quantity of fuel required in [MODEL QUESTION]
a) nuclear power plant b) hydro-electric power plant
c) thermal power plant d) none of these
Answer: (a)

10. The running cost of a nuclear power plant at the time of first time installation was approximately found to be about [MODEL QUESTION]
a) 20 Paise per unit b) 40 Paise per unit
c) 60 Paise per unit d) Rs.1 per unit
Answer: (a)

11. The first nuclear power plant n the world was commissioned in [MODEL QUESTION]
a) U.S.A. b) U.S.S.R. IN 1954 c) England d) China
Answer: (b)

12. The most simple and clean plant is [MODEL QUESTION]
a) hydro-electric b) steam power c) nuclear power
Answer: (a)

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13. The heart of a nuclear power plant is the [MODEL QUESTION]
a) Nuclear reactor b) Heat exchanger
c) Nuclear fuel d) Control rod
Answer: (a)

14. Demand factor is [MODEL QUESTION]
a) always greater than 1 b) always less than 1
c) of any value d) depends upon the system
Answer: (b)

15. Efficiency of a thermal power plant is [MODEL QUESTION]
a) 40% b) 60% c) 80% d) 30%
Answer: (d)

16. Power available in wind is proportional to [MODEL QUESTION]
a) wind speed b) square of the wind speed
c) cube of the wind speed d) fourth power of the wind speed
Answer: (c)

Short Answer Type Questions

1. What are atomic number and mass number of an atom? [MODEL QUESTION]

Answer:

The atomic number Z1 is the number of protons in the nucleus. It identifies the chemical properties of the atom.

The mass number of an atom, A1 is the total number of protons and neutrons in its nucleus. Protons and neutrons in its nucleus together are called nucleons.

2. What is nuclear energy? [MODEL QUESTION]

Answer:

Inside an atom, electrons are revolving in different orbits. These electrons are held in their orbits by electrostatic forces. The forces that hold the protons and neutrons inside the nucleus are million times as strong as the electrostatic forces holding the electrons to the nucleus.

It was found that enormous energy will be released when an atom was split or when the nucleus was split into two smaller nuclei. The energy thus released is known as the **atomic energy or nuclear energy**. The process of splitting the nuclear is called **nuclear fission**. The schematic U^{235} fission can be seen in Fig. 1.

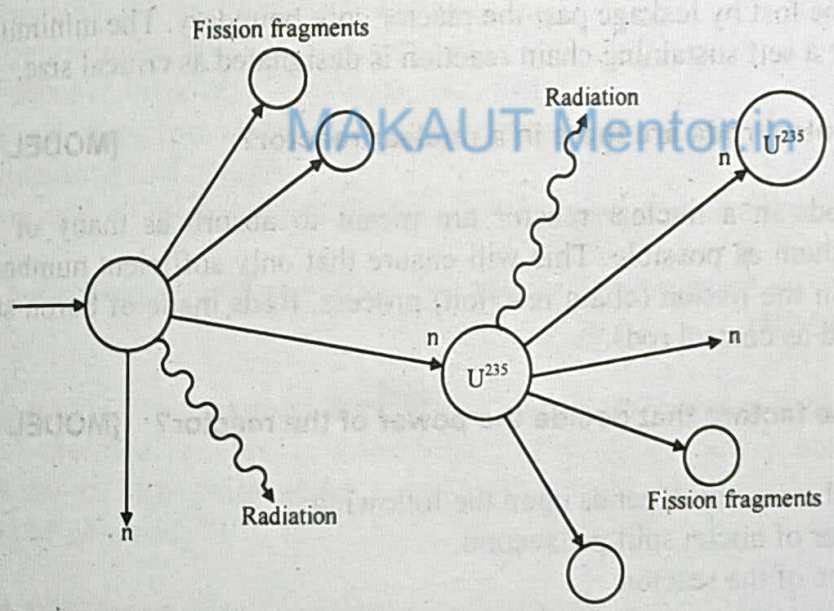

Fig: 1 Schematic of U^{235} fission

3. What is chain reaction? What is nuclear fission? [MODEL QUESTION]

Answer:

When a nucleus of uranium was split into smaller nuclei, two or three neutrons are emitted from the splitting nucleus. Each neutron thus emitted can, when slowed down sufficiently, cause another nucleus of uranium to split and release more energy, and still more neutrons which can be used to split further nuclei and so on. Such a continuous reaction is known as chain reaction in nuclear field.

By chain reaction, continuous release of energy in the form of heat will take place. This process of splitting the nucleus of an atom is called fission process.

4. a) What is nuclear fusion? **[MODEL QUESTION]**

Answer:

Nuclear fusion is the process of forcing and combining together two light atoms to make a heavier one. Fusion reaction creates much more heat than fission.

b) What is meant by critical mass (of fuel) in a reactor? **[MODEL QUESTION]**

Answer:

In a reactor, for the chain reaction to sustain, enough fuel must be assembled in the place, so that the neutrons released due to the reaction will have a good chance of finding another fuel nucleus to split. For the chain reaction to be maintained, the systems fuel quantity must exceed a certain quantity. This quantity of fuel mass is known as critical mass.

5. What is meant by critical size of the reactor core? **[MODEL QUESTION]**

Answer:

In a reactor, if the core is smaller than the critical mass, too large a fraction of neutrons produced will be lost by leakage past the reactor core boundary. The minimum size of the reactor core for a self sustaining chain reaction is designated as critical size.

6. What for control rods are there in a nuclear reactor? **[MODEL QUESTION]**

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Answer:

The control rods in a nuclear reactor are meant to absorb as many of the neutrons impinging on them as possible. This will ensure that only sufficient number of neutrons will take part in the fission (chain reaction) process. Rods made of boron steel are most commonly used as control rods.

7. What are the factors that decide the power of the reactor? **[MODEL QUESTION]**

Answer:

The power of the reactor depends upon the following:

a. Number of nuclei split per second.
b. Volume of the reactor.
c. Number of neutrons formed per Cu.m of the central part of the reactor.
d. Velocity and length of the free path of the neutrons which are capable of splitting the nuclei.

8. a) What is a spillway? **[MODEL QUESTION]**

Answer:

Spillway permits surplus water to overflow over the dam and thereby controls the level of water in the head pond and the level in the canal to the head pone.

b) What is a drainage gallery? **[MODEL QUESTION]**

Answer:
A drainage gallery, usually incorporated inside the dam structure, serves as an outlet for the water that seeps from the upstream masonry and from the foundation. It also helps inspection of the dam interior along its length.

9. Advantages and disadvantages of nuclear power plants. **[MODEL QUESTION]**

Answer:
The advantages of nuclear power plants are:

a. Less space requirement.
b. Very well suited for large power demands.
c. No atmospheric pollution as there are no combustible products.
d. Cost of fuel transportation and storage is less.
e. Power generation is not affected by weather conditions.
f. Greater reliability of operation.
g. Water requirement is les compared to hydel plants.

The disadvantages of nuclear plants are:

a. High initial cost.
b. Not suitable for varying power demands.
c. Danger of radioactivity always persists.
d. Failure of controls may lead to nuclear explosion.
e. Disposal of nuclear waste is a major problem.
f. Maintenance cost is high.
g. Complexity of the fuel cycle increases cost of power generation.

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10. What is hydroelectric power station and where it is located? **[MODEL QUESTION]**

Answer:
A generating station which utilises the potential energy of water at a high level for the generation of electrical energy is known as hydroelectric power station. They are generally located in hilly areas where dams can be built conveniently and large water reservoirs can be obtained.

11. State the main types of hydroelectric installations. **[MODEL QUESTION]**

Answer:
Types are:

a) High head or stored
b) Medium head or pondage
c) Run of river
d) In India mini or micro-hydroelectric schemes have been installed on canals wherever 1m or so head is available. Often cascaded plants are also constructed on the same water stream where is discharge of one plant becomes the inflow of a down stream plant.

12. What is pumped storage scheme? **[MODEL QUESTION]**

Answer:

In areas where sufficient hydroelectric generation is not available, peak load may be handled by means of pumped storage.

13. State the functioning method of pump-storage scheme. **[MODEL QUESTION]**

Answer:

This consists of upper and lower reservoirs and reversible turbine-generator sets, which can also be used as motor-pump sets.

14. What are the major electrical equipments required to run a hydroelectric power stations? **[MODEL QUESTION]**

Answer:

The electrical equipment of a hydroelectric power station includes alternator transformers, circuit breaker and other switching and protective devices.

15. What are the salient factors that are considered for selecting the location of a coal-based thermal power plant? **[MODEL QUESTION]**

Answer:

Considering factors for selection of suitable site for thermal power plant:

i) Proximity to load centre
ii) Population distribution
iii) Land use
iv) Meteorology
v) Geology
vi) Seismology
vii) Hydrology

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16. a) Describe a single crystalline solar cell with constructional details.
b) What is 'fill factor' of a PV cell? **[MODEL QUESTION]**

Answer:

a) The first silicon PV cells were of the single crystal array. Single crystal silicon cells are the most efficient and most robust of the silicon PV family. Their main drawbacks are: (i) they are most energy intensive in their production and (ii) the unit consumption of silicon to produce one unit of PV electricity is also quite high. Other variations of PV cells are being developed to overcome mainly these two drawbacks. Let us have a brief overview of the main steps involved in their production.

The first step is the production of metallurgical grade (99% pure) silicon, MgSi from its ore, SiO_2 by reduction reaction with carbon in an arc furnace. The energy cost of this step is 50 kWh/kg of silicon. Also, in this process CO_2 is produced as a byproduct, which is a greenhouse gas. Electronic grade pure (an impurity of about 1 part in 10^7) polysilicon (or polycrystalline silicon) is then obtained by refining it further through various complex operations at an energy cost of 200 kWh/kg of silicon. These two steps are highly energy intensive.

The polysilicon is then melted and the IIIrd group impurity (generally boron) in a desired quantity is introduced in the melt to get a *p*-type base material. The bulk resistivity of this material is chosen appropriately by controlled doping. Low doping or high resistivity should result in a wider depletion layer and increased short-circuit current. But this would also result into lower open-circuit voltage and a large series resistance leading to reduction of fill factor. On the other hand, too low resistivity, or a high doping leads to lower photocurrent due to larger carrier recombination. Such considerations have lead to selection of resistivity in the range 1 to 3 ohm-cm as an optimum value for bulk silicon solar cells. The molten mass is recrystallized into a single crystal ingot as large as 4 to 6 inches in diameter and 3 to 5 feet long, using a silicon seed crystal. Special saws are then used to cut the ingots into wafers of thickness between 200 to 400 microns. Again, this crystal growth and wafering processes are quite energy intensive. Also about 40–50% of this expensive material is lost in this slicing operation. Efforts are on to fabricate a thin ribbon-shaped crystal to avoid the need of wafering. The edges of the wafers are then trimmed to make it closer to a square so as to increase the packing density, as circular wafers mounted on a module would leave a large amount of space between them. After preparation of the surface, on each wafer a Vth group impurity (usually phosphorus) is diffused to get a thin (fraction of a micron) layer of *n*-type material and thus a *pn* junction is formed. Low-resistance ohmic contacts are made on both sides for external connection. The most common commercially produced silicon cell has an *n*-on-*p* structure, where the base material is *p*-type, which has a thin diffused *n* layer on top of it. Since the diffused layer is relatively heavily doped, it is likely to have a large number of unwanted recombination centres. Therefore, the diffusion length of minority carriers in this region is quite small and they are not expected to contribute significantly to photocurrent. The major contribution would normally come from the base region. The minority carrier diffusion length for electron is about twice that of a hole in silicon. Therefore, a *p*-type silicon base material, which has electrons as its minority carriers are preferred for making single crystalline bulk silicon solar cell.

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b) *Fill Factor* of a PV cell indicates the quality of a cell which is defined as the ratio of the peak power to the product of open-circuit voltage and short-circuit current, i.e.,

$$FF = \frac{V_m I_m}{V_{oc} I_{sc}}.$$

17. A solar cell of active area 6cm^2 gave the following results: $V_{oc} = 400mV$, $I_{sc} = 200mA$, incident intensity 80 mW/cm^2. What is the energy conversion efficiency of the device? (Assume fill factor of 80%).

[MODEL QUESTION]

Answer:

Maximum power output of the device

$= V_{oc} I_{sc} . FF \quad = V_m . I_m \quad = 400\,\text{mV} \times 200\text{mA} \times 0.80$

$= 400\text{mV} \times 0.2\text{A} \times 0.80 \quad = 64\text{mW}$

Total incident Insolation = 80 mW/cm^2 × 6 cm^2 = 480 Mw

$$\therefore \text{Efficiency} = \frac{V_m I_m}{\text{Total Insolation}} = \frac{64\,\text{mW}}{480\,\text{mW}} \times 100 = 13.33\%$$

18. Explain how we can get maximum power from a solar cell and deduce expression for that. **[MODEL QUESTION]**

Answer:

Maximum power output can be got from the solar cells when they are connected in parallel. Efficiency = Power developed per unit area. In this condition when they are kept in full sunlight and we get maximum power output.

Desirable features of a solar cell are – maximum values of V_{oc} *and* I_{sc}, low series resistance that will lead to high fill factor and high shunt resistance. I_{ac} is related to photocurrent and V_{oc} depends on the ratio of I_{sc} to I_o. Shunt resistance is maximized by ensuring that no leakage occurs at the perimeter of the cell. This is done by passivating the surface. Reduction of series resistance requires high doping of semiconductor. But high doping will also decrease the width of depletion layer, which in turn decreases the photocurrent. Therefore, both V_{oc} and I_{sc} are affected. Therefore, trade-off is made in choosing the level of doping to get optimal performance.

19. a) How is the power output related to wind speed?
b) What type of generators are coupled to wind turbines? **[MODEL QUESTION]**

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Answer:

a) If u_o is the speed of free wind in unperturbed state, the volume of air column passing through an area A per unit time is given by Au_o. If ρ is the density of air, the air-mass flow rate, through area A, is given as, $\rho A u_o$. Power (P_o) available in wind, is equal to kinetic energy associated with the mass of moving air, i.e.,

$$P_o = \frac{1}{2}(\rho A u_o) u_0^2$$

or, $$P_o = \frac{1}{2}(\rho A) u_0^3$$

Power available in wind per unit area is

$$\frac{P_o}{A} = \frac{1}{2}\rho u_0^3$$

This indicates that power available in wind is proportional to the cube of wind speed. Assuming a typical value of wind density, ρ at 15°C and at sea level to be 1.2 kg/m^3, power available in moderate wind of 10 m/s is 600 W/m^2.

b) The generators which are coupled to wind turbines

1. Squirrel cage induction generator

2. Doubly fed (wound rotor) induction generator
3. Direct drive synchronous generator

20. What is the basic principle of wind energy conversion? [MODEL QUESTION]

Answer:
The windmill works on the principle of momentum. The work done by the turbine rotor is the difference between the kinetic energies of incoming and outgoing streams through the rotor.
A horizontal-axis, propeller type windmill is shown in Fig. 1. The thickness of wheel is a-b. The pressure and velocity changes are also plotted.

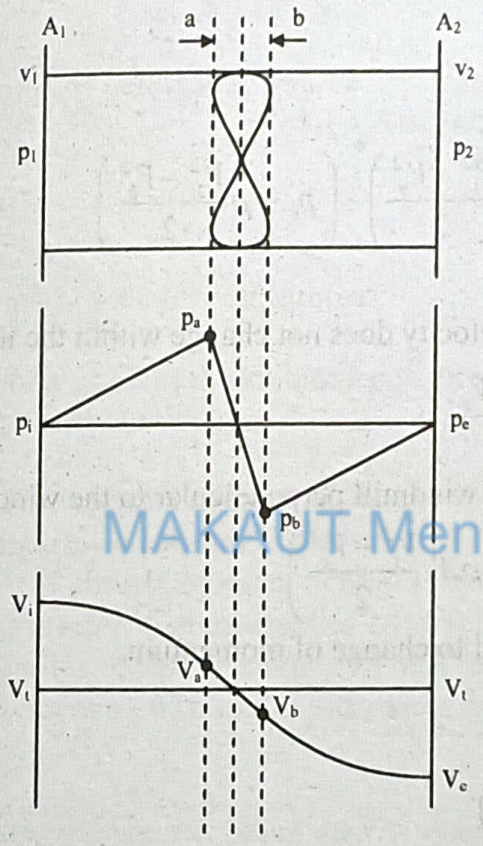

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Fig: 1 Pressure and velocity profiles for air flow through a wind turbine

The exit velocity V_e is less than V_i because kinetic energy is extracted by turbine. The pressure p_e is almost equal to p_i. Applying total energy equation and taking air density ρ = constant.

$$PE_1 = PE_2$$

$$p_i v + \frac{V_i^2}{2} = p_a v + \frac{V_a^2}{2}$$

$$p_i + \rho\frac{V_i}{2} = p_a + \rho\frac{V_a^2}{2}$$

where $v = \frac{1}{\rho}$

For exit area,

$$p_e v + \frac{V_e^2}{2} = p_b v + \frac{V_b^2}{2}$$

$$p_e + \rho\frac{V_2^2}{2} = p_b + \rho\frac{V_b^2}{2}$$

Now $V_i > V_a$

and $V_b > V_c$

$p_a > p_i$

$p_b < p_e$

$$\therefore \quad p_a - p_b = p_i + \rho\left(\frac{V_i^2 - V_a^2}{2}\right) - \left(p_e + \rho\frac{V_2^2 - V_b^2}{2}\right)$$

as $p_e = p_i$

$V_i = V_a = V_b$ [velocity does not change within the turbine]

$$\therefore \quad p_a - p_b = \rho\left(\frac{V_i^2 - V_e^2}{2}\right)$$

If A is the projected area of windmill perpendicular to the wind stream, the axial force,

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$$F_x = (p_a - p_b)A = \rho A\left(\frac{V_i^2 - V_e^2}{2}\right)$$

The axial force is also equal to change of momentum.

$$F_x = \Delta(\dot{m}u)$$

$$\dot{m} = \rho A V_i$$

$$\therefore \quad F_x = \rho A V_i (V_i - V_e)$$

where $V_i = \left(\frac{V_i - V_e}{2}\right)$

Now steady flow work,

$$W = KE_i - KE_e = \frac{V_i^2 - V_e^2}{2}$$

The power produced is rate of work.

$$\therefore \quad P = \dot{m}\left(\frac{V_i^2 - V_e^2}{2}\right)$$

$$P = \frac{1}{2}\rho A V_i (V_i^2 - V_e^2)$$

$$P = \frac{1}{4}\rho A (V_i + V_e)(V_i^2 - V_e^2)$$

For maximum power,

$$\frac{dP}{dV_e} = 0$$

$$\therefore \quad 3V_e^2 + 2V_iV_e - V_i^2 = 0$$

$$V_{e_{opt}} = \frac{V_i}{3}$$

$$\therefore \quad P_{max} = \frac{8}{27}\rho A V_i^3$$

The maximum efficiency,

$$\eta_{max} = \frac{P_{max}}{P_{tot}} = \frac{8}{27} \times 2 = \frac{16}{27} = 0.5926 \approx 60\%$$

Therefore actual power,

$$P = \eta P_{tot} = \eta \frac{AV_i^3}{2}$$

where η varies between 30 to 40% for real turbines.

21. a) Why are control rods used in the nuclear power plant?
b) State the advantages of wind energy. **[MODEL QUESTION]**

Answer:

a) Control rods are used in nuclear reactors to control the fission rate of uranium and plutonium. They are composed of chemical elements such as boron, silver, indium and cadmium that are capable of absorbing many neutrons without themselves fissioning. In the operation of a nuclear reactor, fuel assemblies are put into place and then the control rods are slowly lifted until a chain reaction can just be sustained. As the reaction proceeds, the number of uranium-235 nuclei decreases and fission by-products which absorb neutrons build up.

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b) Wind energy is a clean fuel source. Wind energy doesn't pollute the air like power plants that rely on combustion of fossil fuels, such as coal or natural gas. Wind turbines don't produce atmospheric emissions that increase health problems like asthma or create acid rain or greenhouse gases.

22. What are the different methods of firing coal? Discuss the advantages of mechanical methods of firing coal. **[MODEL QUESTION]**

Answer:

The fuel for a coal-fired furnace or boiler may be fed either auto-matically or by hand. Both methods have certain advantages and disadvantages. For example, automatic (stoker) firing is initially more expensive because it requires the purchase and installation of a suitable mechanical stoker to feed the coal to the furnace or boiler. As a result, stoker firing is a common practice in larger buildings (e. g., stores, hotels) where the initial high cost of the equipment can be more easily absorbed into the total cost of the structure. Despite the relative high cost of stokers, there are some designed for use in single-family

residences. Because there is no need to invest in special and expensive coal — handling equipment, hand-firing the coal has been the traditional method used for firing house heating furnaces and boilers. Although hand-firing coal is less expensive than stoker-firing for these smaller installations, the following objections to the hand — firing method should be noted:

The frequent opening of the furnace or boiler doors allows a large excess of air to enter and chill the flame. The combus-tion efficiency of the flame therefore tends to fluctuate. The dumping of a lot of fuel at each firing results in a smoke period until normal combustion conditions are restored. Hand-firing coal is by its nature an intermittent firing method. The flame often reaches a low and inefficient level or is extin-guished before new fuel is added.

Mechanical methods of firing coal

When fuel i.e. coal is put into the steam boiler furnace by means of mechanical stoker, the firing of boiler method is referred as mechanical stoker firing. There are mainly two types of mechanical stoker firing systems.

Here, combustion takes place on the grate. The primary air is fed below the grate. The primary air is fed below the grate. The secondary air is allowed at the top. When the coal is burnt, it is pushed down by fresh coal. The fresh coal is pushed on the grate by means of rams as shown. The ignition occurs downwards against the primary air flow. The volatile matter filters through the bed and is completely burnt. The combustion rate is high. The light ash contents and combustion gases fly away to the atmosphere along with primary air. Heavier ash content comes down over the grate and ultimately falls into ash pit.

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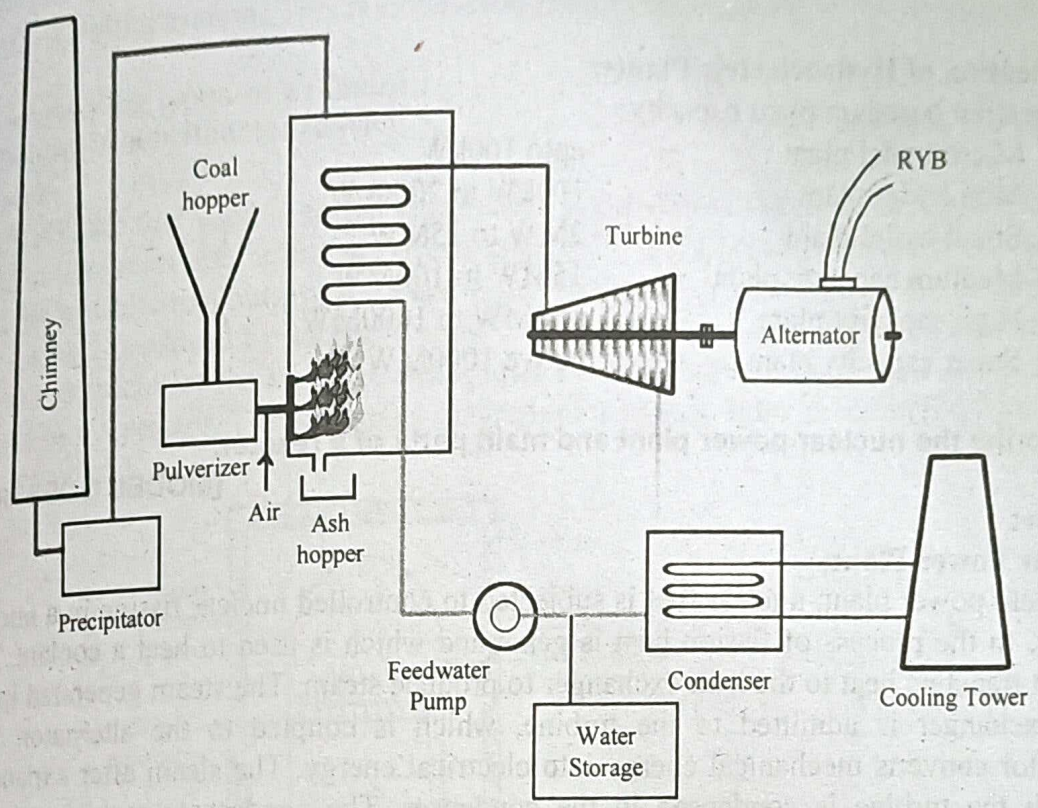
23. Give Lay out of Coal fired power plant. **[MODEL QUESTION]**

Answer:



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Long Answer Type Questions

1. Describe the hydroelectric power plants and its classification.

[MODEL QUESTION]

Answer:

Hydroelectric Power Plants:

In a hydroelectric power plant stored energy in water is converted into electrical energy by the use of water turbine coupled with an alternator. The turbine converts the potential energy of water into mechanical energy which drives the alternator. The cost of generation per kWh is lower than the energy generated at thermal power stations or combined cycle gas turbine. Hydropower uses a renewable source of energy where fossil fuels are finite in nature and, therefore, need to be conserved in the long term interest of the country. This type of project do not require any feed stock, unlike thermal power projects for which coal has to be transported to a long distance from coal mines to thermal plant sites. While the life of a hydro plant is very long of the order of 35 - 40 years and its efficiency does not reduce much with age, the generation of power is dependent upon the availability of water in its reservoir. Since more than 70% of the annual run-off in India takes place during 3 - 4 monsoon months, it is necessary to build suitable storage reservoir schemes so as to store water during monsoon period for utilization in non-monsoon months. While selecting the site for hydroelectric power

station, it is the prime consideration that there must be large quantity of availability of water.

Classification of Hydroelectric Plants:

Classification based on plant capacity:

(a) Micro hydel plant → upto 100kW
(b) Mini hydel plant → 100kW to 2000kW
(c) Small hydel plant → 2MW to 15MW
(d) Medium capacity plant → 15MW to 100MW
(e) High capacity plant → 100MW to 1000MW
(f) Super capacity plant → above 1000MW

2. Describe the nuclear power plant and main parts of a reactor.

[MODEL QUESTION]

Answer:

Nuclear Power Plant:

In nuclear power plant, nuclear fuel is subjected to controlled nuclear fission in a nuclear reactor. In the process of fission heat is generated which is used to heat a coolant. The coolant transfers heat to the heat exchanger to produce steam. The steam generated in the heat exchanger is admitted to the turbine, which is coupled to the alternator. The alternator converts mechanical energy into electrical energy. The steam after expansion through the turbine is condensed in the condenser. The condensate pump sends the condensate back to the heat exchanger thus forming a closed-feed system. The reactor and the heat exchanger are equivalent to the furnace and the boiler in a conventional coal fired steam power plant.

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Main Parts of a Reactor:

(a) **Reactor core:** It consists of a number of fuel rods made of fissile material.
(b) **Moderator:** This material in the reactor core is used to moderate or reduce the neutron speed to a value that increases the probability of fission occurring.
(c) **Reflector:** This completely surrenders the reactor within the thermal shielding arrangement and helps to bounce escaping neutrons back into the core. This conserves the nuclear fuel, as the low speed neutrons thus returned are useful in continuing the chain reaction.
(d) **Shielding:** It helps in giving protection to the personnel from the deadly α and β particle radiations and γ rays as well as neutrons given off by the process of fission within reactor. Concrete is found to be the most commonly used shielding material.
(e) **Reactor control:** This is effected by inserting neutron-absorbing materials to keep the chain reaction at a desired level. Cadmium and boron are the most commonly used materials. A reactor has three different types of control rods:-
   (i) Regulating rod for rapid fine adjustment.
   (ii) Skim rod for occasional coarse adjustment.

(iii) Safety rods for scramming, or shutting down the reactor quickly in case of an earthquake, excessive power generation etc.

(f) **Cooling system:** This removes heat from the core produced by nuclear reaction.

3. Describe the types of a reactor

(a) Boiling Water Reactor (BWR): **[MODEL QUESTION]**

Answer:

In a BWR the fuel used is enriched uranium. Light water is used as both moderator and coolant. Uranium fuel elements are arranged in a particular lattice from inside the pressure vessel containing water. Feed water enters the reactor tank at the bottom and it absorbs heat produced by nuclear fission. The steam is generated in the reactor itself and leaves the reactor at the top. The steam after passing through the turbine and condenser returns to the reactor. The schematic diagram of a boiling water reactor (BWR) is shown below in Fig. 1.

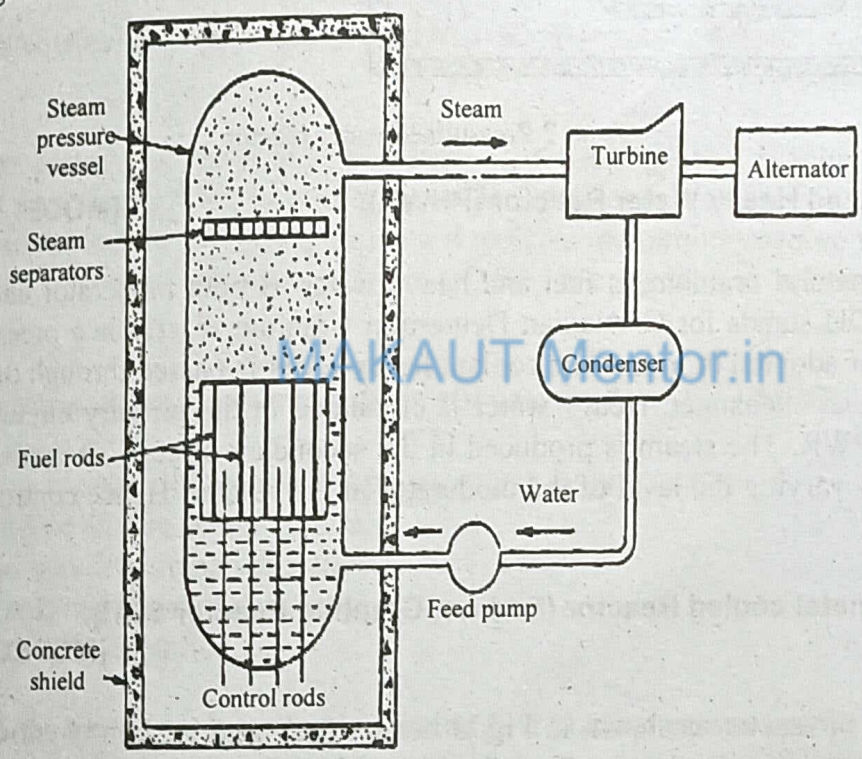

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Fig: 1 Boiling water reactor (BWR)

(b) Pressurized Water Reactor (PWR): **[MODEL QUESTION]**

Answer:

In PWR fuel used is enriched uranium clad with stainless steel or zirconium alloy. Light water under pressure is used as both moderator and coolant. The schematic diagram of pressurized water Reactor is shown in Fig. 2.

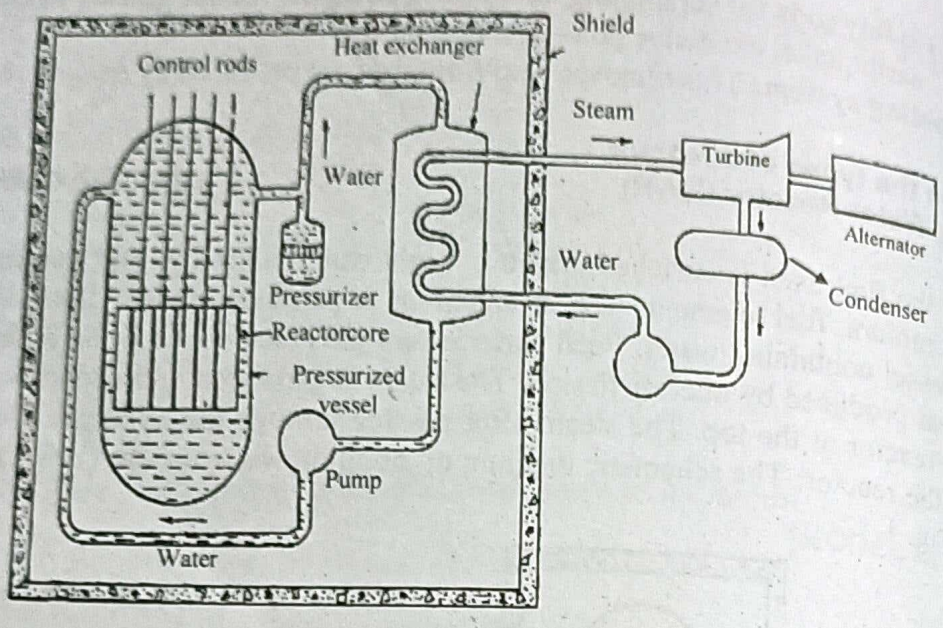

Fig: 2 Pressurised water reactor

(c) Pressurized Heavy Water Reactor (PHWR): **[MODEL QUESTION]**

Answer:

In PHWR, natural uranium as fuel and heavy water as both moderator and coolant are used. CANDU stands for CANadian Deuterium Uranium reactor is a pressurized heavy water reactor adopted in India. The coolant heavy water is passed through the pressurized fuel tubes heat exchanger. Heavy water is circulated in the primary circuit in the same way, as in PWR. The steam is produced in the secondary circuit. The power output can be varied by varying the level of the moderator in the reactor. Hence control rods are not required.

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(d) Liquid metal cooled Reactor (Sodium Graphite Reactor SGR):

[MODEL QUESTION]

Answer:

In this type of reactor as shown in Fig. 3 below, fuel used is slightly enriched uranium. Graphite is used as a moderator. Two liquid metal coolants are used. Liquid sodium (Na) is circulated through the reactor core and the intermediate heat exchanger (IHX). This is used to prevent the steam from becoming radioactive. In the intermediate heat exchanger the heat from the sodium is transferred to the sodium (NaK) liquid metal, which gives up its heat to the heat exchanger HX to generate steam. This steam is fed to the steam turbine.

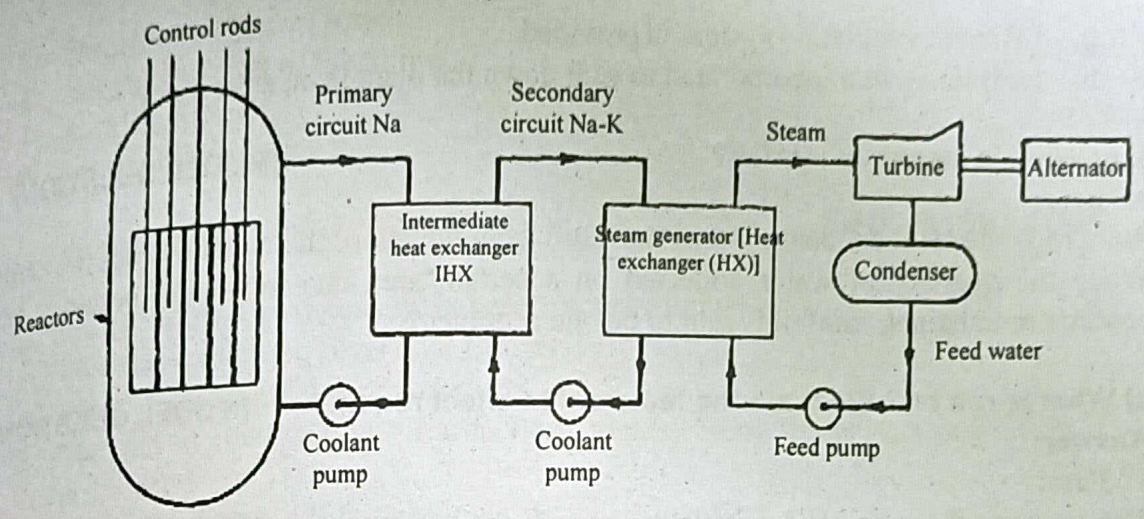

Fig: 3 Schematic diagram of a liquid metal cooled reactor

4. a) How electrical energy is generated in a nuclear power plant?
[MODEL QUESTION]

Answer:
In a nuclear power station, heat is produced by the energy that is released during the splitting of the nucleus. This heat energy inside the reactor is utilized to produce steam, either directly or indirectly, the steam is used to drive the turbine coupled to an electrical generator. In this way, the energy locked inside the nucleus is released to produce electricity.

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b) Mention a few atomic power plants in our country? **[MODEL QUESTION]**

Answer:
The following are some of the nuclear power plants in our country:

a. Tarapore atomic power station.
b. Rajasthan atomic power station.
c. Kalpakkam atomic power station.
d. Narora power station.

c) What are the safety features incorporated in a nuclear power plant?
[MODEL QUESTION]

Answer:
The following safety features are there in a nuclear power plant:

a. Fuel cladding is of highest quantity tubing and extensively tested.
b. Coolant circuit is tested to be leak proof.
c. The concrete vaults around the reactor and its coolant circuits are of a massive double walled system.
d. The reactor is separately enclosed by a steel shell.
e. The exhaust gases are continuously monitored for radioactivity and are let into the atmosphere from a tall stack (100m height).
f. Electronic instruments and radiation detectors are there to measure and detect radiation levels inside and outside the reactor plant.

g. Efficient ventilation system is provided.
h. Failsafe system incorporated to shut down the plant in an emergency.

5. a) What is meant by rainfall? **[MODEL QUESTION]**

Answer:

Rainfall is the total condensation of moisture from the atmosphere that reaches the earth. When the quantity of water collected on a certain area due to rainfall becomes one centimetre in height, rainfall is said to be one centimetre.

b) What is run off? What are the factors that affect run off? **[MODEL QUESTION]**

Answer:

1st Part:

The portion of the rainfall that flows through the catchment area on the surface of the earth is known as run off. The unit of run off is cum/sec.

2nd Part:

The following factors affect run off:

a. Rainfall pattern,
b. Character of the catchment area,
c. Shape and size of the catchment area,
d. Vegetation,
e. Geology of the area,
f. Weather conditions.

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c) What is a hydrograph? What is flow duration curve? What is a mass curve? **[MODEL QUESTION]**

Answer:

1st Part:

The hydrograph is a graph showing discharge (i.e., run off) of flowing water with respect to time, for a specified period.

2nd Part:

The flow duration curve is made with magnitudes of run off as ordinates against corresponding percents of time as abscissa.

3rd Part:

The mass curve is the graph of the cumulative values of the water quantity (run off) against time.

6. a) How the hydraulic turbines are classified? **[MODEL QUESTION]**

Answer:

The hydraulic turbines are classified according to the following features.

1. Head and quantity of water available.
2. Nature of working on the blade.

3. Direction of flow of water.
4. Axis of the shaft of the turbine.
5. Specific speed.
6. Name of the originator.

b) How are dams classified? **[MODEL QUESTION]**

Answer:

Dams can be classified in various ways based on the following:

1. Function – Storage, Diversion, Buttress.
2. Shape – Trapezoidal, Arch, Buttress.
3. Material of construction – Earth, Rock pieces, Stone masonry, Concrete, RCC, and Timber.
4. Hydraulic design – Non-overflow type, Overflow type.

c) What are the main parameters of water on which the magnitude of hydropower depends? **[MODEL QUESTION]**

Answer:

The magnitude of the hydropower depends on (1) flow or discharge and (2) height of fall of water or head.

d) What is catchment area? **[MODEL QUESTION]**

Answer:

The catchment area of drainage area is the whole area which collects rain water and drains the same into a river or stream at any particular point in its course.

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7. a) What is a reflector in a reactor? **[MODEL QUESTION]**

Answer:

In a reactor, some of the neutrons may escape completely and hence make no contribution to the continuing chain reaction. This leakage loss is reduced by surrounding the reactor core by a reflector. Many neutrons leaving the ore encounter scattering collisions in the reflector and are directed back in the core. These returned neutrons may cause fissions. Thus, an assembly is surrounded by a reflector.

b) How does a pressurized water reactor power plant work? **[MODEL QUESTION]**

Answer:

The pressurized water reactor power plant is a double loop cooling system unit. The coolant (water) in the primary circuit gets heated by absorbing the heat energy liberated in the reactor core by fission process. This energy is given away by the coolant in the heat exchanger to generate steam. This steam is used to drive a turbine coupled to an electrical generator.

c) How does a boiling water reactor power plant work? **[MODEL QUESTION]**

Answer:
The boiling water reactor power plant is also called direct cycle system. In this power plant, the steam is generated in the reactor itself instead of in a separate steam generator (heat exchanger). This steam is used to drive a turbine coupled to an electrical generator.

d) What is moderator in a reactor? **[MODEL QUESTION]**
Answer:
The moderator in a nuclear reactor slows down or moderates the fast fission neutrons travelling at about 4200 km/sec to about 1.5 km/sec, before subsequent fission occurs. The most usual moderators are carbon. Beryllium or beryllium oxide, heavy water (D_2O) and ordinary water (H_2O).

8. a) What is dam? **[MODEL QUESTION]**
Answer:
Dam is an impervious (or fairly impervious) structure erected across a stream or a river. The dam holds up water on one side of it upto a certain limiting level. It creates a head (of water) on the power plant.

b) What are the usual types of dams? **[MODEL QUESTION]**
Answer:
There are two types of dams:

1. Rigid dams:
   a. Timber dam
   b. Steel dam
   c. Masonry dam
2. Non-rigid dams
   a. Earth dam
   b. Rockfill dam.

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c) What are the three major classes of masonry dams? **[MODEL QUESTION]**
Answer:
The masonry dams are of three major classes:

1. Solid gravity dam is solid throughout its length.
2. Hollow buttress reinforced concrete dam.
3. Arched dam is constructed in a valley, where the width of the valley is narrow compared with the height. This is a curved dam.

9. a) What is storage plant? What is run off river plant? **[MODEL QUESTION]**
Answer:
1st Part:
The storage plants have reservoirs of fairly large size. The usually keep sufficient water to carry over from wet season to dry season and sometimes from one year to another. These plants can be operated both as peak and base load plants.

2nd Plant:
The run off river plant utilizes the flow of water as it runs through the river. It has no storage constructed. Run off river plants are normally base load plants.

b) What is low head plant? What is a high head plant? [MODEL QUESTION]

Answer:
1st Part:
When the head of water available is less than 30 metres, the plant is known as a low head plant. Low head plants use Francis, propeller or Kaplan type turbines.

2nd Part:
When the water head available for power generation exceeds 100 metres, the plant is known as a high head plant. Francis turbine is used upto 300 metres and beyond that head Pelton wheel is used.

c) What is a base load plant? What is peak load plant? [MODEL QUESTION]

Answer:
1st Part:
The base load plant takes care of the base load portion of the load curve. The load on this plant is more or less constant throughout its operation. The load factor of the base load plant is considerably high. Base load plants are generally larger in capacity.

2nd Part:
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The peak load plant takes care of peak loads on the load curve. It operates for short duration when the load becomes greater than the base load. Run off river plant with pondage, and pumped storage plants are usually used as peak load plants. The load factor of the peak load plants is considerably low compared to that of the base load plants.

10. What are the factors to be considered for site selection of [MODEL QUESTION]
a) Nuclear Power Plant
b) Hydroelectric Power Plant

Answer:
a) The factors to be considered for the site selection of nuclear power plants are:
i) Availability of water
ii) Disposal of waste
iii) Distance from populated area
iv) Transportation facilities.

From the above-mentioned factors it becomes apparent that ideal choice for a nuclear power plant would be near sea or river and away from thickly populated areas.

b) The following factors should be taken into account while selecting the site for a hydroelectric power station:
i) Availability of water
ii) Storage of water

iii) Cost and type of land
iv) Transportation facilities.

It is clear from the above-mentioned factors that ideal choice of site for such a plant is near a river in hilly areas where dam can be conveniently built and large reservoirs can be obtained.

11. Write short notes on any *three* of the following: **[MODEL QUESTION]**

a) Storage and Pondage
b) Fast breeder reactor
c) Surge tank
d) Draft tube
e) Nuclear reactor
f) Fertile materials and Fissile materials
g) Nuclear fuels

Answer:

a) Storage: Storage for water must be provided at the power house site, by constructing a dam when a major portion of the natural water flow is to be used. The water can be stored during off peak periods and this stored water can be used during peak periods.

Pondage: When the power station is away from the main storage, small storage called pondage is usually provided near the power house.

b) In a fast breeder reactor, the chain reaction is sustained primarily by fast moving neutrons rather than by thermal neutrons as in a conventional reactor. These reactors contain little or no moderator. The best fuel for fast breeder reactor is found to be plutonium.

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c) A surge tank is a small (vertical) reservoir into which the water from the closed conduit flows in or flows out to reduce the pressure swings. In this way the pressure swings are not transmitted to the closed conduit. The surge tank prevents damage to the conduit due to water hammer that occurs when the water supply to the turbine is stopped suddenly.

d) The draft tube allows the turbine to be set above the tailrace to facilitate inspection and maintenance. By diffuser action (gradual enlargement in section) regains the major portion of the kinetic energy or velocity head at the runner outlet. By this way the draft tube reduces the exit loss.

e) A reactor is an assembly in which the chain reaction is kept going at a steady controlled rate so that heat will be produced continuously. For this to happen, the number as well as the speed of the neutrons will have to be controlled.

f) Uranium 235, plutonium 239 and uranium 233 which can be more easily split by bombardment with neutrons are called fissile materials. Uranium 238 and uranium 232

are called fertile materials. These can be converted inside a nuclear reactor into fissile materials.

g) Nuclear fuels of most interest are uranium and plutonium.
Natural uranium consists of two isotopes, namely, uranium 235 (U^{235}) and uranium 238 (U^{238}) in the ratio of 1:139. The less abundant isotope uranium 235 can be more easily split by bombardment with neutrons than uranium 238.
It is found that plutonium 239 and uranium 233 (the former obtained from uranium 238 and the latter obtained from uranium 232, both by absorption of neutrons) are also capable of being easily split by neutrons and thus enormous amount of energy can be released.
Uranium 235, plutonium 239 and uranium 233 are, therefore, called **fissile materials**. These are used as nuclear fuels for generating power.
On the other hand, uranium 238 and uranium 232 are called **fertile materials**. These can be converted inside a nuclear reactor into fissile materials.
Enriched uranium, which is nothing but the natural uranium in which the concentration of the isotope uranium 235 has been increased, is also used as a fuel in nuclear power plants.
Our country possesses one of the largest reserves of thorium. Though uranium is also found, the present known resource of this fuel is very much limited. Thus, in the long run, the nuclear power programme of our country has to depend on the huge stocks of thorium. A vast resource of thorium is located in the mineral sands on the south west coast of our country. Attempts are being made to get the fuel from these mineral sands.

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INDIAN ELECTRICITY RULE

Short Answer Type Questions

1. Discuss main features of Indian Electricity rule – 1956. **[WBUT 2009, 2015]**

Answer:

The main features of Indian Electricity rule - 1956 implies the need to maintain high standards of carrying out electrical installation work etc. right from generating station to consumer premises and then to appliances and complying with the certain requirements, regulations and code of practice as laid down in Indian Electricity Rule (IER) in our country. Some of the major rules are given:

Rule 30:	Service line and apparatus on consumer's premises.
Rule 31:	Cut out consumer's premises
Rule 32:	Identification earthed and earthed neutral conductor and position of switches and cut outs there in.
Rule 33:	Earthed terminal on consumer's premises.
Rule 34:	Accessibility of bare conductors.
Rule 35:	Caution notices.
Rule 36:	Handling of electric supply line apparatus.
Rule 37:	Supply of vehicles cranes etc.
Rule 38:	Cables for portable and transportable apparatus
Rule 39:	Cables protected by bituminous materials.
Rule 40:	Street boxes.
Rule 45:	Precautions to be adopted by consumer's owners electrical contractor, electrical workmen and supplier's
Rule 46:	Periodical inspection and testing of consumer's installation.
Rule 47:	Testing a consumer's installation.
Rule 48:	Precautions against leakage before connecting.
Rule 49:	Leakage on consumer's premises.
Rule 50:	Supply to consumers.
Rule 51:	Provisions applicable to medium high or extra high voltage installation.
Rule 57:	Meters, maximum demand indicators and other apparatus on consumer's premises.
Rule 61:	Connecting with earth.
Rule 64:	Use of energy at high and extra high voltage.
Rule 68:	General conditions as to transformation and control of energy.
Rule 71:	Additional provisions for supply to high voltage luminous tube sign installation.

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OVERHEAD TRANSMISSION LINE

Multiple Choice Type Questions

1. Skin effect in a conduction becomes more pronounced [WBUT 2006, 2007]
   a) at higher frequency
   b) at lower frequency
   c) at d.c.
   d) none of these

Answer: (a)

2. The function of steel wire in an ACSR conductor is to [WBUT 2007, 2018]
   a) compensate skin effect
   b) provide additional mechanical strength
   c) reduce inductance
   d) none of these

Answer: (b)

3. Transposition of lines is done to [WBUT 2007, 2009, 2010, 2016, 2018]
   a) reduce line loss
   b) reduce skin effect
   c) balance the line voltage drop
   d) reduce corona

Answer: (c)

4. Use of bundle conductors in EHV transmission system provides [WBUT 2008, 2010, 2013, 2016]
   a) Increased line reactance
   b) Decreased capacitance
   c) Reduced voltage gradient
   d) Increased corona loss

Answer: (c)

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5. For a stranded conductor, the ratio of GMR to actual radius is [WBUT 2008, 2016]
   a) equal to 1
   b) greater than 1
   c) equal to 0.7788
   d) less than 0.7788

Answer: (d)

6. In a transmission line having negligible resistance, the surge impedance is [WBUT 2009, 2013]
   a) $\sqrt{LC}$
   b) $\sqrt{C/L}$
   c) $\sqrt{\frac{1}{LC}}$
   d) $\sqrt{L/C}$

Answer: (d)

7. The presence of earth in case of overhead lines [WBUT 2010, 2016, 2019]
   a) increases the capacitance
   b) increases the inductance
   c) decreases the capacitance
   d) decreases the inductance

Answer: (a)

8. The surge impedance of a transmission line is [WBUT 2010]
   a) $\sqrt{LC}$
   b) $\sqrt{C/L}$
   c) $\sqrt{L/C}$
   d) $1\sqrt{LC}$

Answer: (c)

9. ACSR in an overhead transmission line stands for [WBUT 2011]
   a) Alloy Copper Steel Reinforced b) Aluminium Conductor Steel Reinforced
   c) All Cooper Steel Reinforced d) None of these

Answer: (b)

10. The function of earth wire in a transmission line is to [WBUT 2011, 2017]
   a) prevent earth fault
   b) provide a safety measure for any high flying objects
   c) provide a shield to the phase conductors from direct lightning stroke
   d) provide mechanical strength to the tower

Answer: (c)

11. Stranded conductors are used to [WBUT 2011, 2013]
   a) reduce transmission loss b) increase mechanical flexibility
   c) reduce skin effect d) increase stability of the system

Answer: (b)

12. The a.c. resistance of a conductor is greater than its d.c. value due to [WBUT 2011, 2016]
   a) skin effect only b) proximity effect only
   c) Ferranti effect only d) both (a) and (b)

Answer: (d)

13. ACSR conductor stands for [WBUT 2012]
   a) All Conductor Steel Reinforced
   b) Aluminum Conductor Steel Reinforced
   c) Aluminum Copper Steel Reinforced
   d) All Copper Steel Reinforced Conductor

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Answer: (b)

14. The transmission efficiency of a line is [WBUT 2012, 2016]
   a) directly proportional to the load power factor
   b) inversely proportional to the load power factor
   c) does not depend on load power factor
   d) proportional to the square of load power factor

Answer: (b)

15. The surge impedance of 400 km long transmission line is 50 ohms. The surge impedance of 100 km of that line is [WBUT 2012]
   a) 20 Ω b) 12.5 Ω c) 50 Ω d) 100 Ω

Answer: (c)

16. The length of a short transmission line is up to about [WBUT 2013]
   a) 50 km b) 120 km c) 200 km d) 300 km

Answer: (a)

17. The volume of copper required for an overhead transmission line is inversely proportional to [WBUT 2013]
a) current b) voltage c) power factor d) both (b) & (c)
Answer: (d)

18. The self GMD method is used to evaluate [WBUT 2013]
a) inductance b) capacitance
c) both inductance and capacitance d) none of these
Answer: (a)

19. Bundle conductors are used to [WBUT 2014]
a) reduce inductance of the line
b) reduce both inductance and capacitance
c) reduce corona loss
d) reduce corona loss and line inductance
Answer: (d)

20. Constant power locus of a transmission line at a particular sending end and receiving end voltage is [WBUT 2014]
a) a straight line b) a circle c) a parabola d) an ellipse
Answer: (a)

21. The presence of ground causes the line capacitance to [WBUT 2014]
a) increase by about 12% b) decrease by about 12%
c) increase by about 0.2% d) none of these
Answer: (c)

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22. At the time of transposition of three phase line, the equivalent equilateral spacing between the conductors is [WBUT 2015]
a) $\sqrt[3]{d_1 d_2 d_3}$ b) $\sqrt{d_1 d_2 d_3}$ c) $d_1 d_2 d_3$ d) $\frac{1}{3}(d_1 d_2 d_3)$
Answer: (a)

23. The size of conductors of modern EHV lines is obtained based on [WBUT 2015]
a) voltage drop b) current density c) corona d) skin effect
Answer: (a)

24. The surge impedance of a 100 km long underground cable is 50Ω. The surge impedance of a 40 km long cable of similar type is [WBUT 2015]
a) 20Ω b) 50Ω c) 80Ω d) 125Ω
Answer: (b)

25. When the effective resistance of a conductor increases due to the presence of current carrying conductor nearby, then the effect is called [WBUT 2015]
a) skin effect b) proximity effect
c) Ferranti effect d) corona effect
Answer: (b)

26. The leakage resistance of a 50km long cable is 1MΩ. For a 100 km long cable, it will be [WBUT 2017]

a) 1MΩ b) 0.66MΩ c) 2MΩ d) 0.5MΩ

Answer: (a)

27. The surge impedance of a 400kV, 100km transmission line is 300Ω. For a 200km length the line surge impedance will be [WBUT 2018]

a) 300Ω b) 150Ω c) 600Ω d) 400Ω

Answer: (a)

Short Answer Type Questions

1. What is skin effect? How does in influence the resistance, inductance and capacitance of a conductor? [WBUT 2006]

OR,

Explain skin effect. On which factors does it depend? [WBUT 2010, 2014]

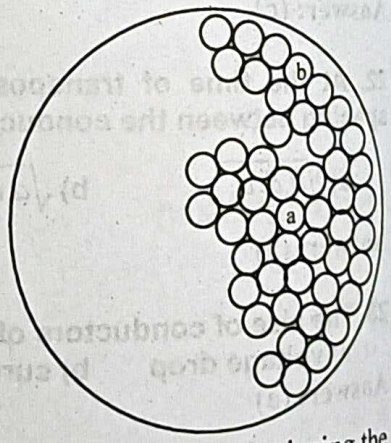
OR,

Define Skin effect. Why it is not happened in case of DC? [WBUT 2012]

Answer:

While the distribution of current through out the cross-section of a conductor is uniform when D.C is passed through it, it is non-uniform when A.C. flows through the conductor resulting higher current density at the surface compared at its center. This effect becomes more pronounced as frequency is increased and the phenomenon is called Skin effect.

Consider solid current carrying conductor of circular cross section. Now assume that the conductor consists of large number of small elements in parallel as shown in the figure.



Each small filament carries fraction of total current and generate its own magnetic field. But there is a difference in the flux set up by the inner and outer elements. The flux due to filament 'a' links with itself but not with any of the other filament. The flux due to an outer element 'b' links with all filaments up to 'b'. It then follows that the inductance of inner filament like 'a' is much more than that of the outer filament likes 'b'. Due to the higher inductive reactance of inner elements the current has a tendency to confine itself to the paths nearer to the surface of conductor thus reducing the effective cross sectional area of conductor. This phenomenon is called **skin effect**. Due to this non-uniform distribution current these will be more loss of power. Hence the skin effect results in increased effective resistance but decreases the effective internal reactance of the conductor. Skin effect will be more prominent for higher frequencies. The phenomenon is due to higher reactance of the inner elements in the conductor, with consequent flow of current in the outer surfaces of the conductor, thus reducing the effective area of cross – section. Due to this, losses will be more.

To account for increased losses due to non – uniform current distribution, it is usually to consider the 'effective resistance" (AC resistance) of a conductor and not its "ohmic resistance".

2. What is understood by 24/7 ACSR conductor? [WBUT 2010, 2014]

Answer:

A 24/7 A.C.S.R. means,

Nos of Steel Conductors in central ACSR → 7 nos.

Nos of Aluminium Conductors in outer surface → 24 Nos.

3. Why are transmission lines classified based on their length? Define regulation of a transmission line. [WBUT 2011]

Answer:

1st Part: The major importance of transmission line is to maintain particular voltage level at different points. So based on the transmission line distance power system divided into three parts, i.e.:

a) Short transmission
b) Medium transmission
c) Long transmission

Transmission lines are classified as short, medium and long. When the length of the line is less than about 80Km the effect of shunt capacitance and conductance is neglected and the line is designated as a short transmission line. For these lines the operating voltage is less than 20KV.

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For medium transmission lines the length of the line is in between 80km - 240km and the operating line voltage will be in between 21KV-100KV.In this case the shunt capacitance can be assumed to be lumped at the middle of the line or half of the shunt capacitance may be considered to be lumped each end of the line. The two representations of medium length lines are termed as nominal-T and nominal-π respectively.

Lines more than 240Km long and line voltage above 100KV require calculations in terms of distributed parameters. Such lines are known as long transmission lines. This classification on the basis of length is more or less arbitrary and the real criterion is the degree of accuracy required.

2nd Part:

Voltage regulation of a transmission line is defined as the rise in voltage at the receiving end, expressed as percentage of full load voltage, when full load at a specified power factor is thrown off, i.e.

$$\text{percent regulation} = \frac{|V_{RO}| - |V_{RL}|}{|V_{RL}|}$$

where,

$|V_{RO}|$ = magnitude of no load receiving end voltage

$|V_{RL}|$ = magnitude of full load receiving end voltage

4. What is surge impedance? What do you mean by surge impedance loading? **[WBUT 2014]**

Answer:

The characteristic impedance or surge impedance (usually written Z_0) of a uniform transmission line is the ratio of the amplitudes of voltage and current of a single wave propagating along the line; that is, a wave travelling in one direction in the absence of reflections in the other direction. Characteristic impedance is determined by the geometry and materials of the transmission line and, for a uniform line, is not dependent on its length. The SI unit of characteristic impedance is the ohm.

Surge impedance loading

In electric power transmission, the characteristic impedance of a transmission line is expressed in terms of the surge impedance loading (SIL), or natural loading, being the power loading at which reactive power is neither produced nor absorbed:

$$SIL = \frac{V_{LL}^2}{Z_0}$$

In which V_{LL} is the line-to-line voltage in volts.

Loaded below its SIL, a line supplies reactive power to the system, tending to raise system voltages. Above it, the line absorbs reactive power, tending to depress the voltage.

5. Derive an expression of inductance for single phase two wire line. **[WBUT 2015, 2017, 2018]**

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Answer:

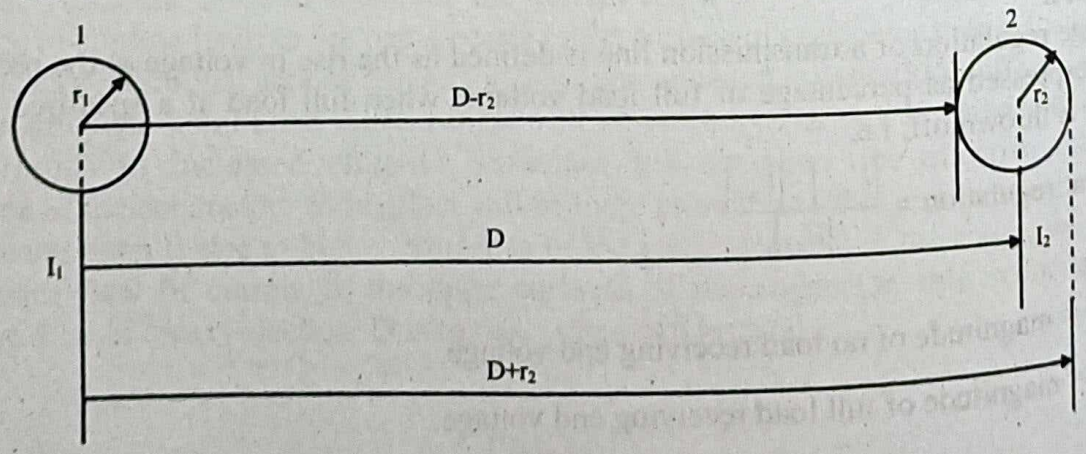
Let conductors carry currents I_1 and I_2 and for Single phase line, $I_1 = -I_2$

Assumptions:

a) Relative permeability of earth is about the same as that of air.

b) Electrical conductivity of earth is relatively small, i.e., the earth's effect on magnetic field geometry is insignificant.

c) Since $D >> r_1$ and $D >> r_2$ the flux from $(D-r_2)$ to the centre of conductor 2 links all the current I_1 and the flux from the centre of conductor 2 to $(D+r_2)$ links Zero current.



Hence flux linkages of the circuit due to current I_1 are

$$\lambda_1 = 2\times10^{-7}\ I\ \ell n\frac{D}{r_1'}\ wbT/m$$

Hence Inductance of conductor due to current I_1 only

$$L_1 = 2\times10^{-7}\ \ell n\frac{D}{r_2'}\ H/m$$

Similarly,

$$L_2 = 2\times10^{-7}\ \ell n\frac{D}{r_2'}\ H/m$$

Total inductance is

$$L = L_1 + L_2 = 4\times10^{-7}\ \ell n\frac{D}{\sqrt{r_1' r_2'}}\ H/m$$

If $r_1 = r_2 = r$

Then $r_1' = r_2' = r'$

Hence $L = 4\times10^{-7}\ \ell n\frac{D}{r'}\ H/m$

6. A 3-phase, 50Hz line consists of three conductors, each of diameter 21mm. the spacing between the conductors are 3m, 5m & 3.6m. Find the inductance & inductive reactances per phase per km of the line. [WBUT 2016, 2018]

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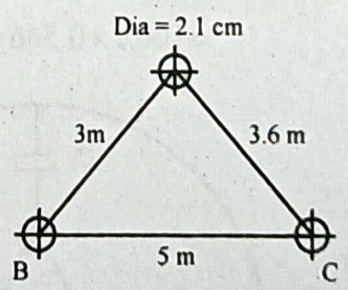
Answer:

Radius of conductor $= \frac{2.1}{2} = 1.05\,\text{cm} = 1.05\times10^{-2}\,\text{m}$

$r' = 0.7788\times r = (0.7788)(1.05\times10^{-2}) = 8.1774\times10^{-3}\,\text{m}$

$D_{AB} = 3m \qquad D_{BC} = 5m \qquad D_{CA} = 3.6m$

$D_{eq} = \sqrt[3]{D_{AB}D_{BC}D_{CA}} = \sqrt[3]{3\times5\times3.6} = 3.77\,m$



Inductance per phase $L_A = 2\times10^{-7}\ \ln\left[\frac{D_{eq}}{r'}\right]$ H/m

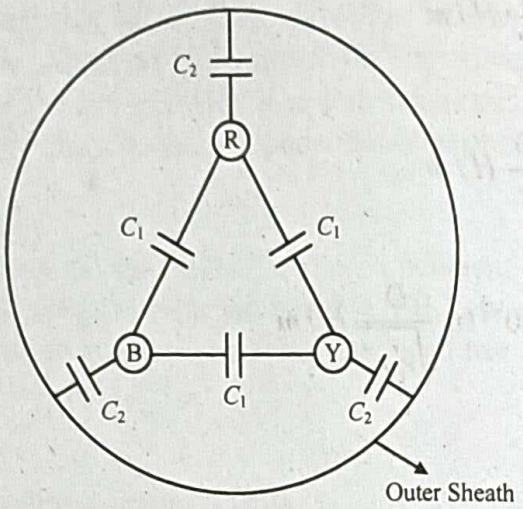
$$= 2\times10^{-4}\ \ln\left[\frac{D_{eq}}{r'}\right]\text{H/km} = 2\times10^{-4}\ \ln\left[\frac{3.77}{8.17774\times10^{-3}}\right]$$

$$= 2\times10^{-4}\ \ln\left[\frac{3.77\times10^{3}}{8.17774}\right] = 2\times10^{-4}\ \ln\left[\frac{3.77}{8.17774}\right]$$

$$= 2\times10^{-4}\ \ln(461.02) = 2\times10^{-4}\times1.813 = 0.362\text{mH/km}$$

$X = 2\pi fL = 2\pi\times50\times0.362 = 113.668\,\Omega/\text{km}$

7. Consider a three-core, three-phase, 50Hz, 11kV cable whose conductors are denoted as *R*, *Y* and *B* in the figure. The inter-phase capacitance (C_1) between each line conductor is 0.2μF and the capacitance (C_2) between core and sheath is 0.4μF. Determine the per-phase charging current. **[WBUT 2017]**



Answer:

Effective capacitance in this case:

$$C = \frac{9C_2 - C_1}{6} \qquad \text{Here,} \quad C_1 = 0.2\ \mu\text{F},\ C_2 = 0.4\ \mu\text{F}$$

$$= \frac{9 \times 0.4 - 0.2}{6} = \frac{3.6 - 0.2}{6} = \frac{3.4}{6} = 0.566\ \mu\text{F}$$

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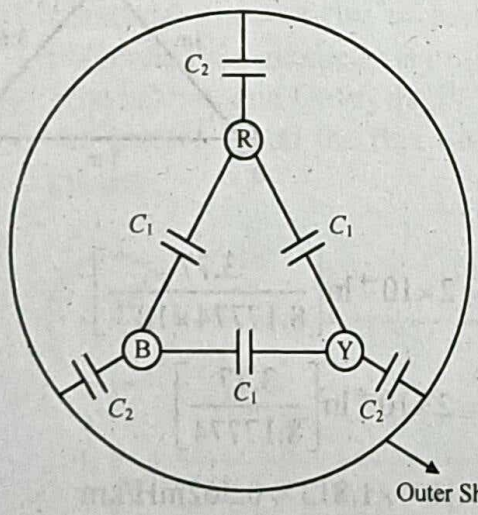
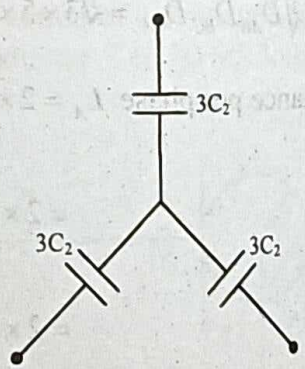
Per phase charging current

$$= \omega CV = 2\pi fCV = 2\pi \times 50 \times 0.566 \times 10^{-6} \times 11 \times 10^3$$

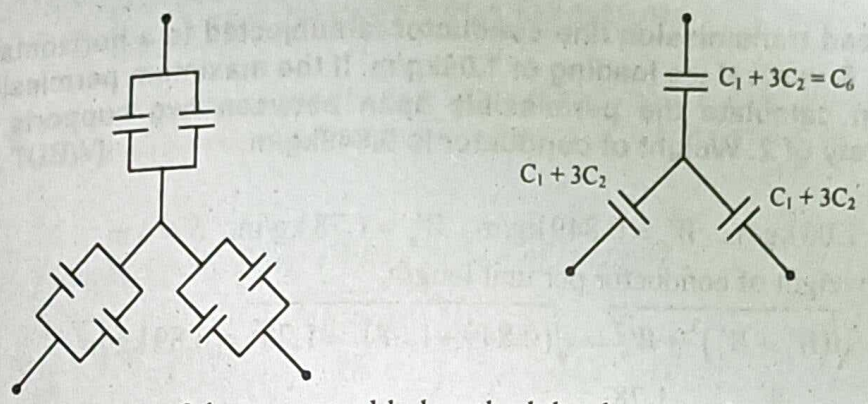
$$= 100\pi \times 0.566 \times 10^{-3} \times 11 = 1.954 \text{ Amps}$$



Capacitance of a three core cable



Star equivalent of delta



i) Equivalent capacitance of three core cable bunched the three conductors and the sheath.
Let, this be C_n given by, $C_n = 3C_1 = 3 \times 0.2\ \mu F = 0.6\ \mu F$

ii) Connect any two cores to the sheath and measure the capacitance between the remaining conductor and the sheath.
Let, this be C_y given by, $C_y = C_1 + 2C_2 = (0.2 + 2 \times 0.4)\ \mu F = 1\ \mu F$

So, per phase capacitance,

$$C_0 = C_1 + 3C_2 = (0.2 + 3 \times 0.4)\ \mu F = (0.2 + 1.2)\ \mu F$$

$$\Rightarrow \quad C_0 = 1.4\ \mu F$$

So, per phase charging current,

$$I_C = 2\pi f C_0 V = 2\pi \times 50 \times 1.4 \times 11 \times 10^3 \times 10^{-6} = 4.8\ A \quad \textbf{(Ans.)}$$

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8. The *A, B, C, D* constants of a 220kV line are: $A = D = 0.94\angle 10$, $B = 130\angle 73°$, $C = 0.001\angle 90°$. If the sending end voltage of the line for a given load delivered at nominal voltage is 240kV, what is the percentage voltage regulation of the line?

[WBUT 2017]

Answer:

$$A = D = 0.94\angle 10°,\ B = 130\angle 73°,\ C = 0.001\angle 90°$$

$$V_s = 240\ kV$$

$$V_s = AV_R + BI_R$$

$$I_s = CV_R + DI_R$$

Now, $A = \left.\dfrac{V_s}{V_R}\right|_{I_R=0} \Rightarrow V_R = \dfrac{240 \times 10^3}{0.94\angle 10°} = 255.32\angle -10°\ kV$

$$\text{Percentage voltage regulation} = \frac{\dfrac{V_s}{A - V_R}}{V_R} \times 100\% = \frac{\dfrac{240}{0.94\angle 10° - 255.32\angle -10°}}{255.32\angle -10°} \times 100\%$$

$$= \frac{\dfrac{240}{253.48\angle -10°}}{255.32\angle -10°} \times 100\% = 0.37\% \quad \textbf{(Ans.)}$$

9. An overhead transmission line conductor is subjected to a horizontal wind load of 1.78 kg/m & vertical ice loading of 1.08kg/m. If the maximum permissible sag is 6 metres, then calculate the permissible span between two supports allowing a factor of safety of 2. Weight of conductor is 0.849kg/m. **[WBUT 2017, 2019]**

Answer:

$$W_i = 1.08\,\text{kg/m},\ W_c = 0.849\,\text{kg/m},\ W_w = 1.78\,\text{kg/m},\ S = 6\,\text{m}$$

So, the total weight of conductor per unit length,

$$W_t = \sqrt{(W_c + W_i)^2 + W_w^2} = \sqrt{(0.849 + 1.08)^2 + 1.78^2} = 6.89\,\text{kg/m}$$

Now, $\tan\theta = \dfrac{W_w}{W_c + W_i} = \dfrac{1.78}{1.929} \Rightarrow \theta = 42.7°$

Now, Sag, $S = \dfrac{W_t L^2}{8T}$ [L = span between two supports]

Given, $S = 6$ m, factor of safety = 2

Ultimate safety = 8060 kgf

Maximum working tension, $T = \dfrac{8060}{2} = 4030$ kgf

So, $6 = \dfrac{6.89 \times L^2}{8 \times 4030}$

$\Rightarrow$ $L = 167.6$ m

Permissible span = 167.6 m **(Ans.)**

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10. A single phase load of 200kVA is delivered at 2500V over a transmission line having R = 1.4Ω, X = 0.8Ω. Calculate the current and voltage at the sending end when the power factor of the load is unity. **[WBUT 2018]**

Answer:

$R_R = 1.4\,\Omega \qquad V_R = 2500$ V

$X_R = 0.8\,\Omega \qquad P = 200$ kVA

$$I_S = I_R = \frac{200 \times 10^3}{2500}$$

$$Z_R = \sqrt{(1.4)^2 + (0.8)^2} = 1.612\,\Omega$$

$$\cos\phi_R = 1$$

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

$$= \sqrt{(2500 \times 1 + 80 \times 1.4)^2 + (80 \times 0.8)^2} = 2612.78\,\text{V}$$

11. Derive the expression of capacitance for single phase overhead line by considering the effect of earth. **[WBUT 2019]**

Answer:

Refer to Question No. 1 of Long Answer Type Questions.

Long Answer Type Questions

1. Derive the expression for capacitance for a single-phase over line considering the effect of earth. Hence deduce the capacitance without the effect of earth.
[WBUT 2008, 2014]

Answer:

Capacitance of Single Phase Line: (With Method of Images)

$$V_{ab} = \frac{I}{2\pi k} q \left[\ln\frac{D}{r} - q \ln\frac{r}{D} - q \ln\left(\frac{\sqrt{4h^2+D^2}}{2h}\right) + q \ln\left(\frac{2h}{\sqrt{4h^2+D^2}}\right)\right]$$

$$= \frac{q}{\pi k} \ln \frac{2hD}{r\left(4h^2+D^2\right)^{1/2}} \quad C_{ab} = \frac{\pi k}{\ln \dfrac{D}{r\left(1+D^2/4h^2\right)^{1/2}}} \text{ F/m (line to line)}$$

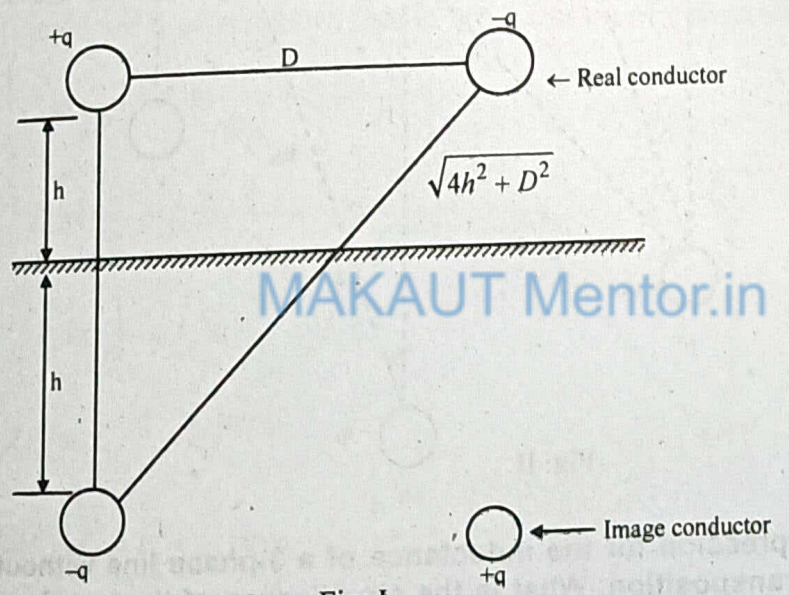

Fig: I

$$C_n = \frac{2\pi k}{\ln \dfrac{D}{r\left(1+D^2/4h^2\right)^{1/2}}} \text{ F/m to neutral}$$

The capacitance of single-phase line without considering the effect of earth is

$$C_n = \frac{2\pi k}{\ln \dfrac{D}{r}} \text{ F/m to neutral.}$$

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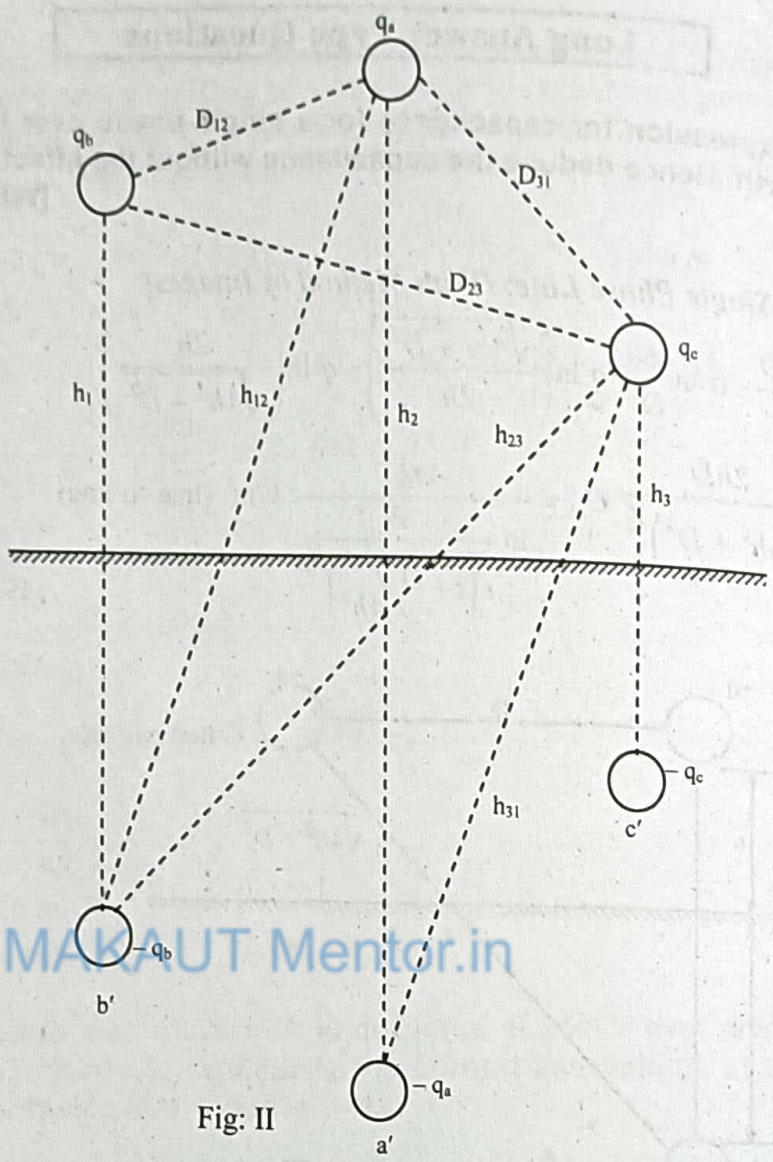

Fig: II

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2. Derive the expression for the inductance of a 3-phase line without considering the effect of a transposition. What is the significance of the imaginary term in the expression for inductance? Hence derive the expression for inductance for a completely transposed line. **[WBUT 2008]**

OR,

Derive the expression for the inductance of a 3-phase line. **[WBUT 2013]**

OR,

Derive the expression for inductance of a 3-phase completely transposed line. **[WBUT 2017]**

Answer:

Flux Linkages of Telephone line running parallel to power line:

According to the figure in which t_1 and t_2 are telephone line conductors and a, b, c are 3ϕ power line conductors.

When Power line not transposed

Flux linkages of telephone line conductors are

$$\lambda_{t1} = 2\times10^{-7}\left[I_a \ln\frac{1}{D_{a1}} + I_b \ln\frac{1}{D_{b1}} + I_c \ln\frac{1}{D_{c1}}\right]$$

$$\lambda_{t2} = 2\times10^{-7}\left[I_a \ln\frac{1}{D_{a2}} + I_b \ln\frac{1}{D_{b2}} + I_c \ln\frac{1}{D_{c2}}\right]$$

Net flux linkages of telephone line are

$$\lambda_t = \lambda_{t1} - \lambda_{t2}$$

$$= 2\times10^{-7}\left[I_a \ln\frac{D_{a2}}{D_{a1}} + I_b \ln\frac{D_{b2}}{D_{b1}} + I_c \ln\frac{D_{c2}}{D_{c1}}\right] wbT/m$$

The EMF induced in telephone line is

$$V_t = 2\pi f \lambda_t \text{ Volt/meter}$$

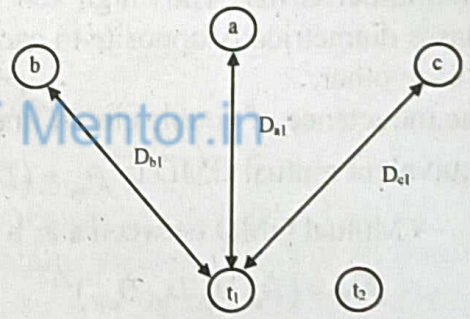
When Power Line Fully Transposed

Flux linkages of conductor t_1 of telephone line in three section of transposition cycle.

$$\lambda_{t1}[I] = 2\times10^{-7}\left[I_a \ln\frac{1}{D_{a1}} + I_b \ln\frac{1}{D_{b1}} + I_c \ln\frac{1}{D_{c1}}\right]$$

$$\lambda_{t1}[II] = 2\times10^{-7}\left[I_a \ln\frac{1}{D_{b1}} + I_b \ln\frac{1}{D_{c1}} + I_c \ln\frac{1}{D_{a1}}\right]$$

$$\lambda_{t1}[III] = 2\times10^{-7}\left[I_a \ln\frac{1}{D_{c1}} + I_b \ln\frac{1}{D_{a1}} + I_c \ln\frac{1}{D_{b1}}\right]$$



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$$\therefore \quad \lambda_{t1} = \frac{1}{3}\left[\lambda_{t1}^{[I]} + \lambda_{t1}^{[II]} + \lambda_{t1}^{[III]}\right]$$

$$= 2\times10^{-7}(I_a + I_b + I_c)\ln\frac{1}{(D_{a1}D_{b1}D_{c1})^{1/3}}$$

In the same way,

$$\lambda_{t2} = 2\times10^{-7}(I_a + I_b + I_c)\ln\frac{1}{(D_{a2}D_{b2}D_{c2})^{1/3}}$$

$$\therefore \quad \lambda_t = \lambda_{t1} - \lambda_{t2} = 2\times10^{-7}(I_a + I_b + I_c)\ln\frac{(D_{a2}D_{b2}D_{c2})^{1/3}}{(D_{a1}D_{b1}D_{c1})^{1/3}}$$

Again for balance power line, $I_a + I_b + I_c = 0$

i.e., $\lambda_t = 0$

Thus voltage induced in telephone line loop is zero over one transpositions cycle of power line.

Double Circuit Three Phase Lines:

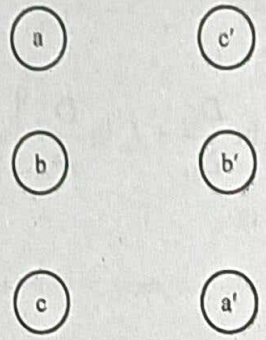
Advantages:

i) Increased reliability

ii) In case one of the circuits goes out of order, the other circuit continues supply.

iii) Total inductance of line is reduced.

iv) Stability of the power system is improved.



It is desirable to build the double circuit line so as to give as low inductance per phase as possible. In order to achieve this self GMD (Ds) should be high and mutual GMD (Dm) should be low, i.e., the individual conductors of a phase should be kept as far as possible (for high self GMD), while distance between phases be kept as low as permissible (for low mutual GMD. Thus high self GMD is obtained by placing the conductors of two phases diametrically opposite to each other and those of third phase horizontally opposite to each other.

The inductance of double circuit line is found by method of GMD as given under:

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Equivalent mutual GMD is $D_{eq} = (D_{ab} D_{bc} D_{ca})^{1/3}$

$D_{ab} \rightarrow$ Mutual GMD between a & b phase

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

$$D_{bc} = (D_{bc} D_{bc'} D_{b'c} D_{b'c'})^{1/4}$$

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

Again equivalent self GMD is

$$D_S = (D_{SA} D_{SB} D_{SC})^{1/3}$$

$$D_{SA} = \text{Self GMD of phase a}$$

$$= (D_{aa} D_{aa'} D_{a'a} D_{a'a'})^{1/4}$$

$$D_{SB} = (D_{bb} D_{bb'} D_{b'b} D_{b'b'})^{1/4}$$

$$D_{SC} = (D_{cc} D_{cc'} D_{c'c} D_{c'c'})^{1/4}$$

So, $$L = 2 \times 10^{-7} \ln \frac{D_{eq}}{D_S} \; H/m/ph$$

3. a) What do you mean by transposition? Why is it done? [WBUT 2010, 2014]

OR,

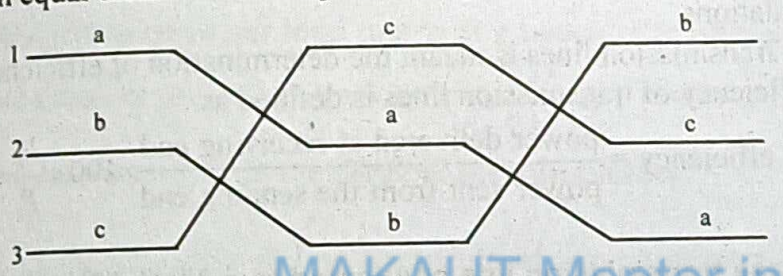
What is meant by "transposition of conductors"? What is the need of transposition of conductors of an overhead transmission line? [WBUT 2011]

b) Derive the expression for the inductance of a three phase transposed line. [WBUT 2010, 2014]

c) Determine the inductance of a 3-phase line operating at 50 Hz and the conductors are arranged in a horizontal plane with spacing such that $D_{31} = 4m$; $D_{12} = D_{23} = 2m$. The conductors are transposed and have a diameter of 2.5 cm. [WBUT 2010, 2014]

Answer:

a) If the distance between the three conductors of a 3-phase line is not same it is called as unsymmetrical spacing of conductors. Unsymmetrical spacing causes the flux linkages and inductances for each conductor to be different. This causes unbalanced receiving end voltages even when sending end voltages and line currents are balanced. Also there is a big problem in communication interference with adjacent communication line. These problems are positions of the conductors are exchanged with position of every other conductor over an equal distance. A complete transposition cycle is shown in figure.



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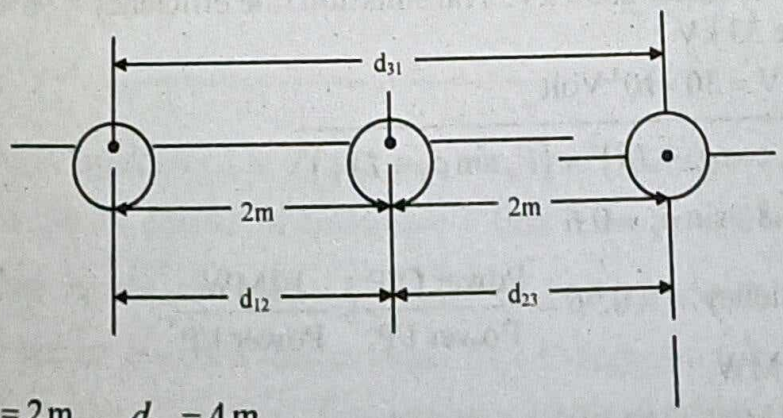
Due to practical difficulties the power lines are not transposed in regular intervals. But the exchanged of conductor positions is made at switching stations only. For all Practical purpose the asymmetry is neglected.

b) ***Refer to Question No. 2 of Long Answer Type Questions (only Transposed Line portion).***

c)



$$d_{12} = d_{23} = 2\,\text{m} \qquad d_{31} = 4\,\text{m}$$

$$\text{Radius of conductor} = \frac{2.5}{2} = 1.25\ \text{cm}$$

$$\text{GMR} = r' = 0.7788 \times 1.25 = 0.9735 \text{ cm}$$

For equivalent spacing

$$D_{eq} = \sqrt[3]{d_{12} \times d_{23} \times d_{31}} = \sqrt[3]{2 \times 2 \times 4} = 2.5198 \text{ m}$$

Inductance per phase per metre is

$$L = 2 \times 10^{-7} \ln\left(\frac{D_{eq}}{r'}\right) = 2 \times 10^{-7} \ln\left[\frac{2.5198}{0.9735 \times 10^{-2}}\right] = 2 \times 10^{-7} \times 5.5562 = 1.11 \mu\text{H/m}$$

$$L = 1.11 \times 10^{-6} \times 1000 \text{ H/m} = 1.11 \text{ mH/km}.$$

4. a) How is efficiency of a transmission line defined? **[WBUT 2011]**

Answer:

The transmission line performance is governed by its four parameters - series resistance and inductance, shunt capacitance and conductance. All these parameters are distributed over the length of the line. The insulation of a line is seldom perfect and leakage currents flow over the surface of insulators especially during bad weather. This leakage is simulated by shunt conductance. The shunt conductance is in parallel with the system capacitance. Generally the leakage currents are small and the shunt conductance is ignored in calculations.

Performance of transmission lines is meant the determination of efficiency and regulation of lines. The efficiency of transmission lines is defined as

$$\% \text{ transmission efficiency} = \frac{\text{power delivered at receiving end}}{\text{power sent from the sending end}} \times 100 = \frac{P_R}{P_S} \times 100$$

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b) A short 3-phase transmission line connected to a 33kV, 50Hz, generating station at the sending end is required to supply a load of 10 MW at 0.8 lagging power factor at 30 kV at the receiving end. If the minimum transmission efficiency is limited to 96%, determine the per phase values of resistance and inductance of the line. **[WBUT 2011]**

Answer:

3-phase transmission line connected to a 33 kV, 50 Hz system. Sending end load, 10 MW at 0.8 lagging power factor at 30 kV. Transmission line efficiency = 96%

Generated voltage 33 kV

$$V_R = 30 \text{ kV} = 30 \times 10^3 \text{ Volt}$$

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

$$\cos\phi_R = 0.8, \ \sin\phi_R = 0.6$$

$$\text{Transmission efficiency } \eta = 0.96 = \frac{\text{Power O/P}}{\text{Power I/P}} = \frac{10 \text{ MW}}{\text{Power I/P}}$$

Power I/P = 10.42 MW.

So total-loss $(10.42 \text{ MW} - 10 \text{ MW}) = 0.42 \text{ MW}$.

Load = 10 MW, so line current $I_L = \frac{P}{\sqrt{3}V_L} = \frac{10\times10^6}{\sqrt{3}\times30\times10^3} = 192.455\text{ A}$

Losses for resistance

So $3I^2R = 0.42\times10^6$

$\Rightarrow$ $3(192.455)^2 R = 0.42\times10^6$

$R = 3.779\Omega$.

So, X(reactance per phase) $\Rightarrow$ $\cos\phi = \frac{R}{Z}$

$\Rightarrow$ $\frac{R}{\sqrt{R^2+X^2}} = 0.8$

$\frac{3.779}{\sqrt{3.779^2+X^2}} = 0.8$

$\Rightarrow$ $4.723 = \sqrt{3.779^2+X^2}$

i.e., $X = 2.83\Omega$.

5. a) Show that the inductance per loop metre of a two-wire transmission line using solid round conductor is given by $L = 4\times10^{-7}\ln\left(\frac{D}{r'}\right)H$, where *D* is the distance between the conductors and r' is the GMR of the conductors. [WBUT 2011]

Answer:

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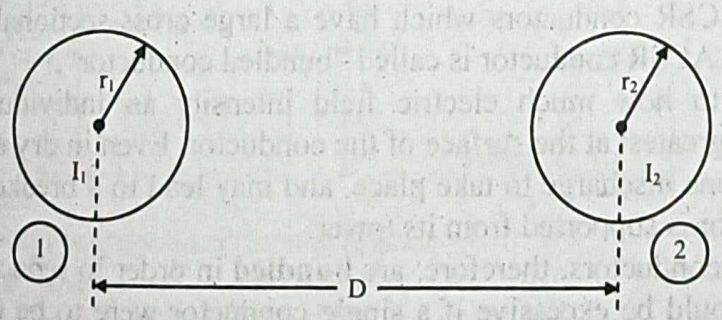
Consider a single phase transmission line consisting of two conductors of radius r_1 and r_2 at a distance of D as shown,



The current flowing in conductor 1 is I_1 and that of conductor 2 is $I_2(=-I_1)$.

Let us consider the flux of current of conductor 1 first. Flux beyond $(D+r_2)$ would be equal to zero as net current enclosed (I_1+I_2) will be zero. As r_2 is very small as compared to D, it can be assumed that external flux linkage for $(D-r_1)$ to D is same whole beyond D it is zero. Therefore, flux linkages to the circuit caused by current in conductor 1 will be given by,

$$\lambda_1 = 2\times10^{-7} I_1 \ln\frac{D}{r_1'}$$

$$L_1 = 2\times10^{-7} \ln\frac{D}{r_1'}$$

Similarly,

$$L_2 = 2\times10^{-7} \ln\frac{D}{r_2'}$$

$$L = L_1 + L_2 = 2\times10^{-7} \ln\frac{D^2}{r_1' r_2'}$$

$$L = 4\times10^{-7} \ln\frac{D}{\sqrt{r_1' r_2'}}$$

i.e., $L = 4\times10^{-7} \ln\frac{D}{r'}$ H

where, $r' = \sqrt{r_1' r_2'}$

b) What is meant by the term "bundled conductors"? What are the advantages of this type of conductors? **[WBUT 2011]**

Answer:

Due to low tensile strength, aluminium conductors produce greater sag. This prohibits their use for large spans and makes them unsuitable for long distance transmission. In order to increase the tensile strength, the aluminium conductor is reinforced with a core of galvanized steel wires. Again by increasing conductor size, the voltage at which corona occurs is raised and hence corona effects are considerably reduced. This is one of the reasons that ACSR conductors which have a large cross-sectional area are used in transmission lines. ACSR conductor is called "bundled conductor".

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There is a limit to how much electric field intensity an individual conductor can withstand. This is greatest at the surface of the conductor. Even in dry air, ionization may result causing corona discharge to take place, and may lead to a breakdown in insulation where the conductor is supported from its tower.

Transmission line conductors, therefore, are **bundled** in order to reduce the electric field intensity which would be excessive if a single conductor were to be used instead. With bundled conductors, the same field is distributed equally between the bundled conductors, reducing the field intensity per conductor.

Advantages of bundled conductors:

1. Reduced reactance
2. Reduced voltage gradient
3. Reduced radio interference
4. Reduced corona loss
5. Reduced surge impedance.

6. A 3-phase, 50 Hz overhead transmission line has the following distributed parameters:
Resistance = 28 ohms;
Capacitive susceptance = 4×10^{-4} mho.
If the load at the receiving end is 75 MVA at 0.8 pf lagging with 132 kV between lines, calculate
(a) voltage
(b) current
(c) power factor at the sending end
(d) regulation and
(e) efficiency of transmission for this load. **[WBUT 2012]**

Answer:

Resistance of line per phase, $R = 28\Omega$

Capacitive susceptance per phase, $Y = 4 \times 10^{-4}$ mho

Receiving-end line voltage, $V_{RL} = 132\,\text{kV}$

$\therefore$ Receiving-end phase voltage, $V_{RP} = \dfrac{132}{\sqrt{3}} = 76.21\,\text{kV}$

$\therefore$ Receiving-end load current, $I_R = \dfrac{75 \times 10^6}{\sqrt{3} \times 132000} = 328\text{ A}$

$\therefore$ Line impedance, $Z = (R + jX) = 28 + j0 = 28\Omega$

In case of equivalent circuit for Nominal-T-Method is given by

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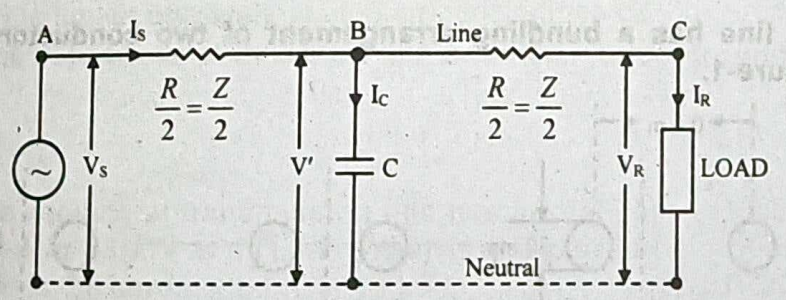

Taking receiving-end voltage as reference phasor →

Power factor $\cos\phi = 0.8$

$\therefore \quad \sin\phi = 0.6$

$\therefore \quad I_R = 328(0.8 - j0.6) = (262.4 - j196.8)\text{ A}$

$\therefore$ Phase voltage across capacitor

$$V' = V_R + I_R \times \frac{Z}{2} = 76210 + (262.4 - j196.8) \times 14$$

$\therefore \quad V' = (79883.6 - j2755.2)$ volts.

$\therefore$ Charging current

$$I_C = V' \times Y = (79883.6 - j2755.5) \times j4 \times 10^{-4} = (1.1 + j31.95)\text{ A.}$$

$\therefore$ Sending-end current, $I_S = I_R + I_C$

$\Rightarrow \quad I_S = (262.4 - j196.8) + (1.1 + j31.95)$

$\therefore \quad I_S = (263.5 - j164.85)\text{ A.} = 310.82\angle -32.03°$ (Ans.)

$\therefore$ Sending-end phase voltage

$$V_{SP} = V' + I_S \frac{Z}{2}$$

$$= (79883.6 - j2755.2) + (263.5 - j164.85)14$$

$$= (83572.6 - j5063.1)\text{ volts}$$

$$= 83725.83\angle -3.47°$$

$\therefore$ Sending-end line voltage $= \sqrt{3} \times 83725.83 = 145017$ volts

$= 145\text{ kV}$ (Ans.)

$\therefore$ Voltage Regulation $= \dfrac{V_{SL} - V_{RL}}{V_{RL}} \times 100\% = \dfrac{145 - 132}{132} \times 100\%$

$= 9.85\%$ (Ans.)

$\therefore$ Line Efficiency,

$$\eta = \frac{\sqrt{3} V_{RL} I_{RL} \cos\phi_R}{\sqrt{3} V_{SL} I_{SL} \cos\phi_S} \times 100 = \frac{\sqrt{3} \times 132000 \times 328 \times 0.8}{\sqrt{3} \times 145000 \times 310.82 \times \cos(-3.47° + 32.03°)} \times 100\%$$

$= 87.5\%$ (Ans.)

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7. A 500 kV line has a bundling arrangement of two conductors per phase as shown in Figure-1.

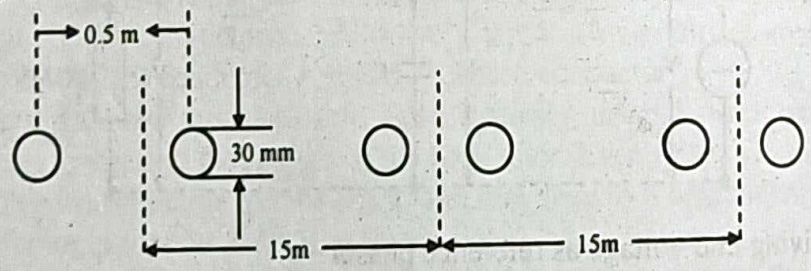
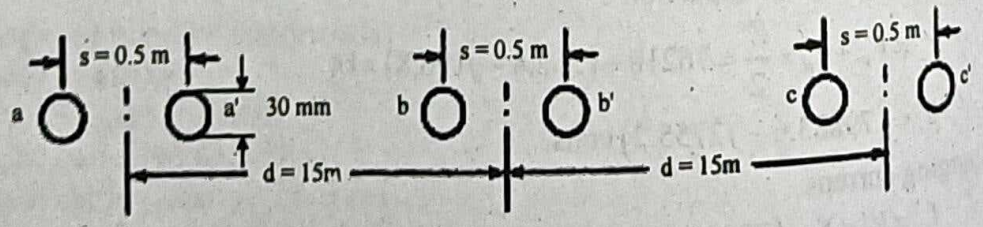


Fig: 1

Computer the reactance per phase of this line at 50 Hz. Each conductor carries 50% of the phase current. Assume full transposition. [WBUT 2014]

Answer:



Bundled conductor three-phase line

The mutual GMD between bundles of phases *a* and *b*

$$D_{ab} = \left(d(d+s)(d-s)d\right)^{\frac{1}{4}}$$

Mutual GMD between bundles of phases b and c

$$D_{bc} = D_{ab} \text{ (By symmetry)}$$

Mutual GMD between bundles of phases c and a

$$D_{ca} = \left(2d(2d+s)(2d-s)2d\right)^{\frac{1}{4}}$$

$$D_{eq} = \left(D_{ab}D_{bc}D_{ca}\right)^{\frac{1}{3}} = \left(4d^6(d+s)^2(d-s)^2(2d+s)(2d-s)\right)^{\frac{1}{12}}$$

$$= \left[4(15)^6(15.5)^2(14.5)^2(30.5)(29.5)\right]^{\frac{1}{12}} = 25.05 \text{ m}$$

$\therefore$ Self GMD of phase A (D_{sa}) = D_{sb} = D_{sc} = 0.108 m [$\therefore$ due to symmetry]

Inductive reactance per phase

$$X_L = 314 \times 0.461 \times 10^{-3} \log \frac{25.05}{0.108} = 0.342 \text{ ohm/km}$$

8. a) Derive the expression of capacitance of a single phase line considering the effect of earth. Hence deduce the capacitance without the effect of earth.

b) A 3-phase, 400 kV, 50 Hz, 350 km overhead transmission line has flat horizontal spacing with three identical conductors. The conductors have an outside diameter of 3.28 cm with 12 m between adjacent conductors.

Determine the capacitive reactance to neutral in ohms/m/ph and the capacitive reactance for the line in ohms/ph.

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c) Why is surge impedance of overhead line more than underground cable?

[WBUT 2016]

Answer:

a)

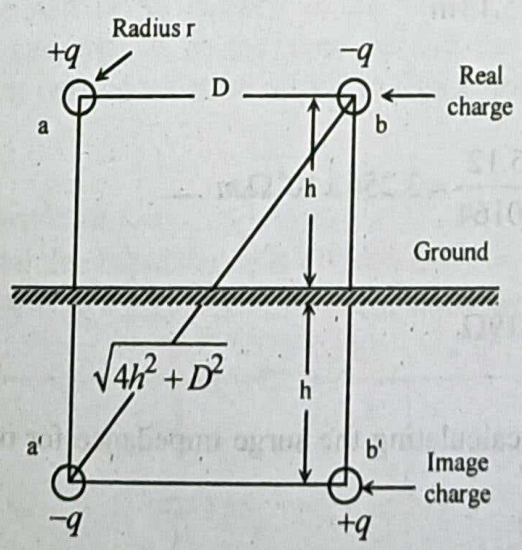

Fig. 1 Single-phase transmission line with images

Capacitance of a Single-Phase Line

Consider a single-phase line shown in Fig. 1. It is required to calculate its Capacitance taking the presence of earth into account by the method of images described above. The equation for the voltage drop V_{ab} as determined by the two charged conductors a and b, and their images a' and b' can be written as follows:

$$V_{ab} = \frac{1}{2\pi k}\left[q_a \ln\frac{D}{r} + q_b ln\frac{r}{D} + q_{a'} \ln\frac{\left(4h^2+D^2\right)^{1/2}}{2h} + q_{b'} \ln\frac{2h}{\left(4h^2+D^2\right)^{1/2}}\right]$$

Substituting the values of different charges and simplifying, we get

$$V_{ab} = \frac{q}{\pi k}\ln\frac{2hD}{r\left(4h^2+D^2\right)^{1/2}}$$

It immediately follows that

$$C_{ab} = \frac{\pi k}{\ln\frac{D}{r\left(1+\left(D^2/4h^2\right)\right)^{1/2}}} F/m \text{ line-to-line} \qquad \ldots (1a)$$

and $$C_n = \frac{2\pi k}{\ln\frac{D}{r\left(1+\left(D^2/4h^2\right)\right)^{1/2}}} F/m \text{ to neutral} \qquad \ldots (1b)$$

It is observed from the above equation that the presence of earth modifies the radius r to $r\left(1+\left(D^2/4h^2\right)\right)^{1/2}$. For h large compared to D (this is the case normally), the effect of earth on line capacitance is of negligible order.

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b) $$D_{eq} = \sqrt[3]{12\times12\times24} = 15.12\text{m}$$

$$r = \frac{0.0328}{2} = 0.0164$$

$$X_C = \frac{2.862}{60}\times10^9 \ln\frac{15.12}{0.0164} = 3.256\times10^8\,\Omega.m$$

For 125 miles,

$$X_C = \frac{3.256\times10^8}{125\times1609} = 1619\Omega$$

c) In this section, we will be calculating the surge impedance for overhead transmission lines and underground cables.

(i) Overhead transmission line

$L = 2\times10^{-7}\, In(D/r)$ F/phase/m

where, D is the distance between the centres of the conductors and r is the radius of the conductor and $D >> r$.

$$Z_0 = \sqrt{(L/C)} = \sqrt{\frac{2\times10^{-7}\ln(D/r)}{10^{-9}/18\ln(D/r)}} = 60\ln(D/r)\Omega$$

(ii) Cable

$L = 2\times10^{-7}\ln(R/r)$ F/phase/m

$$C = \frac{2\pi\varepsilon}{\ln(R/r)} \text{ F/phase/m} = \frac{10^{-9}\varepsilon_1}{18\ln(R/r)}$$

Where, R is the radius of the cable and r is the radius of the conductor. Assuming a dielectric having a relative dielectric constant of ε_r

$$Z_0 = \sqrt{\left(\frac{L}{C}\right)} = \frac{60ln\left(\frac{R}{r}\right)}{\sqrt{\varepsilon_r}}\Omega$$

A value of 500Ω is usually assumed of the surge impedance of an overhead line while a value of 50Ω is assumed for the surge impedance of a cable.

9. a) Point out the difference between the nominal π equivalent and equivalent π circuit model of a transmission line.

b) Find A, B, C, D constants for nominal π circuit of a medium transmission line. Also derive the expression for sending end voltage & current.

c) A 3-phase, 132 kV, 50 Hz transmission line has resistance, reactance and capacitance of 0.1 Ω, 5.0 Ω and 0.01 μF per km. Determine the series and shunt parameter and draw the nominal π circuit model of the line. [WBUT 2016]

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Answer:

a) In Nominal π method, capacitance of each conductor (i.e., line to neutral) is divided into two halves, one half being lumped at the sending end and the other half at the receiving end. The capacitance at the sending end has no effect on the line drop. However, its charging current must be added to line current in order to obtain the total sending end current.

b) ***Nominal – ∏ Representation***

In this method the total line capacitance is divided into two equal parts which are lumped at the sending and receiving – ends resulting in the nominal - ∏ representation like,

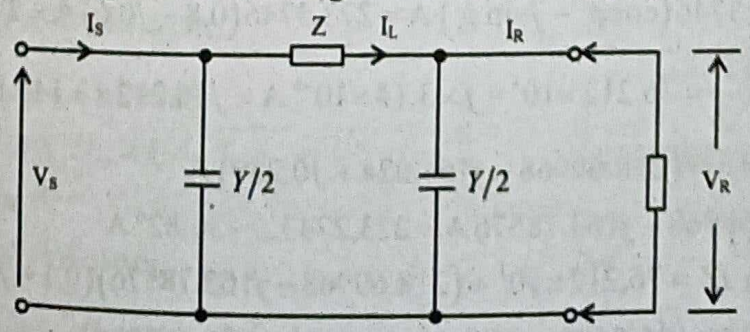

Fig: Medium line π representation

We have,

$$I_S = I_R + \frac{1}{2}V_R Y + \frac{1}{2}V_S Y$$

$$V_S = V_R + \left(I_R + \frac{1}{2}V_R Y\right)Z \quad = V_R\left(1+\frac{1}{2}YZ\right) + I_R Z$$

$$I_S = I_R + \frac{1}{2}V_R Y + \frac{1}{2}Y\left[V_R\left(1+\frac{1}{2}YZ\right) + I_R Z\right] = V_R Y\left(1+\frac{1}{4}YZ\right) + I_R\left(1+\frac{1}{2}YZ\right)$$

So, it is obtained as under:

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

Note:

Nominal –T and nominal $\prod$ with the above constants are not equivalent to each other.

c) $R = 0.1\,\Omega$/phase

$X_L = 5\,\Omega$/phase

$C = 0.01\times10^{-6}$ F/phase

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Receiving end voltage/phase $V_R = \dfrac{132\times10^3}{\sqrt{3}} = 76.212\text{ kV}$

Load current $I_R = \dfrac{50\times10^6}{\sqrt{3}\times132\times10^3\times0.8} = \dfrac{50\times10^3}{\sqrt{3}\times132\times0.8} = 273.3746\text{ A}$

$\cos\phi_R = 0.8$ lagging $\cos\phi_R = 0.6$

$Z = R + j\omega L = 0.1 + j5\,\Omega$/phase

$Y = g + j\omega C$

$= 0 + j\times2\times\pi\times50\times0.01\times10^{-6} = j3.14\times10^{-6}\,\Omega$/phase

In the phasor format, we can write

$V_R = 76.212\text{ kV}$

$I_R = 273.3746(\cos\phi_r - j\sin\phi_r)\text{ A} = 273.3746(0.8 - j0.6)\text{ A} = 273.3746\angle45^\circ\text{ A}$

$I_{C_1} = V_r \times \dfrac{Y}{2} = 76.212\times10^3\times j\times3.14\times10^{-6}\text{ A} = j76.212\times3.14\times10^{-3}\text{ A} = j0.239\text{ A}$

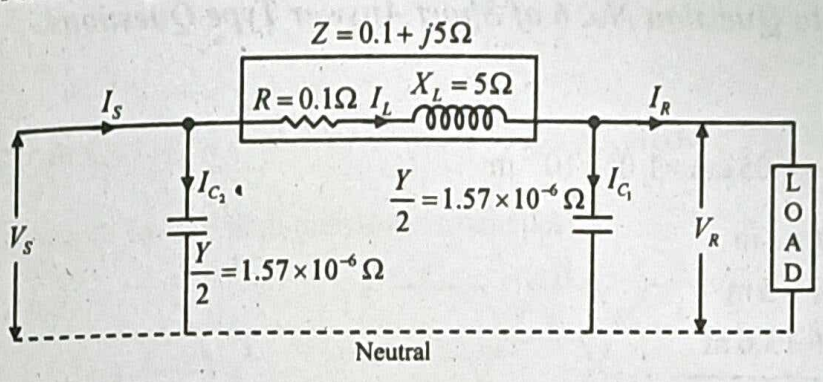
$I = I_R + I_{C_1} = (218.69968 - j164.024 + j0.239)\text{ A}$

$= 218.69968 - j163.78576\text{ A} = 273.2743\angle-36.82^\circ\text{ A}$

$V_S = V_R + IZ = 76.212\times10^3 + (218.69968 - j163.78576)(0.1 + j5)$

$= 76212 + (21.86996 - j16.3785 + 1090 - j^2818.9288)$

$$= 76212 + (1930.79876 - j16.3785) = 78{,}142 - j16.3785\,\text{V}$$
$$= 78{,}142\angle -0.012^\circ$$
$$I_{C_2} = V_S \times \frac{Y}{2} = (78{,}142 - j16.3785)\, j3.14\times10^{-6}$$
$$= j0.24536 - j^2 0.000051\,\text{A} = j0.24536 + 0.000051\,\text{A}$$
$$= 0.24536\angle -0.0119^\circ\,\text{A}$$
$$I_S = I + I_{C_2} = (218.69968 - j163.78576 + j0.24536 + 0.000051)\,\text{A}$$
$$= 218.69973 - j163.5404\,\text{A} = 273.2743\angle -36.82^\circ\,\text{A}$$



10. Determine the capacitance per km per phase to neutral of a 3-phase line arranged as shown in the figure. The diameter of the conductor is 2.8cm. The line is transposed. Take the effect of ground into account. [WBUT 2017]

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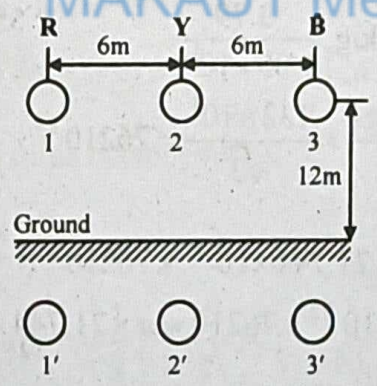


Answer:

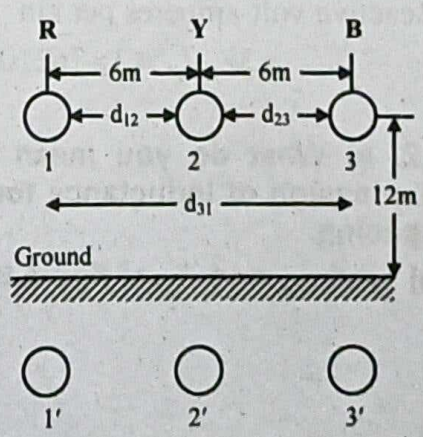
$d_{12} = d_{23} = 6\,\text{m}$ and $d_{31} = 12\,\text{m}$

Radius of conductor $= \dfrac{2.8}{2} = 1.4\,\text{cm}$

$\text{GMR} = r' = 0.7788 \times 1.4 = 1.09032$

For equivalent spacing, $D_{eq} = \sqrt[3]{d_{12}d_{23}d_{31}} = \sqrt[3]{6\times6\times12}$

$\Rightarrow \quad D_{eq} = 7.6\,\text{cm}$



Inductance per phase per metre,

$$L = 2\times10^{-7}\ln\left(\frac{D_{eq}}{r'}\right) = 2\times10^{-7}\ln\left(\frac{7.6}{1.0932}\right) = 3.88\times10^{-7}\,\text{H/m} \quad \textbf{(Ans.)}$$

11. a) Explain the effect of earth on conductor capacitance. **[WBUT 2018]**

Answer: ***Refer to Question No. 1 of Long Answer Type Questions.***

b) A three phase 50Hz line consists of three conductors each of diameter 21mm. The spacing between the conductors is as follows:

A-B = 3m, B-C = 5m, C-A = 3.6m.

Find the capacitance and capacitive reactance per phase per km of the line. If the line operates at 132kV, find the charging current per km and the reactive volt-amperes generated by the line per km. **[WBUT 2018]**

Answer:

1st Part: ***Refer to Question No. 6 of Short Answer Type Questions.***

2nd Part:

$$r = \frac{2.1}{2} = 1.05\text{ cm} = 1.05\times10^{-2}\text{ m}$$

$$d_1 = AB = 3\text{ m}$$

$$d_2 = BC = 5\text{ m}$$

$$d_3 = CA = 3.6\text{ m}$$

$$D_{eq} = \sqrt[3]{3\times5\times3.6} = 3.779\text{ m}$$

Capacitance of each conductor to neutral

$$= \frac{2\pi\varepsilon_0}{\log_e \frac{D_{eq}}{r}}\text{ F/cm} = \frac{2\pi\times8.85\times10^{-12}}{\log_e \frac{3.79}{1.05\times10^{-2}}} = \frac{2\pi\times8.85\times10^{-12}}{2.556} = 21.744\times10^{-12}$$

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Phase voltage, $V_{ph} = \frac{\text{Line voltage}}{\sqrt{3}} = \frac{132\times10^3}{\sqrt{3}} = 76210\text{ V}$

Charging current / phase

$$I_C = \omega C V_{ph} = 2\pi\times50\times21.744\times10^{-12}\times76210$$

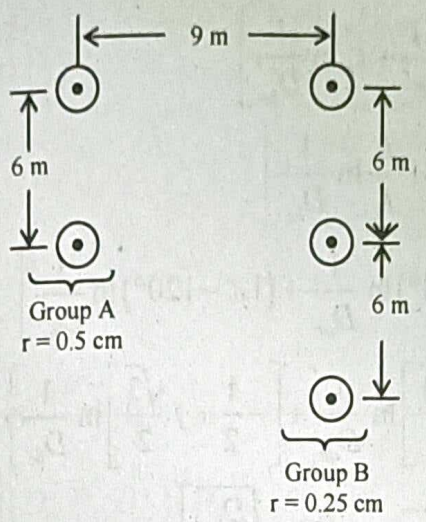
$$= 100\times\pi\times21.744\times10^{-12}\times76210 = \pi\times21.744\times76210\times10^{-10} = 52.03\times10^{-5}\text{ A}$$

Reactive volt-amperes per km

$$= 3V_{ph}I_C = 3\times76210\times52.03\times10^{-5} = 118.95\text{ Kvar}$$

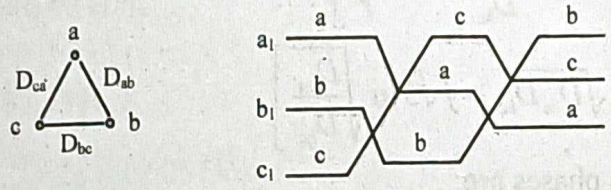
12. a) What do you mean by transposition of a three phase line. Derive the expression of inductance for a three phase transposition line with unsymmetrical spacing.

b) Find L_A and L_B of figure below. Also find the total inductance in H/m. **[WBUT 2019]**



a) 1st part: ***Refer to Question No. 3(a) 1st part of Long Answer Type Questions.***

2nd part: Inductance of 3ϕ line with unsymmetrical spacing.



$$\psi_a = 2\times10^{-7}\left(I_a \ln\frac{1}{r'} + I_b \ln\frac{1}{D_{ab}} + I_c \ln\frac{1}{D_{ca}}\right)$$

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Inductance of conductor a, $L_a = \dfrac{\psi_a}{I_a} = 2\times10^{-7}\left(\ln\dfrac{1}{r'} + \dfrac{I_b}{I_a}\ln\dfrac{1}{D_{ab}} + \dfrac{I_c}{I_a}\ln\dfrac{1}{D_{ca}}\right)$

If all three currents are assumed to be balanced with I_a as a reference phasor

$\overline{I_a} = I_a\angle 0°$; $\overline{I_b} = I_b\angle 240°$; $\overline{I_c} = I_c\angle 120° = I_a\angle 120°$

$$\frac{I_b}{I_a} = 1\angle 240° = \cos 240° + j\sin 240° = -\frac{1}{2} - j\frac{\sqrt{3}}{2}$$

$$\frac{I_c}{I_a} = 1\angle 120° = \cos 120° + j\sin 120° = -\frac{1}{2} + j\frac{\sqrt{3}}{2}$$

Substituting this in equation for L_a,

$$L_a = 2\times10^{-7}\left[\ln\frac{1}{r'} + \left(-\frac{1}{2} - j\frac{\sqrt{3}}{2}\right)\ln\frac{1}{D_{ab}} + \left(-\frac{1}{2} + j\frac{\sqrt{3}}{2}\right)\ln\frac{1}{D_{ca}}\right]$$

$$= 2\times10^{-7}\left[\ln\frac{1}{r'} + \ln\left(\sqrt{D_{ab}D_{ca}}\right) + j\sqrt{3}\ln\sqrt{\frac{D_{ab}}{D_{ca}}}\right]$$

$$\psi_b = 2\times10^{-7}\left[I_a \ln\frac{1}{D_{ab}} + I_b \ln\frac{1}{r'} + I_c \ln\frac{1}{D_{bc}}\right]$$

$$L_b = 2\times10^{-7}\left[\ln\frac{1}{r'} + \frac{I_a}{I_b}\ln\frac{1}{D_{ab}} + \frac{I_c}{I_b}\ln\frac{1}{D_{bc}}\right]$$

$$L_b = 2\times10^{-7}\left[\ln\frac{1}{r'} + (1\angle-240°)\ln\frac{1}{D_{ab}} + (1\angle-120°)\ln\frac{1}{D_{bc}}\right]$$

$$= 2\times10^{-7}\left\{\ln\frac{1}{r'}\left[-\frac{1}{2}+j\frac{\sqrt{3}}{2}\right]\ln\frac{1}{D_{ab}} + \left[-\frac{1}{2}-j\frac{\sqrt{3}}{2}\right]\ln\frac{1}{D_{bc}}\right\}$$

$$= 2\times10^{-7}\left[\ln\frac{1}{r'} + \ln\sqrt{D_{ab}D_{bc}} + j\sqrt{3}\ln\sqrt{\frac{D_{bc}}{D_{ab}}}\right]$$

$$\psi_c = 2\times10^{-7}\left[I_a \ln\frac{1}{D_{ca}} + I_b \ln\frac{1}{D_{bc}} + I_c \ln\frac{1}{r'}\right]$$

$$\psi_c = 2\times10^{-7}\left[\ln\frac{1}{r'} + \ln\sqrt{D_{ca}D_{bc}} + j\sqrt{3}\ln\sqrt{\frac{D_{ca}}{D_{bc}}}\right]$$

$\therefore$ Inductances of three phases are:

$$L_a = 2\times10^{-7}\left[\ln\frac{1}{r'} + \ln\sqrt{D_{ab}D_{ca}} + j\sqrt{3}\ln\sqrt{\frac{D_{ab}}{D_{ca}}}\right]$$

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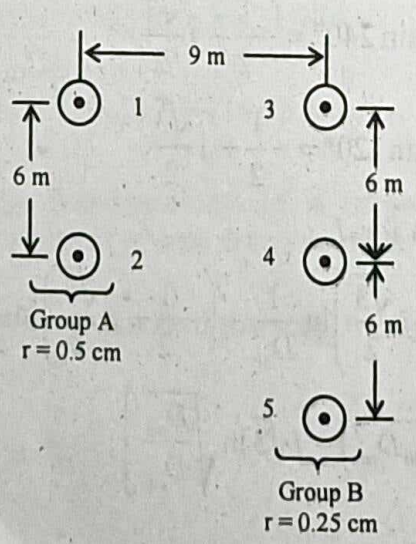
$$L_b = 2\times10^{-7}\left[\ln\frac{1}{r'} + \ln\sqrt{D_{ab}D_{ca}} + j\sqrt{3}\ln\sqrt{\frac{D_{bc}}{D_{ab}}}\right]$$

$$L_c = 2\times10^{-7}\left[\ln\frac{1}{r'} + \ln\sqrt{D_{ca}D_{bc}} + j\sqrt{3}\ln\sqrt{\frac{D_{ca}}{D_{bc}}}\right]$$

b)



Mutual GMD between A & B is

$$D_m = \left[(D_{31}D_{32})(D_{41}D_{42})(D_{51}D_{52})\right]^{1/6}$$

$$D_{31} = D_{41} = D_{42} = D_{52} = \sqrt{87}\text{ m} = D_{51} = D_{32}$$

$$D_m = \left(87^2 \times 100\right)^{1/6} = 9.546\text{ m}$$

Self GMD for $A = (D_{11}D_{12}D_{22})^{1/3}$

$$D_{11} = D_{22} = 0.5\times10^{-2}\times0.7788\text{ m}$$

$$D_{SA} = \left[\left(0.5\times10^{-2}\times0.7788\right)^2\times6^2\right]^{1/3} = 0.081\text{m}$$

Similarly, $D_{SB} = \left[(D_{33}D_{34}D_{35})(D_{44}D_{45}D_{43})(D_{55}D_{54}D_{53})\right]^{1/9}$

$$= \left[\left(0.25\times10^{-2}\times0.7788\right)^3\times9^2\times6^2\right]^{1/9} = 0.302\text{m}$$

$$\therefore L_A = 0.461\log\frac{8.8}{0.081} = 0.93\text{ H/m}$$

$$L_B = 0.461\log\frac{8.8}{0.302} = 0.675\text{ H/m}$$

$\therefore$ Total inductance $= L_A + L_B = 1.605$ H/m

13. Write short notes on the following:

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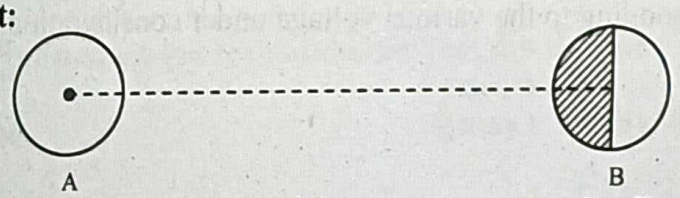
a) Proximity effect **[WBUT 2007, 2010, 2013, 2014]**

b) Choice of voltage for transmission line **[WBUT 2009, 2010, 2013, 2014]**

Answer:

a) Proximity effect:



The proximity effect results into non-uniformity of current distribution in a conductor cross-section. Consider the conductor A and B placed near to each other as shown in figure where conductor A carries current its flux links with conductor B in such a fashion that more flux links with nearer half (shaded). If conductors carry the currents in opposite directions the magnetic fields setup will tend to increases the current density in the adjacent portion of the conductors. On the other hand if the currents are in the same direction there is an increase in effective resistance of conductor and hence losses. Proximity effect depends on conductor size, frequency, distance between conductors and permeability of conductor material.

Proximity effect is influenced by the following factors:

i) Size of conductor

ii) Frequency of supply

iii) Resistivity (ρ_0) of the material

iv) Permeability (μ_r) of the material,

v) Distance between conductors

b) Choice of voltage for transmission line:

With increase in the power to be transmitted over long distances, use of high voltages for power transmission has been developed. A choice could be made out of standard voltages which are to be used in country. The voltage selected has to be economical and depends upon cost of lines, cost of apparatus such as transformers, circuit breakers etc. The voltages used as standard in India and UK are 11kV,22kV,33kV for short lines ,66kV and 110kV for medium line and 132kV,166kV,and 230kV for long lines.

In selection of voltage of transmission lines the existing and future voltages of other lines in the vicinity should be considered. This is required for possible interconnection of grid lines. The choice of voltage also linked with conductor size, performance of line as expected within permissible percentage losses and regulation of the lines. The following table is also used-

Line –line voltage (kV)	Line loading KW Km
11	24×10^3
33	200×10^3
66	600×10^3
110	11×10^6
132	20×10^6
166	35×10^6
230	90×10^6

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The best method to decide the voltage for transmission would be to study the initial and operating cost corresponding to the various voltage under consideration.

OVERHEAD LINE CONSTRUCTION

Multiple Choice Type Questions

1. Stringing chart is useful for [WBUT 2007, 2008, 2010, 2017, 2019]
   a) finding the sag in the conductor
   b) in the design of tower
   c) in the design of insulator string
   d) finding the distance between the towers

Answer: (a)

2. Tower footing resistance of a transmission tower should be [WBUT 2009]
   a) as high as possible
   b) as low as possible
   c) moderately high
   d) moderately low

Answer: (b)

3. Vertical sag is [WBUT 2012]
   a) S tant θ
   b) S cos θ
   c) S sin θ
   d) none of these

Answer: (b)

4. Stringing chart is used in transmission lines for [WBUT 2015]
   a) designing the tower
   b) calculating the sag in the conductor
   c) determining the distance between the conductor
   d) design of insulator string

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Answer: (b)

5. By increasing the sag on the transmission line, the tension [WBUT 2016]
   a) increases
   b) decrease
   c) not affected
   d) may increase or decrease

Answer: (b)

6. The sag of a transmission line is least effected owing to [WBUT 2018]
   a) weight of the conductor
   b) current through the conductor
   c) atmospheric temperature
   d) ice deposition on the conductor

Answer: (b)

Short Answer Type Questions

1. What is a stringing chart? What is its utility? [WBUT 2009]

OR,

What sort of information is obtained from a stringing chart? Why is it important? [WBUT 2011]

Answer:

1st Part:

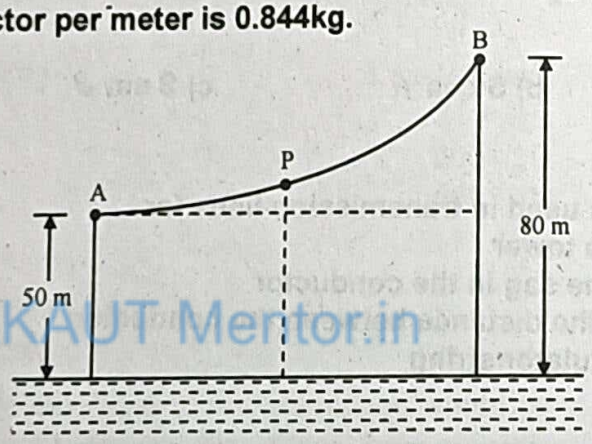
Under statutory conditions, the sag is required to be determined for worst probable conditions and the minimum ground clearance is to be maintained for these conditions. At the time of erection the severe conditions do not prevail, the temperature is usually higher, the designer, therefore, should know the sag to be allowed and the tension in the line to be allowed, so that under no condition there should be any danger to the line.

2nd Part:

String chart is helpful in knowing the sag and tension at any temperature. This chart gives the data for sag to be allowed and the tension to be allowed at a particular temperature.

2. A transmission line conductor at a river crossing is supported from two towers at heights of 50m and 80m from water level. The horizontal distance between the towers is 300m. If the tension in the Conductor is 200kg, find the clearance between the conductor and water level at a point midway between the towers. Weight of the conductor per meter is 0.844kg. **[WBUT 2015]**

Answer:



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Referring to the above figure, we find that here,

$$h = 80 - 50 = 30\text{ m};\quad \ell = 300\text{ m}$$

$$T = 200\text{ kg};\quad w = 0.844\text{ kg/m}$$

$$x_1 + x_2 = 300\text{ m} \qquad \text{.... (1)}$$

Now, $$h = S_2 - S_1 = \frac{wx_2^2}{2T} - \frac{wk_1^2}{2T}$$

or, $$30 = \frac{w}{2T}(x_2 + x_1)(x_2 - x_1)$$

$$\therefore \quad x_2 - x_1 = \frac{30 \times 2 \times 200}{300 \times 0.844} = 47.39\text{ m} \qquad \text{.... (2)}$$

Solving eqns, (1) and (2), we get,

$$x_2 = 173.68\text{ m and } x_1 = 126\text{ m}$$

$$\therefore \text{ Sag at point P, } S_{mid} = \frac{wx^2}{2T} = \frac{0.844(150)^2}{2 \times 200} = 47.47\text{ m}$$

Now, Sag, $S_2 = \frac{wx_2^2}{2T} = \frac{0.844 \times (173.68)^2}{2 \times 200} = 63.64\,\text{m}$

Height of point 'B' above mid-point 'P' $= S_2 - S_{mid} = 16.17$ m.

3. The towers of height 30 m and 90 m respectively support a transmission line conductor at water crossing. The horizontal distance between the towers is 500 m. If the tension in the conductor is 1600 kg, find the minimum clearance of the conductor and 3water and clearance mid-way between the supports. Weight of the conductor is 1.5 kg/m. bases of the towers can be considered to be at water level.

[WBUT 2016]

Answer:

L = 500 m, T = 1600 kg, w=1.5 kg/m

The arrangement is shown in Fig. 1

h = Difference in level = 90 – 30 = 60 m

$$x_1 = \frac{1}{2} - \frac{Th}{qL} = \frac{500}{2} - \frac{1600 \times 60}{1.5 \times 500} = 122\,\text{m}$$

$$x_2 = \frac{L}{2} + \frac{Th}{wL} = \frac{500}{2} + \frac{1600 \times 60}{1.5 \times 500} = 378\,m$$

It can be cross-checked that $x_1 + x_2 = L = 500\,m$

$$S_1 = \frac{wx_1^2}{2T} = \frac{1.5 \times (122)^2}{2 \times 1600} = 6.9768$$

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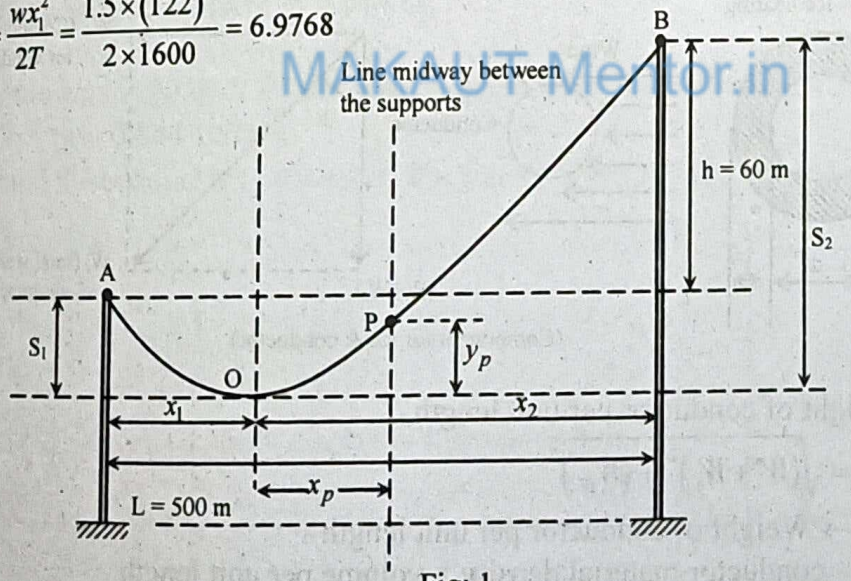


Fig: 1

Hence the minimum clearance of conductor and water

= Height of A – S_1 = 30 – 6.9768 = 23.0232 m

Now we want the distance of point P from the ground which is the clearance midway between the supports.

The origin is point O and co-ordinates of point P are (x_p, y_p)

$$x_p = \frac{L}{2} - x_1 = \frac{500}{2} - 122 = 128$$

The y_p can be obtained from the equation of parabolic trajectory as,

$$y_p = \frac{w(x_p)^2}{2T} = \frac{1.5\times(128)^2}{2\times1600} = 7.68 \text{ m}$$

The point P is y_p distance above the origin O and origin O is 23.0232 m above water. Hence clearance midway between the supports is

$$= \text{Clearance of O} + y_p = 23.0232 + 7.68 = 30.7032 \text{ m}$$

Long Answer Type Questions

1. Discuss the effect of wind and ice on sag. **[WBUT 2008, 2009, 2013]**

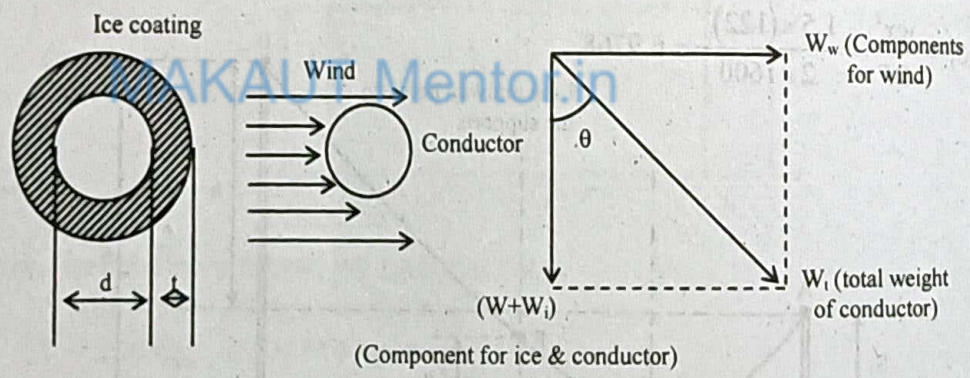
OR,

Write short note on Discuss the effect of wind and ice on sag. **[WBUT 2014]**

Answer:

Effect of Wind on ice loading

All the above equations are applicable for still air and at normal temperature when the conductor is acted by its weight only. But for actual practice, a conductor may have ice coating and simultaneously subjected to wind pressure, The extra height of the ice acts vertically downwards, i.e. in the same direction as the weight of conductor. Again the wind acts horizontally i.e. at the right angle to the projected surface of the conductor.



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So total weight of conductor per unit length

$$W_t = \sqrt{(W+W_i)^2 + (W_W)^2}$$

$W \rightarrow$ Weight of conductor per unit length

= conductor material density × volume per unit length.

$W_i \rightarrow$ Weight of ice per unit length

$$= \text{Density of ice} \times \pi/4\left[(d-2t)^2 - d^2\right]\times 1$$

$$= \text{Density of ice} \times \pi t(d+t)$$

$W_W \rightarrow$ Wind force per unit length

Wind pressure per unit area × projected area per m on which wind is acting

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

So when both wind & ice loading are applicable, then

(a) With the vertical axis the conductor makes an angle θ

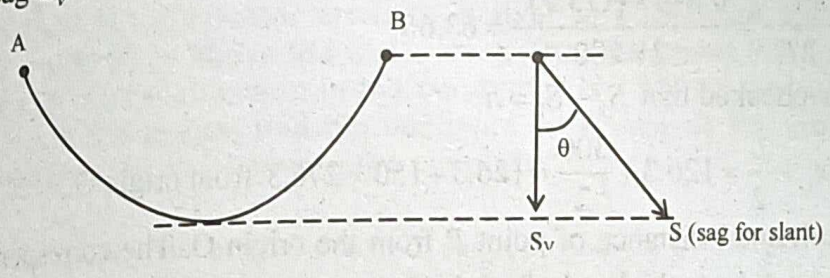
i.e., $\tan\theta = \dfrac{W_W}{W + W_i}$

(b) The sag in the conductor now, becomes:

$$S = \frac{W_i l^2}{2T}$$

Hence S represent the slant sag which make θ angle with the vertical sag.

So, vertical sag $S_v = S\cos\theta$



2. A transmission line conductor at a river crossing is supported from two towers at heights of 50 m and 80 m above water level. The horizontal distance between the towers is 300 m. If the tension in the conductor is 200 kg, find the clearance between the conductor and water level at a point midway between the towers. Weight of the conductor/metre is 0.844 kg. [WBUT 2010]

Answer:

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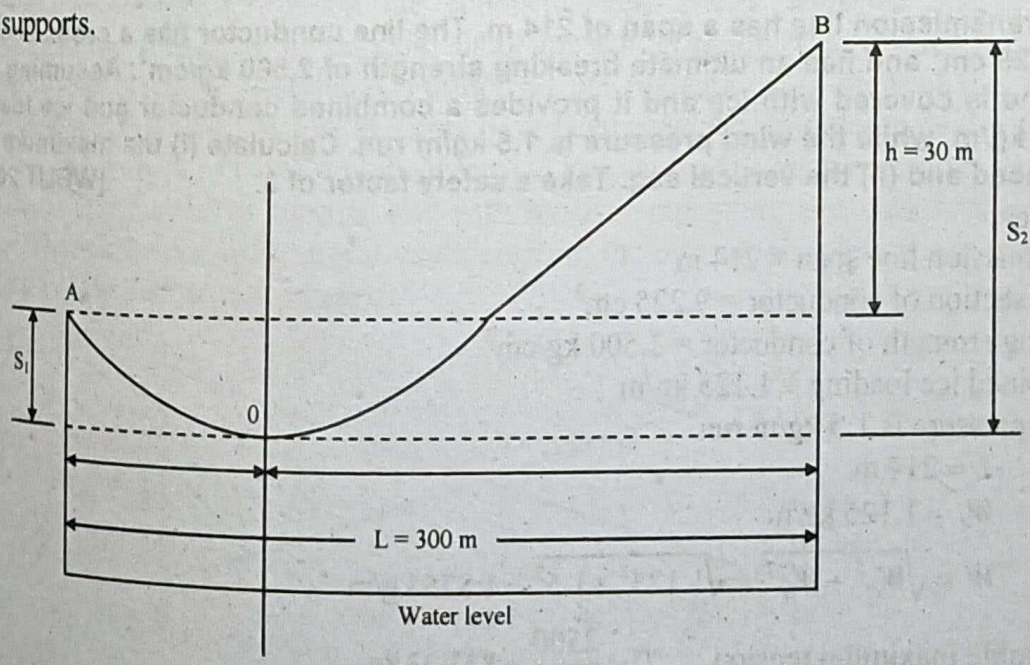
The height of towers is 50 m & 80 m respectively $h = 80 - 50 = 30$ m, $L = 300$ m

$T = 200$ kg $\quad w = 0.844$ kg/m

The towers and the conductor is shown in the figure below, where S_1 and S_2 are sags at two supports.



$$x_1 = \frac{L}{2} - \frac{Th}{wL} = \frac{300}{2} - \frac{200 \times 30}{0.844 \times 300} = 150 - 23.7 = 126.3\,\text{m}$$

$$x_2 = \frac{L}{2} + \frac{Th}{wL} = \frac{300}{2} + \frac{200 \times 30}{0.844 \times 300} = 150 + 23.7 = 173.7\,\text{m}$$

If can be cross-checked at $x_1 + x_2 = 300\,\text{m} = L$

It can be seen that

$$S_1 = \frac{wx_1^2}{2T} = \frac{0.844 \times (126.3)^2}{2 \times 200} = 33.658$$

$$S_2 = \frac{wx_2^2}{2T} = \frac{0.844 \times (173.7)^2}{2 \times 200} = 63.66$$

It can be cross-checked that $S_2 - S_1 = h$

$$x_P = x_1 + \frac{L}{2} = 126.3 + \frac{300}{2} = 126.3 + 150 = 276.3 \text{ from origin O.}$$

This is the horizontal distance of point P from the origin O. The corresponding vertical distance of point P from the level of origin O is y_P is given by

$$y_P = \frac{w(x_P)^2}{2T} = \frac{0.844 \times (276.3)^2}{2 \cdot 200} = 161.$$

The clearance of point O from water level is

$$= \text{height of } A - S_1 = \text{height of } B - S_2 = 50 - 33.658 = 80 - 63.662$$

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Hence clearance of point P i.e. point midway between the towers and water level is

$$= 16.342 + y_P = 16.342 + 161 = 177.342\,\text{m}$$

3. A transmission line has a span of 214 m. The line conductor has a cross-section of 9.225 cm^2 and has an ultimate breaking strength of 2,500 kg/cm^2. Assuming that the line is covered with ice and it provides a combined conductor and ice load of 1.125 kg/m, while the wind pressure is 1.5 kg/m run. Calculate (i) the maximum sag produced and (ii) the vertical sag. Take a safety factor of 3. [WBUT 2011]

Answer:

Transmission line span = 214 m

Cross section of conductor = 9.225 cm^2

Braking strength of conductor = 2,500 kg/cm^2

Combined ice loading = 1.125 kg/m

Wind pressure is 1.5 kg/m run.

i) So, $L = 214$ m.

$W_C = 1.125$ kg/m

$$W = \sqrt{W_C^2 + W_W^2} = \sqrt{1.125^2 + 1.5^2} = 1.875 \text{ kg/m}$$

Allowable maximum tension, $T = \frac{2500}{3} = 833.33\,\text{kg}$

$$\text{Sag} = 'S' = \frac{WL^2}{8T} = \frac{1.875 \times (214)^2}{8 \times 833.33} = 12.88 \text{ m}$$

So maximum Sag = 12.88 m

ii) Vertical Sag, $\cos\theta = \frac{W_C}{W} = \frac{1.125}{1.875} = 0.6$

So, Vertical Sag $S \cdot \cos\theta = 12.88 \times 0.6 = 7.728$ m

[WBUT 2012]

4. a) What is sag?

b) What is string chart? What is its utility?

c) A transmission line conductor crossing a river is supported from towers at heights of 30 m and 80 m above the water level. The horizontal distance between the towers is 450 m. If the tension in the conductor is 1500 kg and weight of the conductor is 1.4 Kg/m length, find the minimum clearance of the conductor and water and clearance mid-way between the supports.

Answer:

a) The difference in level between the points of supports and the lowest point is known as sag.

The conductors in over head lines are supported at the towers (or poles for low voltage lines). The conductors are pulled and stringing effected when the conductor is supported in the fashion it will sag or dip under its own weight and it takes the shape of catenary. The distance between the adjacent supporting tower is called the span.

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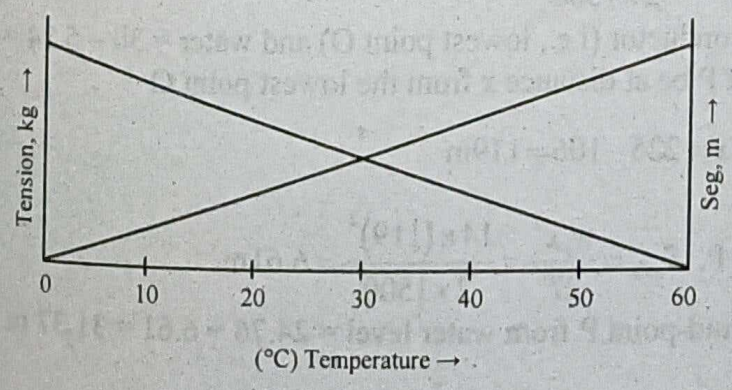
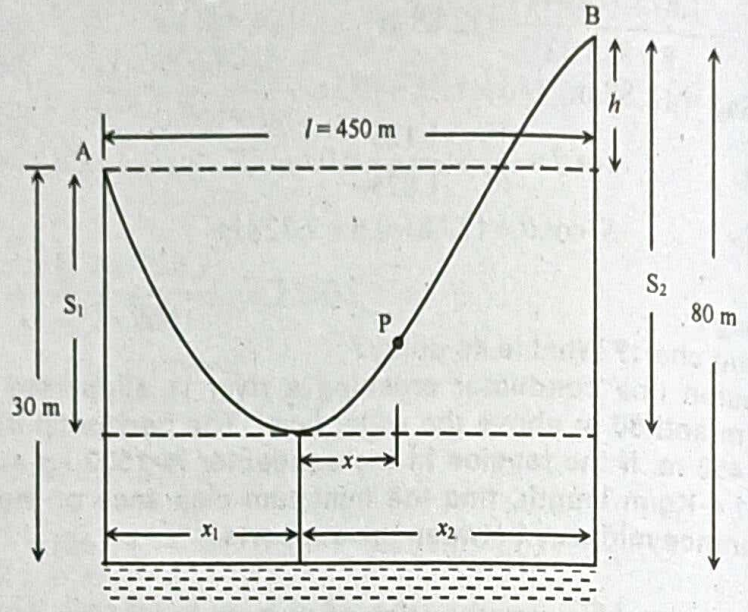
b) The conditions of the line of the time of erection are not same under which it is required to operate. In still air, the conductor is acted upon by its own weight, if the temperature is high; the resulting sag gives a low tension. Probably this is the easiest condition. But sometimes, when the conductor gets coated with ice due to low temperature (which reduces the sag) and simultaneously it is subjected to wind pressure, the situation gets amply aggravated. Further, as per regulations, in view of the above severe conditions, suitable factors of safety have been provided. In order to deal with the problem it is pertinent to prepare plots of tension and sag versus temperature for varying conditions. The curves of tension and sag versus temperature are called "stringing charts." These chart are quite useful white erecting the transmission line conduct or for adjusting the sag and tension properly.



Stringing Chart

c) Given, $l = 300$ m, T = 1500 kg, $w_c = 1.4$ kg/m



Minimum clearance of conductor and water and clearance mid way between the supports.
Difference in levels between the supports, $h = 80 - 30 = 50$ m

Let x_1, x_2 be the distances of the lowest point O from the supports A and B respectively.

Then $x_1 + x_2 = l = 450\text{m}$ ...(1)

Now, $S_1 = \dfrac{w_c x_1^2}{2T}$, $S_2 = \dfrac{w_c x_2^2}{2T}$

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$$h = S_2 - S_1 = \frac{w_c x_2^2}{2T} = \frac{w_c x_1^2}{2T}$$

or, $50 = \dfrac{w_c}{2T}\left(x_2^2 - x_1^2\right) = \dfrac{w_c}{2T}(x_2 + x_1)(x_2 - x_1)$

$\therefore (x_2 - x_1) = \dfrac{50 \times 2 \times 1500}{14 \times 450} = 238\text{m}$ ...(2)

Solving (1) and (2), we get $x_1 = 106\text{m}$, $x_2 = 344\text{m}$

Now, $S_1 = \dfrac{w_c x_1^2}{2T} = \dfrac{14 \times (106)^2}{2 \times 1500} = 5.24\text{m}$

$\therefore$ Clearance of conductor (i.e., lowest point O) and water = 30 – 5.24 = 24.76 m

Let the mid-point P be at distance x from the lowest point O

Then, $x = \dfrac{450}{2} - x = 225 - 106 = 119\text{m}$

Sag at mid-point P, $S_{mid} = \dfrac{w_c x^2}{2T} = \dfrac{14 \times (119)^2}{2 \times 1500} = 6.61\text{m}$

$\therefore$ Clearance of mid-point P from water level = 24.76 + 6.61 = 31.37 m

5. a) What is a stringing chart? How it can be prepared? What is its use?
b) A transmission line has a span of 150 m between level supports. The conductor has a cross section area of 2 cm^2. The tension in the conductor is 2000 kg. If the specific gravity of the conductor material is 9.9 gm/cm^3 and wind pressure is 1.5 kg/m length, calculate the sag. What is vertical sag? [WBUT 2014]

Answer:

a) ***Refer to Question No. 4(b) of Long Answer Type Questions.***

b) Span length, l =150 m; Working tension, T = 2000 kg

Wind force/m length of conductor, $w_w = 1.5$ kg

Wt. of conductor/m length, w = Sp. Gravity × Volume of 1 m conductor

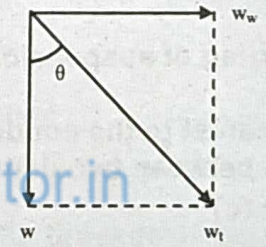
$= 9.9 \times 2 \times 100 = 1980$ gm = 1.98 kg

Total weight of 1 m length of conductor is

$$w_t = \sqrt{w^2 + w_w^2} = \sqrt{(1.98)^2 + (1.5)^2} = 2.48 \text{ kg}$$

$$\therefore \text{ Sag, } S = \frac{w_t l^2}{8T} = \frac{2.48 \times (150)^2}{8 \times 2000} = 3.48 \text{ m}$$

This is the value of slant sag in a direction making an angle θ with the vertical.



Referring to Fig. the value of θ is given by;

$\tan\theta = w_w / w = 1.5/1.98 = 0.76$

$\therefore \theta = \tan^{-1} 0.76 = 37.23°$

∴ Vertical sag = S cos θ = 3.48 × cos 37.23° = 2.77 m

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INSULATORS

Multiple Choice Type Questions

1. A string insulator has 4 units. The voltage across the bottom most unit is 30% of the total voltage. The string efficiency of the insulator is [WBUT 2008, 2012, 2014, 2015]
   a) 30% b) 60% c) 75% d) 83.33%

Answer: (d)

2. Shunt capacitance is suspension insulators can be decreased by increasing in distance of conductor from [WBUT 2012]
   a) tower b) ground c) either (a) or (b) d) none of those

Answer: (a)

3. The economic size of conductor is determined by [WBUT 2012, 2017]
   a) Kelvin's law b) Kirchoff's law c) Faraday's law d) none of these

Answer: (a)

4. In a string of suspension insulator, maximum voltage appears across the unit [WBUT 2012]
   a) nearest to the conductor b) nearest to the cross arm
   c) in between two units d) none of these

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Answer: (c)

5. A three disc string insulator having 50% string efficiency is operated at 66 kV. The voltage across the disc nearest to the conductor is [WBUT 2013]
   a) 40 kV b) 45 kV c) 50 kV d) 44 kV

Answer: (d)

6. Grading ring is used to equalize the potential distribution across the units of the suspension insulator because it [WBUT 2014]
   a) forms capacitances which will help to cancel the charging current from link pins
   b) forms capacitances with link pins to cancel the charging current from link pins
   c) increases the capacitances of lower insulator units
   d) decreases the capacitances of upper insulator units

Answer: (b)

7. The diameter of each strand is 'd', then the diameter of n-layer stranded conductor will be [WBUT 2014]
   a) (2n + 1)d b) 3(n + 1)d c) (2n – 1)d d) 3(n –1)d

Answer: (a)

8. 25% of the line of neutral voltage appears across the bottom-most unit in a string insulators with 5 identical discs. The string efficiency is [WBUT 2016]
a) 80% b) 75% c) 50% d) 25%
Answer: (a)

9. The thickness of the layer of insulation on the conductor, in cables, depends upon [WBUT 2017]
a) reactive power b) power factor
c) voltage d) current carrying capacity
Answer: (c)

10. Which of the following insulators is used in transmission lines at a river and road crossings [WBUT 2017]
a) Pen type b) Suspension type
c) Strain type d) Shackle type
Answer: (c)

11. If the frequency of a transmission system is changed from 50Hz to 100Hz, the string efficiency [WBUT 2018]
a) will increase
b) will decrease
c) remain unchanged
d) may increase or decrease depending on the parameter
Answer: (c)

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12. The breakdown strength of air at STP is 21 kV / cm. Its breakdown strength at 30°C and 72 cm of Hg will be [WBUT 2019]
a) 21.25 kV/cm b) 20.2 kV/cm
c) 23 kV/cm d) 19.5 kV/cm
Answer: (a)

13. Which insulator is used on locations where there is a change in direction of the line? [WBUT 2019]
a) pin type b) strain type
c) shackle type d) suspension type
Answer: (b)

Short Answer Type Questions

1. Explain Kelvin's law for the determination of conductor size. [WBUT 2007, 2012]
Answer:
Kelvin's Law state that, the most economical area of conductor is that for which the total annual cost of transmission line is minimum.
Total annual cost of transmission line can be divided broadly into two parts,
a) Annual charge on capital outlay, and
b) Annual cost of energy wasted in the conductor.

a) *Annual charge on capital outlay:*

This is an account of interest and depreciation on the capital cost of complete installation of transmission line. In case of overhead system it will be the annual interest and depreciation on the capital cost of conductors, supports and insulators and the cost of their erection. Now, for an overhead line, insulator cost is constant, the conductor cost is proportional to the area of cross-section and the cost of supports and their erection is partly constant and partly proportional to area of cross-section of the conductor.

i.e., Annual charge on an overhead transmission line can be expressed as:

Annual Charge = $P_1 + P_2 a$ where $P_1 \& P_2$ are two constant and a is the cross-section of the conductor.

b) *Annual cost of energy wasted:*

This is mainly in the conductor due to I^2R losses.

So, Annual cost of energy wasted $= \frac{P_3}{a}$

As I^2R losses $\propto 1/a$ $\quad a \rightarrow$ Area or cross-section of the conductor

$P_3 \rightarrow$ Constant.

Total annual cost, $C = P_1 + P_2 a + P_3/a$

So, cost will be minimum.

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

$$\Rightarrow \frac{d}{da}(P_1 + P_2 a + P_3/a) = 0$$

$$\Rightarrow \quad P_2 - P_3/a^2 = 0$$

$$P_2 a = P_3/a$$

i.e., Variable part of annual charge = Annual cost of energy wasted.

So, minimum cross-section of conductor $\quad a = \sqrt{P_3/P_2}$.

In other words, the variable part of annual charge should be equal to the cost of annual losses due to energy wasted in the conductor for most economical working.

The above statement is Kelvin's law.

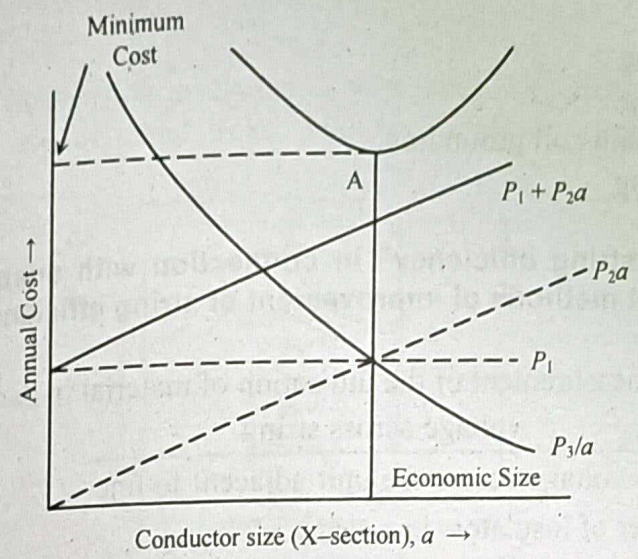

Fig shows the graphical representation of Kelvin's law.

2. Explain what do you mean by 'Back flashover'. **[WBUT 2008]**

OR,

Write short note on Back flashover. **[WBUT 2013]**

Answer:

In flashover an arc occurs between the line conductor and insulator Pin (earth) and discharge jumps across the air gaps following the shortest distance. It is either due to line surges or due to the formation of wet conducting layer over insulator surface. Normally, the insulator is not damaged due to flashover and it will continue to act in its proper capacity unless extreme heat produced by the arc destroys the insulator. Flashovers are reduced by increasing the resistance to leakage currents. The length of leakage current path is made large by constructing several layers called as rain sheds. They keep the inner surface relatively dry in wet weather and thus provide sufficient leakage resistance to prevent flashover. Accumulation of dust, salt and smoke etc. on insulator surface is kept minimum by providing semiconducting glaze over the whole exposed surface of insulator.

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3. What is arcing ground? How it can be minimized? **[WBUT 2009, 2010, 2013]**

Answer:

The insulation of all equipment connected to the lines is subjected to the high voltage. For operating the protection device it is necessary the current should be under limit. But in case of single line to single line to ground fault on an isolated neutral system, resultant capacitive current is usually not large enough to operate the protective device. Further, a current of over 4 or 5A flowing through the fault may give rise to an arc in the ionized part of the fault. With the formation of the arc, the voltage across it become zero and, therefore arc is extinguished. And potential of the faulty conductor is restored and the formation of second arc takes place. This phenomenon is called arcing ground.

Application of neutral grounding is the only solution to reduce the neutral current flow during fault condition.

i.e.
a) Resistance grounding
b) Reactance grounding
c) Resonance or Peterson coil grounding.
d) Resonance grounding

4. Define the term "string efficiency" in connection with suspension insulators. What are the different methods of improvement of string efficiency? [WBUT 2011]

Answer:

String efficiency is a measurement of the utilisation of material in the string, define as:

$$\text{String efficiency} = \frac{\text{voltage across string}}{n \times \text{voltage across the unit adjacent to line}}$$

Where n = total number of insulators in a string.

Methods of increasing string efficiency:

a) grading of the units
b) Static shielding

5. String efficiency for a d.c system is 100%. Discuss. Can string efficiency in an ac system be 100%? [WBUT 2014]

Answer:

The ratio of voltage across the whole string to the product of number of discs and the voltage across the disc nearest to the conductor is known as string efficiency.

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$$\text{i.e., string efficiency} = \frac{\text{Voltage across the string} \times 100\%}{n \times \text{ voltage across disc nearest to conductor}}$$

Where n = number of discs in the string.

So, if D.C. voltage is applied across a string of suspension insulators the voltage across each unit will be the same. It is because insulator capacitances are ineffective for D.C. Therefore, string efficiency for a D.C. system is 100%.

But if the A.C. voltage is impressed on a string of suspension insulators, the voltage across the individual discs does not distribute itself uniformly due to the presence of shunt capacitance. So, the disc nearest to the conductor has maximum voltage across it and under maximum electrical stress. As we move towards the cross-arm, the voltage across each disc goes on decreasing. That's why in an A.C. system it is impossible to achieve 100% string efficiency, yet efforts should be made to improve it as close to this value as possible.

6. Give reasons for unequal potential distribution over a string of suspension insulators. Why are suspension insulators preferred for high voltage power transmission? [WBUT 2014]

Answer:

1st part:

Consider a string of suspension insulators. The numbers of porcelain discs are connected in series with the help of metal links. The Fig: a shows string of 4 porcelain disc suspension insulators.

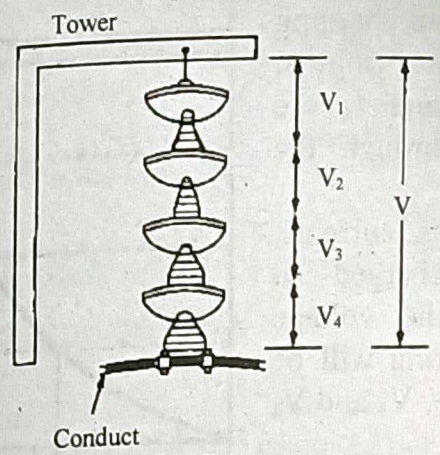

Fig: (a)

The porcelain portion which is an insulator is in between the two metal fittings. Thus it forms a capacitor. This is called "self capacitance" or "mutual capacitance". Hence the whole string shown in the Fig:b will consist of 4 such self capacitors in series. If only such self or mutual capacitors exist alone in series, the voltage across them would have been equal and series charging current through them would have been same.

But in addition to the self capacitances, there will be capacitance between each metal fitting and the earth i.e. tower. The air acts as a dielectric. Such a capacitance is called "shunt capacitance."

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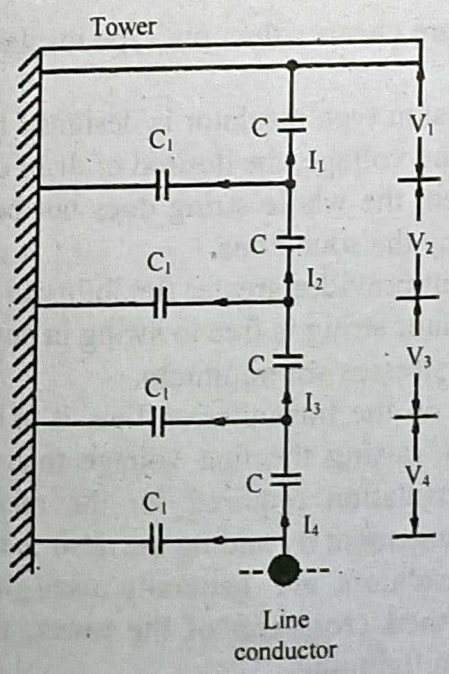


Fig: (b)

Due to shunt capacitors, the charging current no longer remains same.

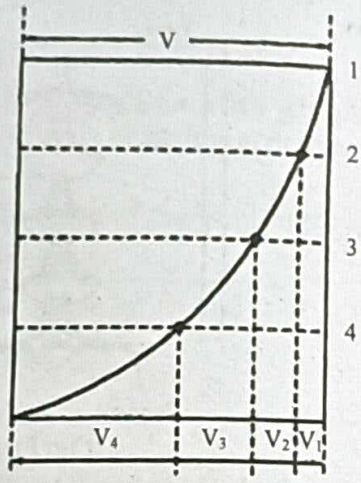
The different currents, mutual capacitors and shunt capacitors are shown in the Fig: b The mutual capacitors are denoted as C while the shunt capacitors are denoted as C_1.

Assuming the design of each section of the string same, the mutual capacitors are assumed equal. Similarly all shunt capacitors are also assumed equal.

There will be capacitance between metal fitting and the line conductor also. But its value is very small and generally it is neglected.

The currents I_1, I_2, I_3 and I_4 are charging currents flowing through mutual capacitors while i_1, i_2, i_3 and i_4 are charging currents flowing through the shunt capacitors.

Due to the different charging currents, each capacitor will get charged to different potential. Hence the voltage across each section of the string will be different. it is shown as V_1, V_2, V_3 and V_4 in the Fig:b.



$V_4 > V_3 > V_2 > V_1$

Fig: (c)

As the charging current is highest nearest to the line conductor, the voltage across the capacitor nearest to the line conductor will be maximum. Thus V_4 will be maximum, for the case considered. Hence the insulator adjacent to the line conductor is under maximum electrical stress and is liable to puncture. The graphically such potential variation can be shown as in the Fig: c.

2nd Part:

(i) Suspension type insulators are cheaper than pin type insulators for voltage beyond 33 kV.

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(ii) Each unit or disc of suspension type insulator is designed for low voltage, usually 11 kV. Depending upon the working voltage, the desired of discs can be connected in series.

(iii) If any one disc is damaged, the whole string does not become useless because the damaged disc can be replaced by the sound one.

(iv) The suspension arrangement provides greater flexibility to the line. The connection at the cross arm is such that insulator string is free to swing in any direction and can take up the position where mechanical stresses are minimum.

(v) In case increased demand on the transmission line, it is found more satisfactory to supply the greater demand by raising the line voltage than to provide another set of conductors. The additional insulation required for the raised voltage can be easily obtained in the suspension arrangement by adding the desired number of discs.

(vi) The suspension type insulators are generally used with steel towers. As the conductors run below the earthed cross-arm of the tower, therefore, this arrangement provides partial protection from lightning.

Long Answer Type Questions

1. Define string efficiency. State how with the help of guard rings string efficiency can be improved. **[WBUT 2008, 2012]**

OR,

State and explain what do you mean by string efficiency. **[WBUT 2013]**

Answer:

The voltage applied across the string of suspension insulators is not uniformly distributed across various units of discs. The disc nearer to the conductor must have higher potential than the others. But this unequal potential distribution is undesirable and is usually expressed in terms of string efficiency.

The ratio of voltage across the whole string to the product of number of discs and the voltage across the disc nearest to the conductor is known as **String Efficiency.**

i.e., **string efficiency** $= \dfrac{\text{Voltage across the string}}{n \times \text{Voltage across the disc nearest to conductor}}$

Where, $n \longrightarrow$ number of discs in the string.

Mathematical representation:

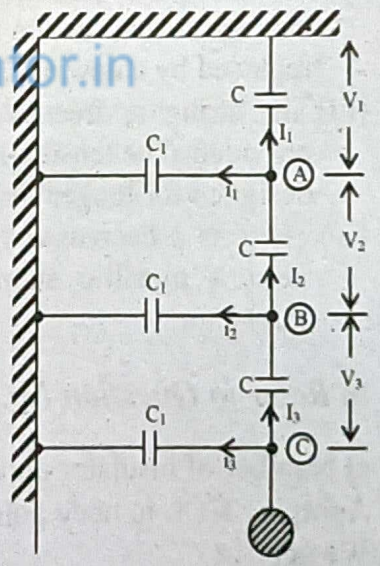
Consider the equivalent circuit diagram for three discs, where the capacitor for each disc is 'C'. And consider shunt capacitor as C_1

i.e., $C_1 = KC$

Where $K \longrightarrow$ factor

Starting form tower, the voltage across each unit is V_1, V_2 and V_3 respectively.

Applying KCL at node 'A'



$$I_2 = I_1 + i_1$$

or, $V_2\omega c = V_1\omega c + V_1\omega c_1$

or, $V_2\omega c = V_1\omega c + V_1\omega Kc$

or, $V_2 = V_1(1+k)$

Applying KCL at nose 'B'

$$I_3 = I_2 + i_2$$

or, $V_3\omega c = V_2\omega c + (V_1 + V_2)\omega c_1$

or, $V_3\omega c = V_2\omega c + (V_1 + V_2)\omega Kc$

or, $V_3 = V_2 + (V_1 + V_2)k$

or, $V_3 = KV_1 + V_2(1+K)$

$= KV_1 + V_1(1+K)^2 \left[\text{As } V_2 = V_1(1+K)\right]$

i.e., $V_3 = V_1\left[1 + 3K + K^2\right]$

Voltage between conductor & tower

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

$\therefore$ Voltage across for unit, $V_1 = \dfrac{V}{(1+3K+K^2)}$

So voltage across second unit from top $V_2 = V_1(1+K)$

Voltage across third unit, $V_3 = V_1(1+3K+K^2)$

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So for that string, the string efficiency

$$\% \text{ age string efficiency} = \frac{\text{Voltage across string}}{n \times \text{voltage aross disc nearest to conductor}} = \frac{V}{3 \times V_3} \times 100$$

2. a) Describe Suspension type insulator. **[WBUT 2012]**

b) What is string efficiency?

c) In a 33 kV overhead line, there are four units in the string insulator. If the capacitance between each insulator pin and earth is 11% of self capacitance of each insulator. Find

i) The distribution of voltage over 3 insulator

ii) String efficiency.

Answer:

a) A suspension insulator consists of a number of separate units connected with each other by metal links to form a flexible chain or a string. The insulator string is suspended from the cross arm of the support. The conductor is attached to the lowest unit.

Suspension insulators offer the following advantages:

(i) Each unit is designed for operating voltage of about 11kV, so that a string can be assembled by connecting several units to suit the service voltage and weather conditions.

(ii) In case the line is to be operate on a higher voltage in future to cope with the increasing load, additional units would be introduced to the same string. In case of damage to one of the units only the damage insulator, but not the whole string, is replaced by a new one.

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(iii) The string is free to swing in any direction and therefore greater flexibility is provided. The tension in the successive spans are balanced. The lines can therefore be designed for longer spans and higher mechanical loading.

(iv) There is a decreased liability to lightening disturbenance if the string is suspended from a metallic supporting structure, which works as a lightening shield for conductor.

b) ***Refer to Question No. 1 of Long Answer Type Questions.***

c) Number of insulator units, $n = 4$

Applying KCL to node points A and B, C

We get,

$$I_2 = I_1 + i_1$$

$$I_3 = I_2 + i_2$$

and $$I_4 = I_3 + i_3$$

$$\therefore \quad \omega C V_2 = \omega C V_1 + 0.11 C \omega V_1$$

$$\Rightarrow \quad \boxed{V_2 = V_1 + 0.11 V_1 = V_1 \cdot 1.11}$$

$$\therefore \quad \omega C V_3 = \omega C V_2 + \omega 0.11 C \cdot (V_1 + V_2)$$

$$\therefore \quad V_3 = V_2 + 0.11 V_1 + 0.11 V_2$$

$$\boxed{V_3 = 0.11V_1 + 1.11V_2} = 0.11V_1 + 1.11(V_1 + 0.11V_1) = 0.11V_1 + 1.2321V_1$$

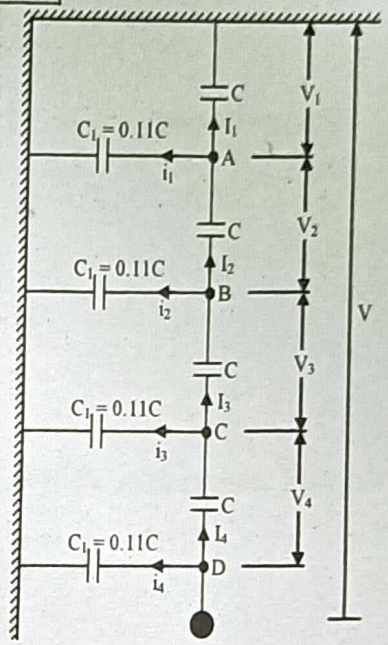
$$\Rightarrow \quad \omega C V_4 = \omega C V_3 + 0.11C\omega \cdot (V_1 + V_2 + V_3) \qquad \boxed{V_3 = 1.3421V_1}$$

$$\therefore \quad V_4 = V_3 + 0.11V_1 + 0.11V_2 + 0.11V_3$$

$$\Rightarrow \quad V_4 = 0.11V_1 + 0.11V_2 + (1.11)V_3$$

$$\therefore \quad = 0.11V_1 + 0.1221V_1 + 1.4897V_1$$

$$\boxed{\therefore \quad V_4 = 1.722V_1}$$



$\therefore$ Voltage between line conductor and earth:

$$V = V_1 + V_2 + V_3 + V_4$$

or, $$V = V_1 + 1.11V_2 + 1.3421V_1 + 1.722V_1$$

$$\therefore \quad V = 5.1739V_1$$

$$\therefore \quad V_1 = \frac{33}{5.1739} = 6.378\,\text{kV}$$

$$\therefore \quad V_2 = 1.11V_1 = 7.079\,\text{kV}$$

$$\therefore \quad V_3 = 1.3421V_1 = 8.56\,\text{kV}$$

$$\therefore \quad V_4 = 1.722V_1 = 10.98\,\text{kV}$$

$$\text{String efficiency} = \frac{33}{4 \times 10.98} \times 100 \qquad = 75.12\%$$

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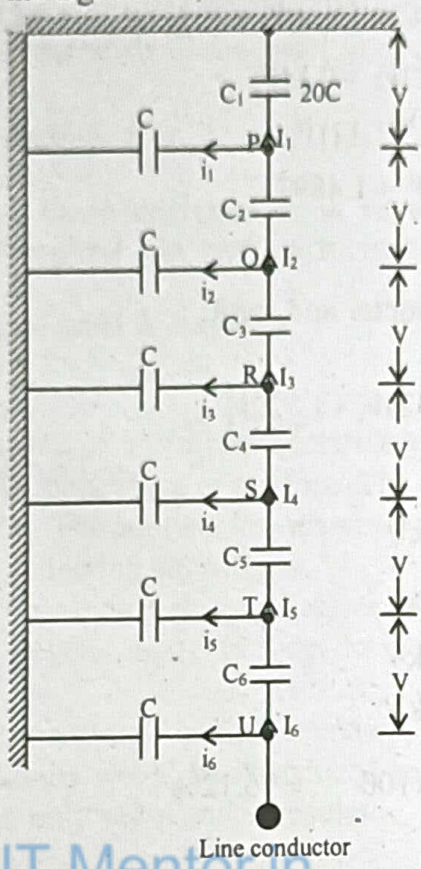
3. A string of 6 suspension insulators is to be graded to obtain uniform distribution of voltage across the string. If pin to earth capacitances are all equal to C and mutual capacitance of the top insulator is 20C, find the mutual capacitance of each unit in terms of C. [WBUT 2013]

Answer:

The arrangement is shown in the fig: below,



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Let the mutual capacitances be C_1, C_2, C_3, C_4, C_5 and C_6

Now, $C_1 = 20C$ .... Given

The voltage distribution is uniform so voltage across each unit is same denoted as V.

Applying Kirchhoff's current law at various nodes we get,

$I_2 = i_1 + I_1$ .... At Node P

$\therefore \frac{V}{X_{C2}} = \frac{V}{X_C} + \frac{V}{X_{C1}}$ .... But $X_C = \frac{1}{\omega C}$

$\therefore \omega C_2 V = \omega C V + \omega C_1 V$

$\therefore C_2 = C + C_1 = C + 20C$

$\therefore C_2 = 21C$ ... (1)

$I_3 = I_2 + I_2$ .... At node Q

$\therefore \frac{V}{X_{C3}} = \frac{(V+V)}{X_C} + \frac{V}{X_{C2}}$ .... But $X_C = \frac{1}{\omega C}$

Note that the voltage across C carrying current i_2 is V +V = 2V with reaspect to earth i.e. metal work of tower.

$\therefore \omega C_3 V = \omega C(2V) + \omega C_2 V$

$\therefore C_3 = 2C + C_2 = 2C + 21C$

$\therefore C_3 = 23C$ .... (2)

$I_4 = i_3 + I_3$ .... At node R

$\therefore \frac{V}{X_{C4}} = \frac{3V}{X_C} + \frac{V}{X_{C3}}$ ... But $X_C = \frac{1}{\omega C}$

The voltage across C, carrying current i_3 is V + V + V = 3V with respect to earth.

$\therefore \omega C_4 V = \omega C_3 V + \omega C_3 V$

$\therefore C_4 = 3C + C_3 = 3C + 23C$ .... (3)

$C_4 = 26C$ .... At node s

$I_5 = i_4 + I_4$

$\therefore \frac{V}{X_{C3}} = \frac{4V}{X_C} + \frac{V}{X_{C4}}$ .... But $X_C = \frac{1}{\omega C}$

The voltage across C, carrying current i_4 is V + V + V + V = 4V with respect to earth.

$\therefore \omega C_5 V = 4\omega CV + \omega C_4 V$

$\therefore C_5 = 4C + C_4 = 4C + 26C$

$\therefore C_5 = 30C$ .... (4)

And $I_6 = i_5 + I_5$ ..., At node T

$\therefore I_6 = i_5 + I_5$

$\therefore \frac{V}{X_{C6}} = \frac{5V}{X_C} + \frac{V}{X_{CS}}$ .... But $X_C = \frac{1}{\omega C}$

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The voltage across C_1 carrying current i_5 is V + V + V + V= 5V with respect to earth.

$\omega C_6 V = 5C_\omega V + \omega C_5 V$

$C_6 = 5C + C_5 = 5C + 30C = 35C$

Thus the mutual capacitances must be graded as 20C, 21C, 23C, 26C, 30C and 35C to obtain uniform voltage distribution.

4. a) Define string efficiency. Briefly explain one method of improving the efficiency. [WBUT 2015]

Answer:

String efficiency is the ratio of voltage across the whole string to the product of number of discs and the voltage across the disc nearest to the conductor.

$$\text{String efficiency} = \frac{\text{Voltage across the string}}{n \times \text{Voltage across the disc nearest to the conductor}}$$

where n = number of discs in the string efficiency decides the potential distribution along the string.

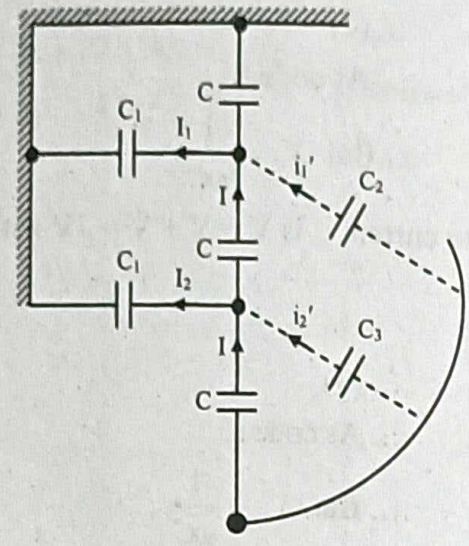

Fig: 1 Guard ring

The methods of improving the string efficiency are:

i) By using longer cross arm
ii) By grading the insulators
iii) By using a guard ring

Out of these three methods, use of guard ring is briefly explained.

The potential across each unit in a string can be equalised by using a guard ring which is a metal ring electrically connected to the conductor and surrounding the bottom insulator as shown in Fig. (1). The guard ring introduces capacitance between metal fittings and the line conductor. The guard ring is connected in such a way that shown capacitance currents i_1 and i_2 etc. are equal to metal fitting line capacitance currents i_1' and i_2' etc. The result is that same charging current I flows through each unit of string consequently there will be uniform potential distribution across the units.

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b) Each conductor of a 33 kV, 3 phase system is suspended by a string of three similar insulators. If the capacitance of each disc unit is five times the capacitance to ground of each unit, calculate
i) The voltage across each unit,
ii) String efficiency. **[WBUT 2015]**

Answer:

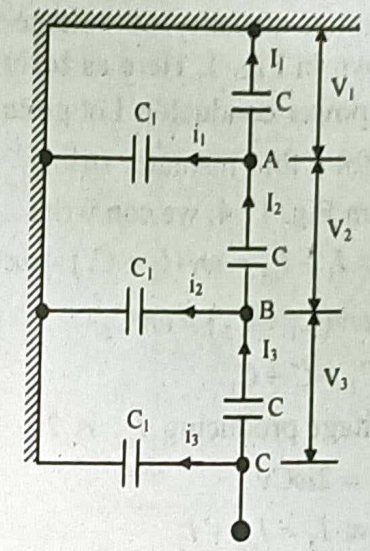
Assuming that self-capacitance is some fraction K of self-capacitance then we may write that –

$$K = \frac{\text{Shunt-capacitance}}{\text{Self-capacitance}} = \frac{1}{5} = 0.2$$

Voltage across string

$$V = \frac{33}{\sqrt{3}} = 19.05\,\text{kV}$$

$$C_1 = KC$$



At junction A

Applying KCL

$$I_2 = I_1 + i_1$$

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

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

$$V_2 = 1.2V_1$$

At junction B

$$I_3 = I_2 + i_2$$

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

$$V_3 = V_2 + (V_1+V_2)K = 1.2V_1 + (V_1 + 1.2V_1)0.2$$

$$V_3 = 1.2V_1 + 0.2V_1 + 0.24V_1$$

$$V_3 = 1.64V_1$$

Voltage across the whole string

$$V = V_1 + V_2 + V_3 = V_1 + 1.2V_1 + 1.64V_1$$

$$19.05 = 3.84V_1$$

(i) $\therefore \quad V_1 = \dfrac{19.05}{3.84} = 4.96\text{ kV}$

$$V_2 = 1.2V_1 = 5.95\text{ kV}$$

$$V_3 = 1.64V_1 = 8.134\text{ kV}$$

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(ii) String efficiency $= \dfrac{19.05}{3\times 8.134}\times 100\% = 78.06\%$ **(Ans.)**

5. a) What are the methods of equalizing potential distribution over a string of insulator?

b) In a string of three insulator unit, the self-capacitance of each unit is C, from each connector to ground is C/3 and from each connector to line is C/5. Calculate the voltage across each unit as a percentage of total voltage.

c) Name the different types of insulators. What is string efficiency? [WBUT 2016]

Answer:

a) The methods of equalizing potential are as under:

Selection of m

Performance of the string is dependent on the value of m, and as m is increased (by increasing length of cross arm which reduces C) the division of voltage becomes more equalized. But as stated earlier beyond a certain value of m, say $m=10$, it is uneconomical.

Grading of the Units

Since the voltage for a given current is inversely proportional to the capacitance, the unit nearest to the nearest to the cross arm should have the maximum capacitance in order to reduce the voltage across it. Further, as we move towards the power conductor the unit capacitance should progressively increase. By correct grading of the capacitances,

complete equality of voltage can be achieved. This is called capacitance grading as shown in Fig. 1. Here as before, we ignore the capacitance between the metal work and the power conductor. Let ground capacitances be C while mutual capacitances are C_1 to C_4 for a four insulator string.

From Fig. 17.4, we can write

$I_2 = I_1 + I_{c1} = \omega v(C + C_1) = \omega c C_2$

or $\omega v(C_1 + C_2) = \omega v C_2$

$\therefore C_2 = C + C_1$

Voltage producing I_{c2} is $2v$

$I_{c2} = 2\omega C v$

Now $I_3 = I_{c2} + I_2$

or $\omega C_3 v = 2\omega C v + \omega(C + C_1)v$

$\therefore C_3 = 3C + C_1 = C_1 + (1+2)C$

Thus we can write capacity for the nth unit as

$C_n = C_1 + (1 + 2 + 3 + ... + \overline{n-1})C$

If $C_1 = 5C$, then

$C_2 = 6C, C_3 = 8C, C_4 = 11C$ and so on

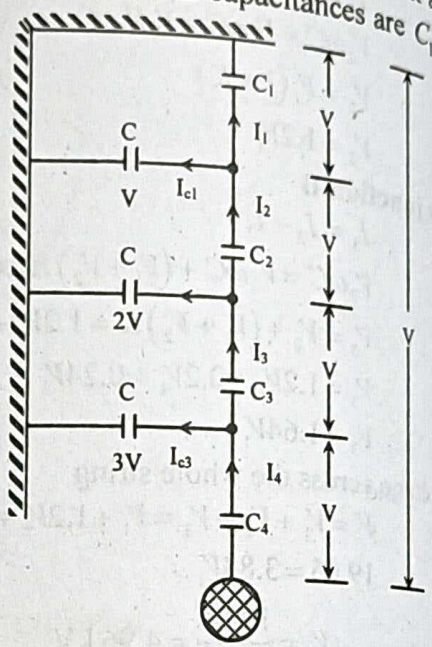

Fig. 1 Capacitance grading over a string of four insulators-unequal capacities

From this, it is clear that if the capacitance of one unit is fixed, the capacitance of other units can be determined for equal distribution of voltage across the units of the string. This, however, requires units of different capacities, which is uneconomical and impractical and, therefore, this method is usually not employed except for very high voltage lines, where the string is graded in groups, may be two/three.

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Static Shielding

The voltage distribution is equalized in this method by providing grading, or guard ring, in the from of a large metal ring surrounding the bottom unit and connected to the metal work at the bottom of this unit, and therefore to the line. This ring increases the capacitances between the string metal work and the line, which in fact, were neglected in our earlier analysis. The idea, thus, is to cancel exactly the pin to tower charging currents so that the same current flows through the units of identical capacities to produce equal voltage drops across each unit.

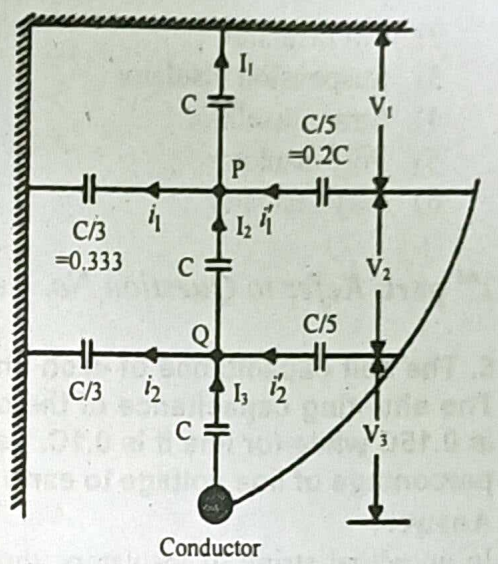
b) Let V_1, V_2 and V_3 be the voltage across the discs as shown in the figure.

Applying KCL at the node P, we get

$$I_2 + i_1' = I_1 + i_1$$

or, $$V_2\omega C + (V_2 + V_3)\omega \times 0.2C = V_1\omega C + 0.333V_1\omega C$$

or, $$V_2 + (V_2 + V_3) \times 0.2 = V_1 + 0.333V_1$$



$$V_2 + 0.2V_2 + 0.2V_3 = 1.333V_1$$

or, $1.2V_3 + 0.2V_3 = 1.333V_1$

or, $1.333V_1 - 1.2V_2 - 0.2V_3 = 0 \quad \ldots (1)$

Applying KCL at node Q, we have

$$I_3 + i_2' = I_2 + i_2$$

or, $V_3\omega C + 0.2V_3\omega C = V_2\omega C + (V_1 + V_2) \times 0.333\omega C$

or, $1.2V_3\omega C = V_2\omega C + (0.333V_1 + 0.333V_2)\omega C$

or, $1.2V_3 = V_2 + 0.333V_1 + 0.333V_2$

or, $1.2V_3 = 1.333V_2 + 0.333V_1$

or, $0.333V_1 + 1.333V_2 - 1.2V_3 = 0 \quad \ldots (2)$

There are three unknowns and two equations only. Hence we divide both the equations by V_3 and rewrite them as

$$1.333x - 1.2y = 0.2$$

or, $13.33x - 12y = 2 \quad \ldots (3)$

and $0.333x + 1.33y = 1.2$

or, $3.33x + 13.33y = 12$

where $x = \frac{V_1}{V_3}\ y = \frac{V_2}{V_3}$

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Solving (3) and (4) we get

$x = 0.70 = \frac{V_1}{V_3} \qquad y = 0.78 = \frac{V_2}{V_3}$

$V_1 = 0.7V_3 \qquad V_2 = 0.78V_3$

$\therefore V = V_1 + V_2 + V_3$

$= 0.7V_3 + 0.78V_3 + V_3 = 2.48V_3$

$V_3 = \frac{V}{2.48} = 0.403V = 40.3\%$ (Ans.)

$V_2 = 0.78 \times V_3 = 0.78 \times 0.403V = 0.314V = 31.4\%V$

$V_1 = 0.7V_3 = 0.7 \times 0.403V = 0.2821V = 28.21\%$

String efficiency $= \frac{V}{3 \times V_3} = \frac{V}{3 \times 0.403} = 0.8271 = 82.71\%$

c) 1st Part:

There are many types of insulators in use in the over-head system. The common types of which are as follows:

1) Shackle insulator

2) Pin insulator
3) Suspension insulator
4) Strain insulator
5) Post insulator
6) Guy insulator

2nd part: *Refer to Question No. 4 of Short Answer Type Questions.*

6. The self capacitance of each unit in a string of three suspension insulator is C. The shunting capacitance of the connecting metal work of each insulator to earth is 0.15C while for line it is 0.1C. Calculate (i) the voltage across each insulator as a percentage of line voltage to earth and (ii) string efficiency. [WBUT 2017]

Answer:

In an actual string of insulators, three capacitances exists viz., self capacitance of each insulator, shunt capacitance and capacitance of each unit to line as shown in Fig. (1) and (2) below:

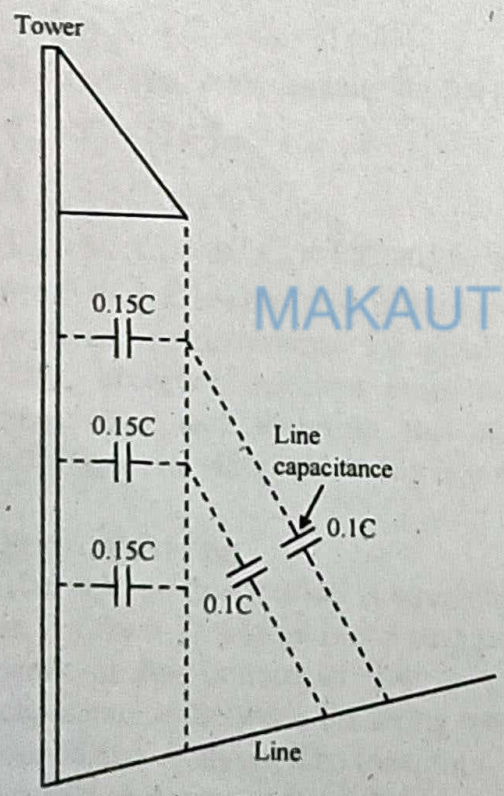

Fig: (1)

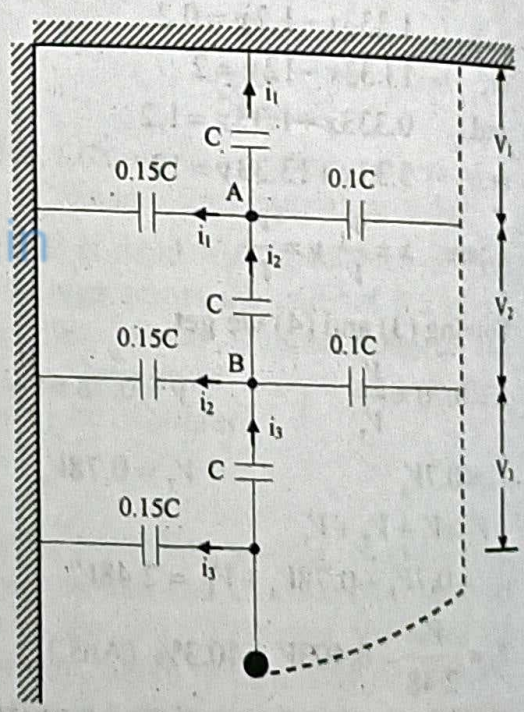

Fig: (2)

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At junction A,

$$I_2 + i_1' = I_1 + i_1$$

or, $V_2\omega C + (V_2 + V_3)0.1\omega C = V_1\omega C + 0.15CV_1\omega$

or, $0.1V_3 = 1.15V_1 - 1.1V_2$

or, $V_3 = 11.5V_1 - 11V_2$ .... (1)

At junction B,

$$I_3 + i_2' = I_2 + i_2$$

or, $$V_3\omega C + V_3 \times 0.1C \times \omega = V_2\omega C + (V_1 + V_2)\omega \times 0.15C$$

or, $$1.1V_3 = 1.15V_2 + 0.15V_1 \quad \text{.... (2)}$$

Putting the value of V_3 from exp. (1) into exp. (2) we get,

$$1.1(11.5V_1 - 11V_2) = 1.15V_2 + 0.15V_1$$

or, $$13.25V_2 = 12.5V_1$$

or, $$V_2 = \frac{12.5}{13.25}V_1 \quad \text{.... (3)}$$

Putting the value of V_2 from exp. (3) into exp. (1) we get,

$$V_3 = 11.5V_1 - 11\left(\frac{12.5V_1}{13.25}\right) = \left(\frac{14.8}{13.25}\right)V_1$$

Now voltage between conductor and earth

$$V = V_1 + V_2 + V_3 = V_1\left(1 + \frac{12.5}{13.25} + \frac{14.8}{13.25}\right) = \left(\frac{40.55}{13.25}\right)\text{Volts}$$

$$V_1 = \frac{13.25V}{40.55} = 0.326V \text{ Volts}$$

$$V_2 = 12.5 \times \frac{0.326V}{13.25} = 0.307V \text{ Volts}$$

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$$V_3 = 14.8 \times \frac{0.326V}{13.25} = 0.364V \text{ Volts}$$

(i) The voltage across each unit expressed as a percentage of V becomes.

$$\text{Top unit} = V_1 \times \frac{100}{V} = 0.326 \times 100 = 32.6\%$$

$$\text{Second from top} = V_2 \times \frac{100}{V} = 0.307 \times 100 = 30.7\%$$

$$\text{Third from top} = V_3 \times \frac{100}{V} = 0.364 \times 100 = 36.4\%$$

(ii) $$\text{String efficiency} = \frac{V}{3 \times 0.364} \times 100 = 91.5\%$$

7. a) What are the different types of insulator and where are they used?
b) Briefly explain the method of equalizing potential distribution of each disc of an string insulator.
c) Each of the three insulators forming a string has a self capacitance of C farads. The shunting capacitance of the connecting metal work of each insulator is 0.2C to earth and 0.1C to line. Calculate the voltage across each insulator as a percentage of the line voltage to earth and also the string efficiency of the arrangement.

[WBUT 2019]

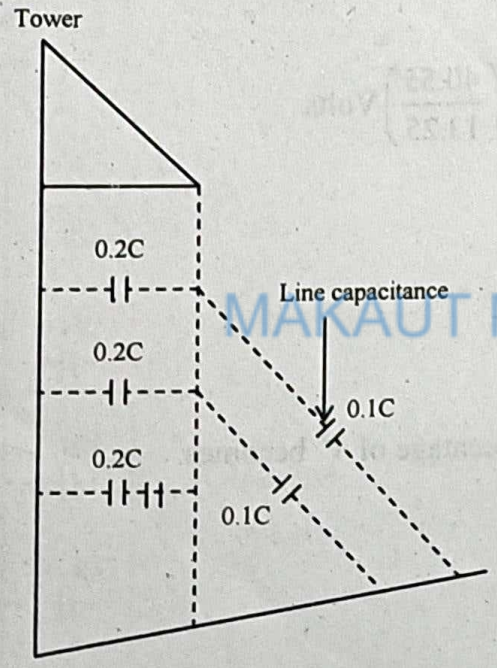
Answer:

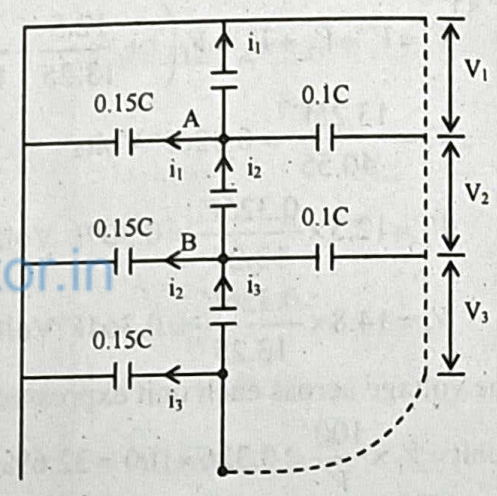
a) An insulator in the overhead transmission and distribution system not only provides support for the conductor but also keeps it insulated from other conductors and metal parts of the pole or tower. There are many types of insulators in use in the over-head system. They are:

- Shackle insulator
- Pin insulator
- Suspension insulator
- Strain insulator
- Post insulator
- Guy insulator

b) ***Refer to Question No. 5(a) of Long Answer Type Questions.***

c)





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At junction A,

$I_2 + i_1' = I_1 + i_1$

or, $V_2\omega C + (V_2 + V_3)0.1\omega C = V_1\omega C + 0.2CV_1\omega$

$0.1V_3 = 1.2V_1 - 11V_2$

$V_3 = 12V_1 - 11V_2$ .... (i)

At junction B,

$I_3 + i_2' = I_2 + i_2$

$V_3\omega C + V_3 \times 0.1C \times \omega = V_2\omega C + (V_1 + V_2) \times 0.2C$

$1.1V_3 = 1.2V_2 + 0.2V_1$ .... (ii)

Putting the value of V_3 from equation (i) into (ii) we get,

$$1.1(12V_1 - 11V_2) = 1.2V_2 + 0.2V_1$$

$$13V_1 = 13.3V_2$$

$$V_2 = \frac{13}{13.3}V_1$$

$$V_2 = 0.977V_1 \qquad \text{.... (iii)}$$

Putting the value of V_2 from (iii) into (i),

$$V_3 = 12V_1 - 11 \times 0.977V_1$$

$$V_3 = 1.253V_1$$

$$V = V_1 + V_2 + V_3 = V_1(1 + 0.977 + 1.253) = 3.23V_1$$

$$\therefore V_1 = \frac{1}{3.23}V = 0.30V \text{ volts}$$

$$V_2 = 0.977 \times 0.30 = 0.302V \text{ volts}$$

$$V_3 = 1.253 \times 0.30 = 0.375V \text{ volts}$$

$$\text{Top unit} = V_1 \times \frac{100}{V} = 0.30 \times 100 = 30\%$$

$$\text{Second from top} = V_2 \times \frac{100}{V} = 0.302 \times 100 = 30.2\%$$

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$$\text{Third from top} = V_3 \times \frac{100}{V} = 0.375 \times 100 = 37.5\%$$

$$\text{String efficiency} = \frac{V}{3 \times 0.375} \times 100 = 88.8\%$$

8. Write short notes on the following:

a) String Insulator Efficiency and methods of its improvement **[WBUT 2007]**

b) Techniques adopted for improvement of string efficiency. **[WBUT 2010]**

Answer:

a) String Insulator Efficiency and methods of its improvement:

Refer to Question No. 1 of Long Answer Type Questions.

b) Techniques adopted for improvement of string efficiency:

The methods of improvement of string efficiency are-

1) Long cross arm method
2) Capacitance Grading Method
3) Static Shielding

1) Long cross arm method:

The value of string efficiency increases with decrease in value of K. The value of K can be decreased by reducing shunt capacitance. This requires long cross arms and hence

taller supporting structures; as such it is uneconomical to go beyond certain value of length of cross arm.

2) Capacitance Grading Method:

Unequal distribution of voltage is due to leakage current from insulator pin to the tower structure. This makes voltage unequal. To make the voltages equal the discs of the string are used of different capacitances, such that product of their capacitive reactance and current flowing through the respective unit is same. This requires that the unit nearest the cross arm should have the minimum capacitances .By this grading method complete equality of voltages can be obtained.

The disadvantage of this method is that large number of different sized insulators are required .This method is very inconvenient and not used in practice below 200 kV.

3) Static Shielding:

In static shielding, the idea is to cancel exactly the pin to tower charging current so that same current flows through units of identical capacities to produce equal voltage drop across each unit.

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CORONA

Multiple Choice Type Questions

1. Corona loss can be reduced by using [WBUT 2009]
   a) solid conductor of diameter 'd' b) hollow conductor of diameter '$d+\delta d$'
   c) bundle conductor d) both (a) and (b)
   e) both (b) and (c)

Answer: (c)

2. Corona loss is less when the shape of the conductor is [WBUT 2011]
   a) circular b) flat c) oval d) independent of shape

Answer: (a)

3. Corona loss increases with [WBUT 2011]
   a) increase in supply frequency and conductor size
   b) increase in supply frequency but reduction in conductor size
   c) decrease in supply frequency and conductor size
   d) decrease in supply frequency but increase in conductor size

Answer: (b)

4. Corona is accompanied by [WBUT 2012]
   a) violet visible discharge in darkness b) hissing sound
   c) vibration d) all of these

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Answer: (d)

5. The current drawn by the line owing to corona loss is [WBUT 2014]
   a) non-sinusoidal b) sinusoidal
   c) dc d) square

Answer: (a)

6. Bundle conductor are used to [WBUT 2018]
   a) reduce inductance of the line
   b) reduce corona loss
   c) reduce both inductance and capacitance
   d) reduce corona loss and line inductance

Answer: (d)

7. Corona occurs between two transmission conductors when they [WBUT 2018]
   a) have high potential difference b) are closely spaced
   c) carry dc power d) both (a) and (b)

Answer: (d)

8. If the corona loss for 25 Hz frequency is 100 kW, then for 75 Hz it will be [WBUT 2019]
   a) 100 kW b) 200 kW c) 50 kW d) 25 kW

Answer: (b)

Short Answer Type Questions

1. Derive the expression of critical disruptive voltage of corona. [WBUT 2012, 2014, 2017, 2018]

Answer:

The minimum voltage at which the breakdown of the insulating properties of air occurs and corona starts is called the disrupting critical voltage. The potential gradient corresponding to this value of the voltage is known as disruptive critical voltage gradient.

Disruptive critical voltage for a single phase line

Let E = voltage between the conductors = line to line voltage in volts

r = radius of each conductor in m

D = spacing between the conductors in m.

We know that, $E = \frac{q}{\pi\varepsilon}\ln\frac{D}{r}V$ .... (1)

The electric field intensity or voltage gradient at the conductor surface of radius r is given by $G_r = \frac{q}{2\pi\varepsilon r}$ .... (2)

where q is the charge on the conductor per meter length and ε is the permittivity of the medium combination of equations (1) and (2) gives

$$E = 2rG_r \ln\frac{D}{r} \quad .... (3)$$

Accordingly to F.W. Peek for air under conditions near sea level at 25°C and at atmospheric pressure of 760mm of mercury without impurities, the maximum value of voltage gradient at which ionization of air starts is about 3×10^6 V/m (30 KV/cm). That is, the maximum value of the voltage gradient is the disruptive critical voltage gradient. The voltage corresponding to this voltage gradient is the disruptive critical voltage.

Let $E_{o\max}$ = maximum value of disruptive critical voltage in volts.

$G_{o\max}$ = maximum value of disruptive critical value gradient in V/m

Substituting these values in equation (3), gives

$$E_{o\max} = 2rG_{o\max}\ln\frac{D}{r} \qquad \text{But, } G_{o\max} = 3\times10^6 \text{ V/m}$$

$$\therefore \quad E_{o\max} = 2r\times3\times10^6\ln\frac{D}{r}$$

The rms value of the disruptive critical voltage for a single-phase line is given by

$$E_o = \frac{1}{\sqrt{2}}E_{o\max} = \frac{1}{\sqrt{2}}\times6\times10^6 r\ln\frac{D}{r}V$$

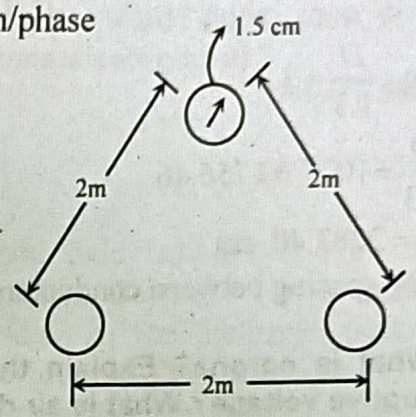
where r and D are in meters.

2. A 3-phase, 220 KV, 50 Hz transmission line consists of 1.5 cm radius conductors spaced 2 m apart in equilateral triangular formation. If the temperature is 40° C and atmospheric pressure is 76 cm. Calculate the corona loss per km of the line. Take irregularity factor is 0.85. [WBUT 2012, 2017]

Answer:

Power loss due to corona is given by

$$P = 242.2\left(\frac{f+25}{\delta}\right)\sqrt{\frac{r}{d}}(V-V_C)^2 \times 10^{-5} \text{ kw/km/phase}$$



where f = supply frequency in Hz

V = phase neutral voltage (r.m.s)

V_C = disruptive voltage (r.m.s) per phase.

$$V_{Ph} = \frac{200}{\sqrt{3}} kV,\ \delta = 0.85,\ r = 1.5\times10^{-2}\text{m},\ d = 2\text{m}$$

$$V_C = r_{go}\ln\frac{D}{r} = 1.5\times21.21\ln\frac{2}{1.5\times10^{-2}} = 105.66\text{kV}$$

$$P = 242.2\left(\frac{50+25}{0.85}\right)\sqrt{\frac{1.5}{200}}(115.47-105.66)^2\times10^{-5} \text{ kW/km/phase}$$

$= 1.781$ kW/km/phase

3. A three phase line has conductors 2 cm in diameter spaced equilaterally 1m apart. If the dielectric strength of air is 30 kV (peak)/cm, find the disruptive critical voltage for the line. Take air density correction factor $\delta = 0.952$ and irregularity factor $md = 0.9$. [WBUT 2013]

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Answer:

Conductor radius $r = 2/2 = 1$ cm

Conductor spacing $d = 1$ m = 100cm

Dielectric strength of air

$g_0 = 30$ kV/cm (max.) = 21.2 kV (r.m.s.)/cm

Disruptive critical voltage

$$V_C = m_d g_0 \delta r \log\left(\frac{d}{r}\right) \text{kV/phase} = .9\times21.2\times0.952\times1\times10\text{g } 100/1 = 83.64 \text{ kV/phase}$$

$\therefore$ Line voltage (r.m.s.) $= \sqrt{3}\times83.64 = 144.8$ kV Ans.

4. A 220 kV three phase transmission line with conductors radius 1.3 cm is built so that corona takes place if the line voltage exceeds 260 kV (rms). Find the spacing between conductors. [WBUT 2014]

Answer:

Corona takes place at

$$V_v = 48.8 m_v \delta r\left(1+\frac{0.3}{\sqrt{\delta r}}\right)\log_{10}\frac{D}{r} \text{ kV/phase}$$

For smooth conductor $(m_v) = 1$

Air density factor $\delta = 1$

Radius of the conductors = 1.3 cm

And D = The spacing between conductors in cm

$$\therefore V_v = 260 = 48.8 \times 1 \times 1.3\left(1+\frac{0.3}{\sqrt{1.3}}\right)\log_{10}\frac{D}{1.3}$$

$$\therefore \log_{10}\frac{D}{1.3} = 3.24$$

$$\therefore \frac{D}{1.3} = 10^{3.24} = 1756.46$$

$$\therefore D = 2283.40 \text{ cm}$$

$\therefore$ The spacing between conductors = 2283 cm = 2.283 m .

5. What is corona? Explain the principle of corona formation. What is critical disruptive voltage? What is air density factor? [WBUT 2016]

Answer:

1st Part: ***Refer to Question No. 1(a) of Long Answer Type Questions.***

2nd Part:

Principle of Corona Formation

When the potential gradient reaches at $30kV/cm$, the velocity acquired by the free electrons is sufficient to strike the neutral molecule with sufficient force to dislodge one or more electrons from it. These dislodged electrons and the pervious free electrons strike other neutral molecules and as a result, a cumulative action occurs and that finally destroys the insulating property of the air. The air becomes conducting.

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3rd Part: ***Refer to Question No. 1 of Short Answer Type Questions.***

4th Part:

From the experimental results obtained by peek, the critical disruptive voltage for rough and dirty conductors is lower than that of smooth conductors. It is calculated by the formula $m_0\delta V_{d0}$, where δ is the air density factor and m_0 is the irregularity factor. Under normal weather conditions, the value of δ being 1, the critical disruptive voltage is equal to $m_0\delta V_{do}$ and the value of m_0 varies from 0.8 to 1 during unfair weather conditions. The value of δ is calculated by the formula; $\frac{3.92b}{273+t} = \delta$ where, b is the barometric pressure in centimeter of mercury and t, the temperature in degree centigrade.

Now the critical disruptive voltage, $V_{d0} = g_0 m_0 \delta r \ln\frac{D}{r} V/phase\ (r.m.s)$.

6. Briefly explain the factors effecting corona loss. [WBUT 2019]

Answer: ***Refer to Question No. 1(b) of Long Answer Type Questions.***

Long Answer Type Questions

1. a) What is corona? **[WBUT 2006, 2007, 2009, 2012]**
b) What are the factors affecting corona? **[WBUT 2006, 2009, 2015]**
c) How are the corona effects reduced in overhead transmission lines? **[WBUT 2006]**

OR,

How to reduce corona effect? **[WBUT 2012]**

Answer:

a) A small discharge current is created in the electric field between two parallel conductors of a transmission line with high potential gradient. Beyond a certain critical voltage gradient (typically 30 kV/cm), electric breakdown of the dielectric medium occurs between the two conductors, establishing an arc between these two conductors accompanied by a violet luminous glow associated with a hissing sound around the conductor. The brightest part of the glow is visible near the rough surface of the conductor. This phenomenon is known as corona. Corona produces power loss and is dependent upon weather condition. During humid and moist climate, corona loss is higher. It should be noted that if the spacing between conductors is not large with respect to their diameter, spark-over may take place before corona is observed. Corona discharge is further prominent as the electric field intensity goes up. In EHV AC transmission lines, the visible glow of corona is uniform about both the conductors whereas in HVDC transmission system, the glow is uniform about the positive wire but spotty about the negative wire.

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b) Factors affecting corona:

1. **Effect of frequency:** Corona loss is directly proportional to system frequency.
2. **Effect of system voltage:** With increase in system voltage, the electric field increases and hence corona loss also increases in a steep way. Figure (a) represents the profile of a corona loss curve with change in system voltage.
3. **Effect of conductivity of air:** If the number of ions in air increases, the conductivity of air also increases. During rain and thunderstorms, ion content in the air enhances and thus corona loss becomes high during bad weather conditions.
4. **Effect of conductor diameter:** The electric field intensity reduces with increase in conductor size (i.e. diameter). Hence, with greater conductor diameters, the electric field intensity reduces, resulting in lower corona loss.
5. **Effect of load current:** The flow of the load current increases the temperature of the conductor. Thus, it prevents deposition of dew or snow on the conductor's surface. This reduces corona loss.
6. **Effect of conductor's surface:** Roughness of the conductor's surface results in field distortion and gives rise to high potential gradient, causing higher corona loss.
7. **Effect of atmospheric condition:** Rain drop and dust deposition increase corona loss, particularly local corona discharge. If the density of air decreases, corona loss increases. Figure (a) represents the effect of rain on corona loss.

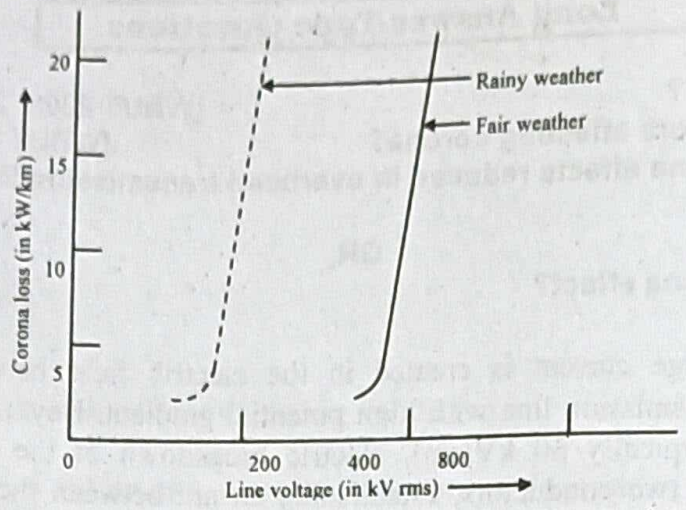

Fig: (a) Effect of line voltage on corona loss

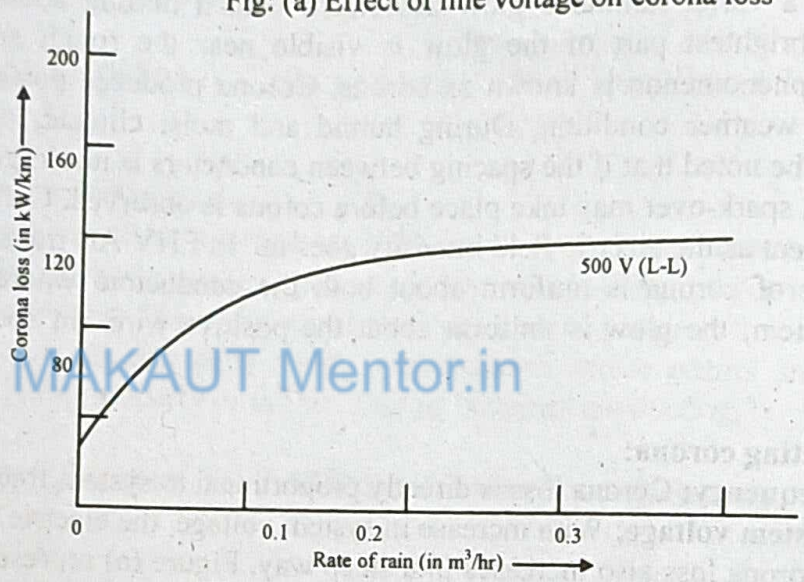

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Fig: (b) Effect of rate of rain on corona loss

c) Reduction of Corona:

Intense corona effects are observed even at a working voltage of 33 kV or above. Therefore, design should be made carefully to avoid corona on the sub-stations or bus bars rated for 33 kV and higher voltage. Otherwise, highly ionised air may cause flash over in the insulator or between the phases, causing considerable damage to equipment. The corona effect may be reduced by the following methods:

1. **By increasing conductor size:** With increase in the conductor size (diameter), the potential gradient decreases. By increasing the conductor size, the voltage at which corona occurs may be raised. This is one of the reasons why ACSR conductor (bundled conductor) having large cross sectional area are extensively used in transmission lines.
2. **By increasing conductor spacing:** With increase in conductor spacing, the voltage at which corona occurs is increased and hence corona effects can be eliminated. However, the cost of tower increases with increase in spacing between conductors and as a result, there is an increase in inductive reactance resulting in higher voltage drop in the line.

2. a) What are the characteristic features of corona ? [WBUT 2007, 2012]
b) What are the advantages and disadvantages of corona?[WBUT 2007, 2010, 2012]

Answer:

a) ***Characteristic features:***

1) Corona occurs when the electrostatic stress in the air around the conductors exceeds 30 kV maximum/cm or 21 kV rms/cm.
2) If the conductors are smooth and polished, the corona glow is uniform along their length
3) If there are any roughness they will be picked up by relatively brighter illumination
4) In the case of conductors with spacing shorter as compared to their diameters sparking may take place without any visible glow.

b) ***Advantages of Corona:***

1. Owing to corona formation the air surrounding the conductor becomes conductive consequently the virtual diameter of the conductor increases resulting in reduced electrostatic stress between the conductors. Thus flash-over possibility is reduced and there is an improvement in the system performance.
2. The effects of transients produced by surges are reduced.

Disadvantages of Corona:

1. There is a loss of power (more prominent under abnormal weather conditions) which affects transmission efficiency of the line.
2. Due to corona formation ozone gas is produced and causes corrosion.
3. Due to non-sinusoidal corona current there is a non-sinusoidal voltage drop which may cause some interference with neighbouring communication circuits due to electromagnetic and electrostatics induction.
4. Due to the distortion of wave form, the harmonics (predominant by 3rd harmonic) are introduced into the transmission line. These harmonics increase corona loss.

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3. A certain 3-phase equilateral transmission line has a total corona loss of 53 kW at 106 kV and a loss of 98 kW at 111 kV. What is the disruptive critical voltage between lines? What is the coronal loss at 113 kV? [WBUT 2008, 2012]

Answer:

Corona Power loss

$$P_C = \frac{244}{\delta}(f+25)(E_n - E_o)(E_n - E_o)^2\sqrt{\frac{r}{D}} \times 10^{-5} \text{ KW/Km/Phase}$$

where P_C = Corona Power loss

f = Frequency of supply in Hz

δ = air density factor

E_n = r.m.s phase voltage (line-to-neutral voltage) in kV

E_o = Disruptive critical voltage per phase in kv (r.m.s.)

r = Radius of conductor in metres.

D = Spacing between conductors in metres.

For two phase $E_n = \frac{1}{2} \times$ line voltage

Three phase $E_n = \frac{1}{\sqrt{3}} \times$ line voltage for this problem power loss of 53 kW of 106 kV

i.e.

$$53 = \frac{244}{\delta}(50+25)\left(\frac{106}{\sqrt{3}} - E_o\right)^2 \sqrt{r/D} \times 10^{-5} \quad \ldots \text{(i)}$$

Power loss 98 kW at 111 kV.

$$98 = \frac{244}{\delta}(50+25)\left(\frac{111}{\sqrt{3}} - E_o\right)^2 \sqrt{\frac{r}{D}} \times 10^{5} \quad \ldots \text{(ii)}$$

Do, $(i \div ii)$

$$53/98 = \frac{\left[\frac{106}{\sqrt{3}} - E_o\right]^2}{\left[\frac{111}{\sqrt{3}} - E_o\right]^2} \quad \text{or } 0.7354 = \left(\frac{61.2 - E_o}{64.08 - E_o}\right) \quad \text{or } E_o = 53.174\text{KV}$$

Again from the equation (i)

$$53 = \frac{244}{\delta}(75)\left(\frac{106}{\sqrt{3}} - E_o\right)^2 \sqrt{r/D} \times 10^{-5}$$

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i.e. $$53/(8.0269)^2 = \frac{244}{\delta}(75)\sqrt{r/D} \times 10^{-5}$$

Corona loss for 113 kV

$$P_C = \frac{244}{\delta}(75)\left[\frac{113}{\sqrt{3}} - 53\right]^2 \sqrt{r/D} \times 10^{-5} = 0.82258 \times \left(113/\sqrt{3} - 53\right)^2 = 123.287 \text{ kW.}$$

4. Find the disruptive critical and visual corona voltages of a grid line operating at 132 kV. The following data is given:
Conductor dia = 1.9 cm, conductor spacing = 3.81 m, temperature = 44°C, barometric pressure = 73.7 cm, conductor surface factor : fine weather = 0.8, rough weather = 0.66. **[WBUT 2009]**

Answer:

Conductor diameter $d = 190\,\text{mm}$

Conductor radius $r = 0.5 \times d = 0.5 \times 190 = 95\,\text{mm}$

Conductor spacing $D = 3.81\,\text{m}$

Breakdown strength of air $= 21.1\text{kV(rms)} = 2.11 \times 10^6$ V/m

Temperature $= 44°\text{C}$

Safety factor = 0.85

Air density factor, $\delta = \frac{0.392\,p}{273+t} = \left[\frac{0.392 \times 737}{273+44}\right] = 0.91136$

The disruptive critical r.m.s voltage per phase is given by,

$$E_0 = G_0 m_0 r\delta \ln\frac{D}{r} = 2.11\times10^6\times0.85\times0.095\times0.91136\times\ln\left\{\frac{3.81}{0.095}\right\} = 573.216\,\text{kV}$$

For local fine weather $m_v = 0.8$

Visual critical r.m.s voltage per phase for local corona (fine weather)

$$E_v = G_0 m_v r\,\delta\left[1+\frac{0.0301}{\sqrt{r\delta}}\right]\ln\frac{D}{r}$$

$$= 2.11\times10^6\times0.8\times0.095\times0.91136\times\left[1+\frac{0.0301}{\sqrt{0.095\times0.91136}}\right]\times\ln\frac{3.81}{0.095}$$

For rough weather, $m_v = 0.66$

The visual critical r.m.s voltage,

$$E_v = 2.11\times10^6\times0.66\times0.095\times0.91136\times\left[1+\frac{0.0301}{\sqrt{0.095\times0.91136}}\right]\times\ln\left(\frac{3.81}{0.095}\right) = 452.53\,\text{kV}$$

5. a) What is corona? **[WBUT 2011]**

Answer: ***Refer to Question No. 1(a) of Long Answer Type Questions.***

b) What is meant by the "disruptive critical voltage" and "visual critical voltage"? **[WBUT 2011]**

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Answer:

Disruptive Critical Voltage:

If it is assumed that:

M_0 = irregularity factor which takes into account the surface conditions of the conductor.

D = distance between wire centers in cm.

r = radius of conductor in cm.

δ = air density factor, then the effective disruptive critical voltage to neutral is given by the relation:

$$V_c = 21.1 M_0 r\delta \times 2.3\log_{10} D/r\,\text{KV}$$

The value of δ is given by:

$$\delta = \frac{3.92b}{273+t}$$

Where b is the barometric pressure in cm. of Hg, t = temperatures in degrees centigrade.

When $b = 76$ and t = 25°, $\delta = 1$

The irregularity factor M_0 depends on the shape of the cross-section of the wire and the state of the surface. Its value is unity for an absolutely smooth wire of one strand of circular section and less than unity for wires roughened due to weathering.

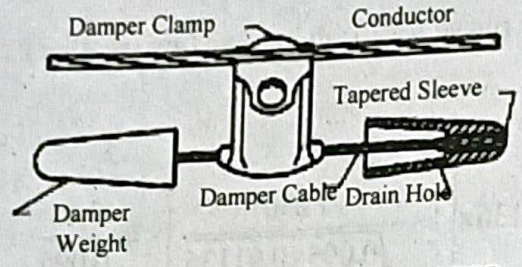
Visual Critical Voltage: In case of parallel wires it is found that visual corona occurs at voltage higher than V_{do}, which may be called as *Visual critical voltage* and denoted by V_{vo}. The visual corona will occur when the break down value is attained at a distance of r $(1+0.3/\sqrt{\delta r})$ log e kV to neutral (r.m.s).

c) How can the corona loss be minimised in a transmission line? **[WBUT 2011]**

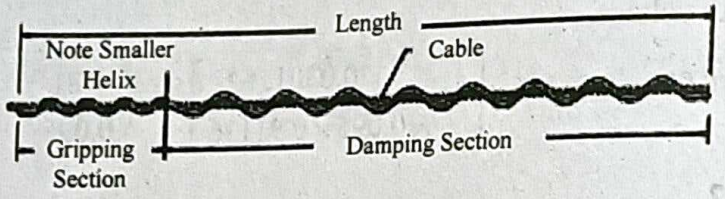
Answer: ***Refer to Question No. 1(b) of Long Answer Type Questions.***

d) Why are vibration dampers required in a transmission line? **[WBUT 2011]**

Answer:



TYPICAL SUSPENSION DAMPER



Spiral Vibration Damper for Small Conductors

Vibration Dampers are used to absorb Aolian Volian Vibrations of conductor of Transmission Lines, as well as ground wire, OPGW, and ADSS. It is mostly composed of the following; Weighs – made up of cast iron, Clamp – made up of Aluminium Alloy, Nuts and Bolts made up of galvanized or stainless steel and Messenger cable made up of Galvanized Steel.

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Vibration Dampers are used in areas of severe vibration. Dampers act to decrease aolian vibration amplitudes thereby reduce the dynamic bending stress at hardware location and extend conductor life. These fatigues stresses have maxima at suspension and dead end attachments.

6. What is corona? What are the advantages and disadvantages of corona? How can corona be minimized? **[WBUT 2017]**

Answer:

1st part: ***Refer to Question No. 1(c) of Long Answer Type Questions.***

2nd Part: ***Refer to Question No. 2(b) of Long Answer Type Questions.***

3rd Part: ***Refer to Question No. 1(c) of Long Answer Type Questions.***

7. Write short notes on Critical disruptive voltage. **[WBUT 2019]**

Answer:

Refer to Question No. 1 of Short Answer Type Questions.

UNDERGROUND CABLES

Multiple Choice Type Questions

1. The electric stress in a cable is maximum at [WBUT 2007, 2016]
   a) center of conductors
   b) interface of sheath and conductors
   c) lead sheath
   d) armour

Answer: (c)

2. The insulation resistance of a cable of length 10 km is 1 Meg-ohms. The resistance for 50 km length will be [WBUT 2007, 2011]
   a) 1 Meg-ohms
   b) 5 Meg-ohms
   c) 0.2 Meg-ohms
   d) none of these

Answer: (c)

3. The surge impedance of a 100 km long underground cable is 50 ohms. The surge impedance of a 40 km long similar cable would be [WBUT 2008, 2010]
   a) 20 ohms
   b) 50 ohms
   c) 80 ohms
   d) 125 ohms

Answer: (b)

4. The capacitance between any two conductors of a 3-core cable with sheath earthed is 3μF. The capacitance per phase will be [WBUT 2011, 2013, 2014]
   a) 1.5μF
   b) 6μF
   c) 1μF
   d) none of these

Answer: (d)

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5. In a 3-core cable, the capacitance between two conductors is 3mF. What will be the capacitance per phase? [WBUT 2017]
   a) 1.5μF
   b) 3μF
   c) 6μF
   d) 12μF

Answer: (c)

6. In a cable the sheath radius is R and conductor radius is r. As r changes from 0.5R to 0.25 R to maximum voltage gradient in the dielectric. [WBUT 2018]
   a) decrease by about 6%
   b) increase by about 6%
   c) decrease by about 15%
   d) increase by about 15%

Answer: (b)

7. The surge impedance of a 50 miles long underground cable is 25 Ω. For a 25 miles length it will be [WBUT 2019]
   a) 50 Ω
   b) 100 Ω
   c) 25 Ω
   d) 200 Ω

Answer: (a)

8. If r is the radius of the conductor and R is the radius of the sheath of the cable, the cable operates stably from the view point of dielectric strength is [WBUT 2019]
   a) $\frac{r}{R} > 1.0$
   b) $\frac{r}{R} < 1.0$
   c) $\frac{r}{R} < 0.632$
   d) $\frac{r}{R} < 0.368$

Answer: (d)

9. If δ is the loss angle of the cable, its power factor is [WBUT 2019]
a) independent of δ b) $\cos\delta$
c) $\sin\delta$ d) none of these
Answer: (c)

Short Answer Type Questions

1. Derive the relation between the conductor radius and inside sheath radius of a single core cable so that the electric stress of the conductor surface is minimum. [WBUT 2007]

Answer:
Let say, r be the radius of the conductor & R the inner radius of the Sheath, & k be the permittivity of the dielectric, q the charge in C/m of axial length.

$g = \frac{q}{2\pi kx} V/m$ i.e. the electric field intensity (gradient) at a distance 'x' from the centre of the conductor.

Now, $$V = \int_r^R g.dx = \int_r^R \frac{q}{2\pi kx} dx = \frac{q}{2\pi k} I_n \frac{R}{r}$$

So from these two equation, $$g = \frac{V}{x\, In\, R/r}$$

For maximum electric stress in the cable dielectric will occur at the surface of the conductor i.e. at $x_{min} = r$ and is given by, $g_{max} = \frac{V}{r\, In\, R/r}$

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and the gradient is minimum at $x_{max} = R$ i.e.

$g_{min} = \frac{V}{R\, In\, R/r}$ and $g_{max}/g_{min} = \frac{R}{r}$

It may be noted that to keep a fixed overall size of the cable (R) for given V, there is a particular r which minimizes g_{max} i.e., we have to maximize "$r\, In\, R/r$", which occurs when $\ln R/r = 1$ or $R/r = e = 2.71882$.

2. Prove that g_{max}/g_{min} in a single core cable is equal to D/d. [WBUT 2012]

OR,

Prove that $g_{max}/g_{min} = D/d$ in a single core cable. [WBUT 2013]

Answer:
Let the diameter of core and internal sheath be d and D respectively.
Again, we know, the electric intensity at a point P metres from the centre of the cable is

$$E_x = \frac{Q}{2\pi\varepsilon_0\varepsilon_r P} \text{ volt/m}$$

By definition, electric intensity is equal to potential gradient.

∴ The potential gradient g at a point P metres from the centre of the cable is

$$g = E_x$$

$$\therefore \quad g = \frac{Q}{2\pi\varepsilon_0\varepsilon_r P} \text{ volts/m} \quad \text{.... (i)}$$

Again, it is proved that, the potential difference V between conductor and sheath is

$$V = \frac{Q}{2\pi\varepsilon_0\varepsilon_r}\log_e\frac{D}{d} \text{ volts.}$$

$$\therefore \quad Q = \frac{2\pi\varepsilon_0\varepsilon_r V}{\log_e\frac{D}{d}} \quad \text{.... (ii)}$$

Now, putting the value of Q from equation (ii) in equation (i), we get

$$\therefore \quad g = \frac{2\pi\varepsilon_0\varepsilon_r V}{2\pi\varepsilon_0\varepsilon_r P\log_e\frac{D}{d}} = \frac{V}{P\log\frac{D}{d}} \text{ volts/m.}$$

In the above expression we see that the potential gradient varies inversely as the distance P.

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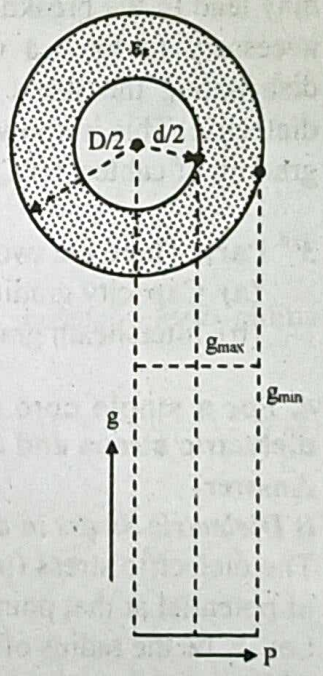

∴ g will be maximum when P is minimum i.e., $P = \frac{d}{2}$

i.e., surface of the conductor.

$$\therefore \quad g_{max} = \frac{2V}{d\log_e\frac{D}{d}} \text{ volts/m}$$

and g will be minimum at $P = \frac{D}{2}$ i.e., P is maximum

i.e., at sheath surface.

$$\therefore \quad g_{min} = \frac{2V}{D\log_e\frac{D}{d}}$$

From the above two expression we get,

$$\frac{g_{max}}{g_{min}} = \frac{\frac{2V}{d\log_e\frac{D}{d}}}{\frac{2V}{D\log_e\frac{D}{d}}} = \frac{D}{d}$$

$$\therefore \quad \frac{g_{max}}{g_{min}} = \frac{D}{d}$$ **(Proved).**

3. What is grading of cable? Why is it necessary? How many types of grading are there? **[WBUT 2015, 2018]**

Answer:

1st Part: The process of achieving uniform electrostatic stress in the dielectric of cables is known as grading of cables.

2nd Part: It is known that electrostatic stress in a single core cable has a maximum value (g_{max}) at the conductor surface and goes on decreasing as we move towards the sheath. The maximum voltage that can be safely applied to a cable depends upon g_{max} i.e., electrostatic stress at the conductor surface. For safe working of a cable having homogeneous dielectric, the strength of dielectric must be more than g_{max}. If a dielectric of high strength is used for a cable, it is useful only near the conductor where stress is maximum. But as we move away from the conductor, the electrostatic stress decreases, so the dielectric will be unnecessarily overstrong.

The unequal stress distribution in a cable is undesirable for two reasons. Firstly, insulation of greater thickness is required which increases the cable size. Secondly, it may lead to the breakdown of insulation. In order to overcome above disadvantages, it is necessary to have a uniform stress distribution in cables. This can be achieved by distributing the stress in such a way that its value is increased in the outer layers of dielectric. This is known as grading of cables. The following are the two main methods of grading of cables: (i) Capacitance grading, (ii) Intersheath grading.

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3rd Part: There are two methods of obtaining it:

(a) Capacity grading and

(b) Intersheath grading.

4. For a single core lead sheathed cable derive the expressions for (i) maximum dielectric stress and (ii) capacitance. **[WBUT 2016]**

Answer:

i) Dielectric Stress in a Cable

The dielectric stress (or potential gradient) at any point is defined as the rate of increase of potential at that point.

Let, r be the radius of the conductor

R be the inner radius of the conductor

q be the charge per meter axial length

The potential gradient at a distance xm from the center of the conductor within the dielectric material, $g = \dfrac{q}{2\pi\varepsilon x}$ ... (1)

is also equal to the electric field intensity, E where, ε is the permittivity of the dielectric material.

The potential difference between the surface of the conductor and the inner surface of the sheath, $V = \int_r^R E dx = \int_r^R \frac{q}{2\pi\varepsilon x} dx = \frac{q}{2\pi\varepsilon} \ln\left(\frac{R}{r}\right)$ volts ... (2)

From Equation (2)

Charge, $q = \frac{2\pi\varepsilon V}{ln\left(\frac{R}{r}\right)}$

Substitute the value of q in Equation (1)

$$g = \frac{q}{2\pi\varepsilon x} = \frac{V}{x ln\left(\frac{R}{r}\right)} \quad \text{... (3)}$$

The gradient (stress) is maximum at the surface of the conductor at $x = r$ and minimum at the surface of the sheath i.e. at $x = R$.

From Equation (3)

$\therefore$ The maximum potential gradient (stress), $g_{max} = \frac{V}{r ln\left(\frac{R}{r}\right)}$ ... (4)

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and minimum gradient, $g_{min} = \frac{V}{R ln\left(\frac{R}{r}\right)}$

ii) Capacitance of a Single-Core Cable

Consider a single-core cable of a conductor of radius $r\left(=\frac{d}{2}\right)$, internal sheath radius $R\left(=\frac{D}{2}\right)$ and a charge of qC/m length. Then, the electric flux density at a distance $x\ m$ form the core center is $\frac{q}{2\pi\varepsilon x} C/m^2$

The dielectric field intensity, $E = \frac{q}{2\pi\varepsilon x} V/m$

The potential difference between conductor and sheath,

$$V = \int_r^R \frac{q}{2\pi\varepsilon x} dx = \frac{q}{2\pi\varepsilon} \int_r^R \frac{dx}{x} = \frac{q}{2\pi\varepsilon} ln \frac{R}{r} volts$$

$\therefore$ Capacitance of a cable per meter $= \dfrac{q}{V} = \dfrac{2\pi\varepsilon}{ln\dfrac{R}{r}} F/m$

where, $\varepsilon = \varepsilon_0 \varepsilon_r = \dfrac{\varepsilon_r}{36\pi \times 10^9}$

where, ε_r is the relative permittivity

$\therefore$ Capacitance of a cable per meter $= \dfrac{\varepsilon_r \times 10^{-9}}{18ln} F/m$.

5. A single core cable of conductor diameter 2 cm and lead sheath of diameter 5.3 cm is to be used on a 66 kV, 3-phase system. Two inter-sheaths of diameter 3.1 cm and 4.2 cm are introduced between the core and lead sheath. If the maximum stress in the layers is the same, find the voltages on the intersheaths. [37.1 kV, 18.87 kV] [WBUT 2016]

Answer:

$d = 2\text{cm}, D = 5.3\text{cm}, d_1 = 3.1\text{cm}, d_2 = 4.2\text{cm}, V_{line} = 66\text{kV}$

$\therefore \quad V_{ph} = \dfrac{V_{line}}{\sqrt{3}} = \dfrac{66}{\sqrt{3}} = 38.105\,\text{kV(r.m.s)}$

$\therefore \quad V = \sqrt{2} \times V_{ph} = \sqrt{2} \times 38.105 = 53.888\,\text{kV(peak)}$

Let $\quad V_1$ = Voltage of intersheath 1 w.r.t outer sheath

V_2 = Voltage of intersheath 2 w.r.t outer sheath

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The maximum stresses in the 3 layers are,

$$g_{1\max} = \frac{V - V_1}{\frac{d}{2}\ln\left(\frac{d_1}{d}\right)}, g_{2\max} = \frac{V_1 - V_2}{\frac{d_1}{2}\ln\left(\frac{d_2}{d_1}\right)}, g_{3\max} = \frac{V_2}{\frac{d_2}{2}\ln\left(\frac{D}{d_2}\right)}$$

All stresses are equal, thus equating $g_{1\max}$ and $g_{2\max}$

$$\frac{53.888 - V_1}{\frac{2}{2} \times 10^{-2} \ln\left(\frac{3.1}{2}\right)} = \frac{V_1 - V_2}{\frac{3.1}{2} \times 10^{-2} \ln\left(\frac{4.2}{3.1}\right)}$$

$\therefore 440.623V_1 - 212.446V_2 = 12.296 \times 10^3 \quad \ldots (1)$

Equating $g_{1\max}$ and $g_{2\max}$

$$\frac{V_1 - V_2}{\frac{3.1}{2} \times 10^{-2} \ln\left(\frac{4.2}{3.1}\right)} = \frac{V_2}{\frac{4.2}{2} \times 10^{-2} \ln\left(\frac{5.3}{4.2}\right)}$$

$\therefore 212.446V_1 - 417.1514V_2 = 0 \quad \ldots (2)$

Solving (1) and (2), $V_1 = 36.988\,\text{kV}, V_2 = 18.837\,\text{kV}$

6. Derive the expression of insulation resistance of an underground cable. [WBUT 2019]

Answer: ***Refer to Question No. 2(b) of Long Answer Type Questions.***

Long Answer Type Questions

1. Explain the method of capacitance grading of an underground cable. **[WBUT 2009]**

OR,

Write short note on capacitance grading of underground cable. [WBUT 2010, 2014]

Answer:

Capacitive grading: In a capacitive grading two or more insulating materials with those having the larger permittivity nearer to the conductor are used.

It is known that: $g = \dfrac{q}{2\pi k_0 k_r x}$

If the permittivity k, could be varied continuously at different radius x in such a fashion that $k_r = \dfrac{m}{x}$ (say). Then for any x $g = \dfrac{q}{2\pi k_0 m}$ = a constant

An infinite gradation in k is however, impossible, but particularly two or three dielectrics with different values of k, may be used.

Three layers of dielectric of outer radii r_1, r_2 and R and of dielectric strength k_1, k_2, and k_3 as shown in fig. (I) below are assumed.

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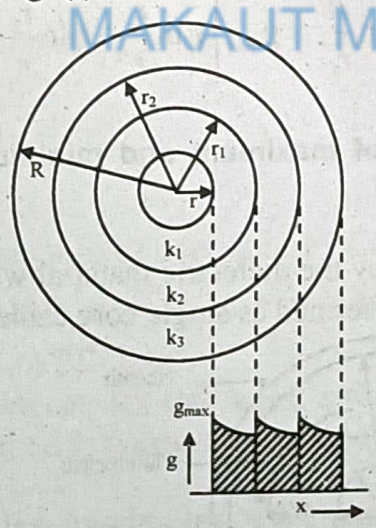

Fig: I capacitive grading and voltage distribution

If the dielectric strengths of three materials are G_1, G_2 and G_3 respectively with the same factor of safety, then $\dfrac{q}{2\pi k_1 r} = \dfrac{G_1}{f}$

Gradient at $x = r_1$ is $\dfrac{q}{2\pi k_2 r_1} = \dfrac{G_2}{f}$

Gradient at $x = r_2$ is $\dfrac{q}{2\pi k_3 r_2} = \dfrac{G_3}{f}$

where, f = factor of safety

from these three relations we get $q = 2\pi k_1 r \frac{G_2}{f} = 2\pi k_2 r_1 \frac{G_3}{f} = 2\pi k_3 r \frac{G_3}{f}$

or, $k_1 r G_1 = k_2 r_1 G_2 = k_3 r_2 G_3$

Since $r < r_1 < r_2$

$k_1 G_1 > k_2 G_2 > k_3 G_3$

This clearly shows that the material with the highest product of dielectric strength and permittivity should be placed nearest to the conductor, and other layers should be in the descending order of the product of dielectric strength and permittivity.

The second alternative is to subject all the materials to the same maximum stress.

Then

$$g_{max} = \frac{q}{2\pi k_1 r} = \frac{q}{2\pi k_2 r_1} = \frac{q}{2\pi k_3 r_3}$$

$\therefore$ $k_1 r = k_2 r_1 = k_3 r_2$

$\therefore$ $k_1 > k_2 > k_3$

The dielectric material with highest permittivity should be kept nearest to the conductor and so on.

Total operating voltage of the cable if g_{max} is the working stress (see fig. I).

$$V = g_{max} r \ln\frac{r_1}{r} + g_{max} r_1 \ln\frac{r_2}{r_1} + g_{max} r_2 \ln\frac{R}{r_2} = g_{max}\left[r \ln\frac{r_1}{r} + r_1 \ln\frac{r_2}{r_1} + r_2 \ln\frac{R}{r_2}\right] V$$

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2. a) Find out the expressions of maximum and minimum dielectric stress in a single core cable. **[WBUT 2010]**

Answer:

When the conductor is surrounded by the dielectric material with an outer metallic sheath as shown below (fig. I), the cable is termed as single core cable.

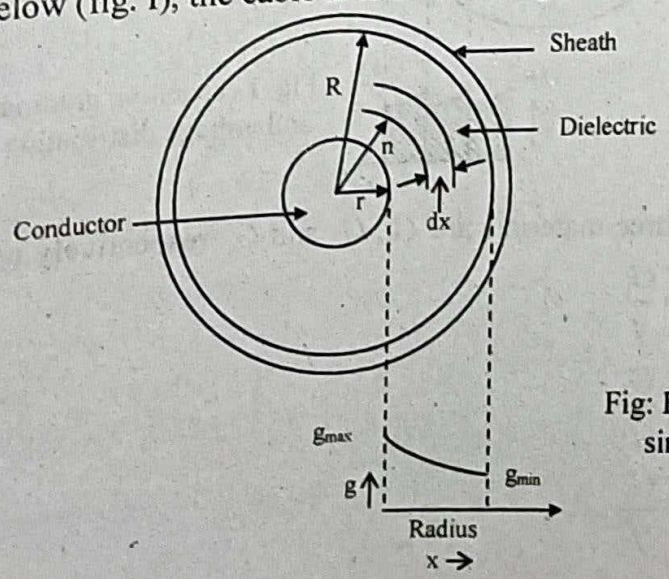

Fig: Electric Stress in a single core cable

If r be the radius of the conductor, R the inner radius of the sheathe, k the permittivity of the dielectric, q the charge in c/m of axial length, V the potential of the conductor with respect to the sheath and g the electric field intensity (gradient) at a distance x from the centre of the conductor within the dielectric material, then

$$g = \frac{q}{2\pi kx} V/m \qquad ...(1)$$

Now

$$V = \int_r^r g.dx = \int_r^R \frac{q}{2\pi kx} dx = \frac{q}{2\pi k} \ln \frac{R}{r} \qquad ...(2)$$

And the capacitance between core and sheath is

$$C = \frac{2\pi k_0 k_r}{\ln R/r} F/m \qquad ...(3)$$

From Equations (1) and (2)

$$g = \frac{V}{x \ln R/r} \qquad ...(4)$$

The maximum electric stress in the cable dielectric will occur at the surface of the conductor i.e. at $x_{min} = r$ and is given by

$$g_{max} = \frac{V}{r \ln R/r} \qquad ...(5)$$

And the gradient is minimum at $x_{max} = R$ i.e.

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$$g_{min} = \frac{V}{R \ln R/r} \qquad ...(6)$$

And $g_{max}/g_{min} = R/r$ ...(7)

It may be noted that to keep a fixed overall size of the cable (R) for given V, there is a particular r which minimizes g_{max} i.e., we have to maximize $r \ln R/r$, which occurs when $\ln R/r = 1$ or $R/r = e = 2.71882$.

Through this equation 4 we can say that when x=R gradient is min and x=r gradient is maximum. i.e. dielectric stress is maximum in the surface of the conductor.

b) What is the insulation resistance of a single core cable? Prove that the insulation resistance is inversely proportional to the length of the cable.

[WBUT 2010, 2014, 2015]

Answer:

1st Part:

Insulation resistance is the resistance offered by the cable insulation to the leakage current following from the conductor to the sheath. The insulation resistance of a cable is inversely proportional to the length of the cable. As the length increases, the leakage current following through the insulation from the conductor to earthed sheath increases and hence the effective insulation resistance decreases.

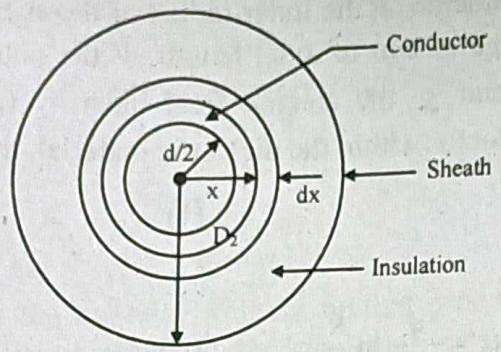

Fig: 1 Single core cable section

2nd Part:

Let d and D be the diameters of the conductor and internal sheath of the single core cable shown in figure-1. The insulation resistance dR of an annular section of the insulation of thickness dx at a radius x from the centre of the conductor is given by,

$$dR = \rho \frac{dx}{(2\pi x)\times 1} \text{Ohms/metre axial length of the cable,}$$

ρ being the resistivity of the insulation in ohms-metre.

So R = Insulation resistance/metre length.

$$dR = \rho \int_{d/2}^{D/2} \frac{dx}{2\pi x} = \frac{\rho}{2\pi} \ln\left(\frac{D}{d}\right) \text{Ohms/metre} \quad \cdots(1)$$

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The insulation resistance of a length of S metres of the cable is

$$R_S = \frac{R}{S} = \frac{\rho}{2\pi S} \ln\left(\frac{D}{d}\right) \text{Ohms} \quad \ldots(2)$$

The resistivity of an insulating material decreases with temperature as given by in control to a conducting material whose resistivity increases with temperature

$$\rho_t = \rho_0 e^{-\alpha t} \quad \ldots(3)$$

ρ_t = resistivity at t° C ρ_0 = resistivity at 0°C

α = resistance temperature coefficient.

With the rise of temperature, insulation resistance of the cable decreases, there by increasing the leakage current.

c) A single core cable for use on 11 kV, 50 Hz system has conductor area of 0.645 cm² and the internal diameter of sheath is 2.18 cm. The permittivity of the dielectric used in the cable is 3.5. Find the capacitance of the above cable per km length. Find the charging current. [WBUT 2010]

Answer:

Area of cross-section of conductor $a = 0.645 \text{ cm}^2$

Diameter of the conductor $d = \sqrt{\frac{4a}{\pi}} = \sqrt{\frac{4\times 0.645}{\pi}} = 0.906 \text{ cm}$

Internal diameter of sheath $D = 2.18\,\text{cm}$

Capacitance of cable $C = \dfrac{\varepsilon_r l}{41.4\log_{10}\dfrac{D}{d}} \times 10^{-9}\,\text{F}$

Here $\varepsilon_r = 3.5\ l = 1\text{km} = 1000\,\text{m}$

$$C = \frac{3.5 \times 1000}{41.4\log_{10}\dfrac{2.18}{0.906}} \times 10^{-9} = 0.22 \times 10^{-6}\,\text{F}$$

Charging current $I_C = \dfrac{V}{X_C} = 2\pi fCV = 2\pi \times 50 \times 0.22 \times 10^{-6} \times 11{,}000 = 0.76\,\text{A}.$

3. A single core cable for use on 11 kV, 50 Hz system has conductor area of 0.645 cm² and the internal diameter of sheath is 2.18 cm the permittivity of the dielectric used in the cable is 3.5, find the minimum and maximum stress in the cable. Find also the capacitance and charging current of the cable. [WBUT 2013]

Answer:

11kV, 50Hz system area 0.645cm²

Internal diameter 2.18cm

Permittivity of dielectric = 3.5

Area of cross-section of conductor $a = 0.645\ \text{cm}^2$

Diameter of the conductor $d = \sqrt{\dfrac{4a}{\pi}} = \sqrt{\dfrac{4 \times 0.645}{\pi}} = 0.906\,\text{cm}$

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Internal diameter of sheath $D = 2.18\,\text{cm}$

i) Maximum electrostatic stress in the cable is

$$g_{max} = \frac{2V}{d\log\dfrac{D}{d}} = \frac{2 \times 11}{0.906\log\dfrac{2.18}{0.906}}\ \text{kV/cm} = 27.65\ \text{kV/cm (r.m.s)}$$

ii) Minimum electrostatic stress in the cable is

$$g_{min} = \frac{2V}{D\log\dfrac{D}{d}} = \frac{2 \times 11}{2.18\log\dfrac{2.18}{0.906}}\ \text{kV/cm} = 11.5\ \text{kV/cm (r.m.s)}$$

iii) Capacitance of cable,

$$C = \frac{\varepsilon_r \ell}{41.4\log\dfrac{D}{d}} \times 10^{-9}\,\text{F}$$

$\varepsilon = 3.5\ \ \ell = 1\,\text{km} = 1000\text{m}$

$$C = \frac{3.5 \times 1000}{41.4\log\dfrac{2.18}{10.906}} \times 10^{-9} = 0.22 \times 10^{-6}\,\text{F}$$

iv) Charging current, $I_C = \frac{V}{X_C} = 2\pi fCV = 2\pi \times 50 \times 0.22 \times 10^{-6} \times 11000 = 0.76\,\text{A}$

4. a) A single core cable has an inner diameter of 6 cm and a core diameter of 2 cm. Its paper dielectric has a working dielectric stress of 60 kV/cm. Calculate the maximum permissible line voltage when such cables are used on a three phase power system. [WBUT 2014]

Answer:

$R = 3\text{ cm}$

$r = 1\text{ cm}$

$\therefore g_{max} = \frac{V}{r}$

$\therefore V = 60 \times 1 = 60\text{ KV}$

$\therefore$ The maximum permissible line voltage = 60 KV

b) Find the most economical value of the diameter of single core cable to be used on 66 kV three phase system. Find also the overall diameter of the insulation if the maximum permissible stress is not to exceed 5 kV/mm. [WBUT 2014, 2015]

Answer:

Phase voltage of cable $= \left(66/\sqrt{3}\right) = 38.10\,\text{kV}$

Peak value of phase voltage $V = 38.10 \times \sqrt{2} = 53.88\,\text{kV}$

Maximum permissible stress $g_{max} = 5\,\text{kV/mm}$

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Therefore, most economical conductor diameter is

$$d = 2Vg_{max} = 2 \times 53.88 \times 5 = 538.8\,\text{mm} = 53.88\text{ cm}$$

Internal diameter of sheath $D = 2.718d = 2.718 \times 53.88 = 146.44584$ cm

Therefore the cable should have a conductor diameter 53.88 cm and internal sheath diameter 146.44584 cm.

5. A single core cable has an inner diameter of 6 cm and a core diameter of 20 cm. Its paper dielectric has a working dielectric stress of 60 kV/cm. Calculate the maximum permissible line voltage when such cables are used on a three phase power system. [WBUT 2015]

Answer:

Given data:

Diameter of core $d = 6$ cm

Radius of core $r = 3$ cm

Diameter of sheath $D = 20$ cm

Radius of the sheath $R = 10$ cm

Maximum dielectric stress $g_{max} = 60\,\text{kV/cm}$

$$g_{max} = \frac{V}{r\ln\left(\frac{R}{r}\right)}$$

$$\therefore \quad 60 = \frac{V}{3\ln\left(\frac{10}{3}\right)}$$

$$\Rightarrow \quad 60 = \frac{V}{3.1203}$$

Phase voltage $V_{Ph} = 216.54\,(\text{peak})\ \text{kV} = 153.57\ \text{kV (rms)}$

Line to line voltage $V_L = 153.57 \times \sqrt{3} = 265.99\ \text{kV}$

6. A 66-kV, single core, lead sheathed cable is graded by using two dielectrics of relative permittivities 5 and 3 respectively, thickness of each being 1cm. The core diameter is 2 cm. Determine the maximum stress in the two dielectrics.

[WBUT 2017]

Answer:

The Fig. (1) shows the composite di-electric of a capacitance graded cable. The potential difference V between conductor and earthed sheath is given by

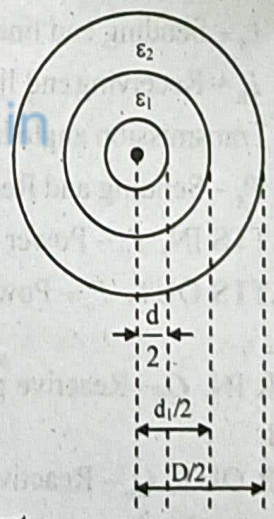

Fig: 1

$$V = \int_{d/2}^{d_1/2} g_1\,dx + \int_{d_1/2}^{D/2} g_2\,dx$$

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$$= \int_{d/2}^{d_1/2} \frac{Q}{2\pi\varepsilon_0\varepsilon_1 x}dx + \int_{d_1/2}^{D/2} \frac{Q}{2\pi\varepsilon_0\varepsilon_2 x}dx$$

$$= \frac{Q}{2\pi\varepsilon_0}\left[\frac{1}{\varepsilon_1}\log_e\frac{d_1}{d} + \frac{1}{\varepsilon_2}\log_e\frac{D}{d_1}\right] \qquad \text{.... (1)}$$

Now $\quad g_{1max} = \dfrac{Q}{\pi\varepsilon_0\varepsilon_1 d} \qquad$ .... (2)

Putting the value of $Q = g_{1max}\pi\varepsilon_0\varepsilon_1 d$ from exp. (2) in exp. (1), we get

$$V = \frac{g_{1max}\varepsilon_1 d}{2}\left[\frac{1}{\varepsilon_1}\log_e\frac{d_1}{d} + \frac{1}{\varepsilon_2}\log_e\frac{D}{d_1}\right]$$

or, $$g_{1max} = \frac{2V}{d\left[\log_e\frac{d_1}{d} + \frac{\varepsilon_1}{\varepsilon_2}\log\frac{D}{d_1}\right]}$$

Here $\quad d = 2\,\text{cm},\ d_1 = 4\,\text{cm},\ D = 6\,\text{cm};\ V = \dfrac{66}{\sqrt{3}} \times \sqrt{2} = 53.9\ \text{kV}$

$\varepsilon_1 = 5,\ \varepsilon_2 = 3$

Substituting the values, we get

$$g_{1\max} = \frac{2\times 53.9}{2\left[\log_e \frac{4}{2} + \frac{5}{3}\log_e \frac{6}{4}\right]} \text{kV/cm} = \frac{2\times 53.9}{2[0.6931+0.6757]} = 39.58 \text{ kV/cm}$$

Similarly:

$$g_{2\max} = \frac{2V}{d_1\left[\frac{\varepsilon_2}{\varepsilon_1}\log_e \frac{d_1}{d} + \log_e \frac{D}{d_1}\right]} \quad \text{.... (3)}$$

$$= \frac{2\times 53.9}{4\left[\frac{3}{5}\log_e \frac{4}{2} + \log_e \frac{6}{4}\right]} \text{kV/cm} = \frac{2\times 53.9}{4[0.4158+0.4054]} = 32.81 \text{kV/cm}$$

7. a) Derive the expression of Receiving End Power Circle Diagram in terms of General Circuit Constant. **[WBUT 2018]**

Answer:

Receiving and power circle diagram:

A, B, C, D – General network constants

V_S, I_S – Sending end line voltage and current

V_R, I_R – Receiving end line voltage and current

δ – Transmission angle between V_S and V_R

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P_S, P_R – Sending and Receiving end reactive powers.

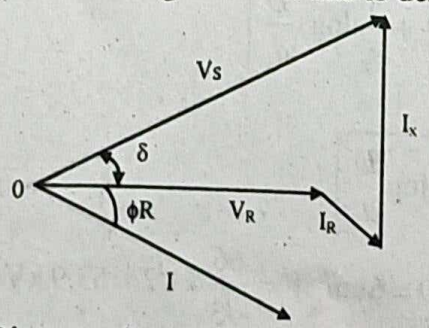
WATTS IN, P_i – Power received by the load at the receiving end of the line.

WATTS OUT, P_o – Power supplied or produced by the source at the sending end of the line.

VAR IN, Q_i – Reactive power absorbed at sending or receiving ends of line by source or load.

VAR OUT, Q_o – Reactive power produced at the sending or receiving ends of line by the source or load.

Power Circle Diagram for the Receiving End of a line is derived from the corresponding voltage phasor diagram.



The derived Power Circle Diagrams have different centers for the voltage circles, with a common active and reactive power axis.

S_R = Total receiving end power

$$= \boxed{-\frac{A}{B}V_R^2\angle(\beta-\alpha)+\frac{V_S V_R}{B}\angle(\beta-\delta)}$$ S_R is in MVA (3ϕ)

V_S, V_R are in KV (line)

$$= -\frac{A}{B}V_R^2\angle(\beta-\alpha)+\frac{V_S V_R}{B}\angle(\beta-\delta)$$

= Constant phasor of receiving end power + phasor of fixed magnitude but variable angle of receiving end power.

= Constant phasor of receiving end power + Phasor of fixed magnitude but variable angle of receiving end power. = Total receiving end power

The loci for S_R would be circle drawn from the tip of constant phasor as centre.

Hence the centre of receiving end circle is located at the tip of phasor

$$= -\frac{A}{B}V_R^2\angle(\beta-\alpha)$$

Hence the horizontal co-ordinates of the centre $= -\frac{A}{B}V_R^2\angle\cos(\beta-\alpha)$ MW

And vertical coordinates of the centre $= -\frac{A}{B}V_R^2\angle\sin(\beta-\alpha)$ MVAR

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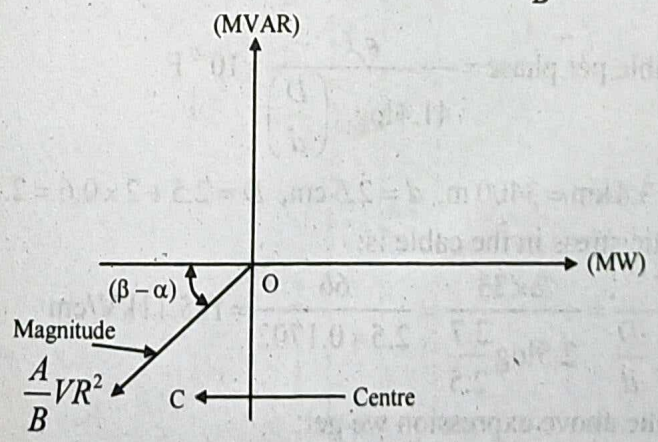
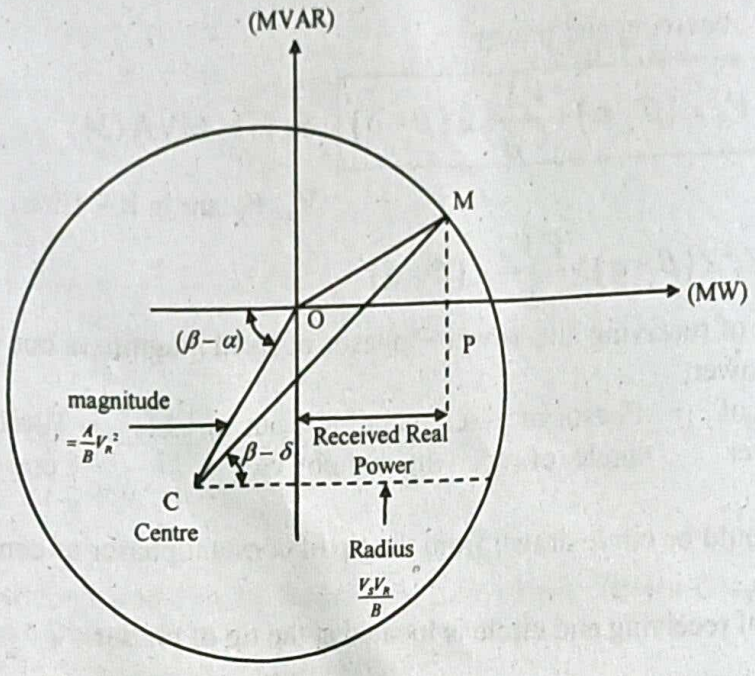
The radius of receiving end circle is $\frac{V_S V_R}{B}$

Steps for receiving end circle diagram

1) First the centre is located by drawing a phasor (OC) of $-\frac{A}{B}V_R^2$ at an angle $(\beta-\alpha)$



2) From the centre C the receiving end circle is drawn with the radius.
3) Once operating point (M) is located, then total received power $S_R = O_M$.



b) Draw the Receiving End Power Circle Diagram. **[WBUT 2018]**

Answer: ***Refer to Question No. 7(a) of Long Answer Type Questions.***

c) Derive the expression of dielectric strength in a single core cable. **[WBUT 2018]**

Answer: ***Refer to Question No. 2(a) of Long Answer Type Questions.***

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d) A 33kV, 3 phase, 50Hz underground line, 3.4 km long, uses three single core cable. Each cable has a core diameter of 2.5cm and the radial thickness of insulation is 0.6cm. The relative permittivity of the dielectric is 3.1. Find –

i) maximum stress and

ii) total charging kVAR. **[WBUT 2018]**

Answer:

$$\text{Capacitance of the cable per phase} = \frac{\varepsilon_r \ell}{41.4\log_{10}\left(\frac{D}{d}\right)} \times 10^{-9}\,\text{F}$$

$$\varepsilon_r = 3.1,\ \ell = 3.4\,\text{km} = 3400\,\text{m},\ d = 2.5\,\text{cm},\ D = 2.5 + 2\times 0.6 = 2.5 + 1.2 = 3.7\,\text{cm}$$

Maximum electrostatic stress in the cable is:

$$g_{max} = \frac{2V}{d\log_e \frac{D}{d}} = \frac{2\times 33}{2.5\log\frac{3.7}{2.5}} = \frac{66}{2.5\times 0.1702} = 155.11\,\text{kV/cm}$$

Putting the value in the above expression we get:

$$C = \frac{3.1\times 3400\times 10^{-9}}{41.4\log\left(\frac{3.7}{2.5}\right)} = \frac{3.1\times 3400}{41.4\times 0.1702}\times 10^{-9} = 1495.82\times 10^{-9}\,\text{F}$$

Voltage/phase,

$$V_{ph} = \frac{33\times10^3}{\sqrt{3}} = 19.05\times10^3 \text{ V}$$

Charging current / phase,

$$I_C = \frac{V_{ph}}{X_C} = 2\pi f C V_{ph} = 2\pi\times50\times1495.82\times10^{-9}\times19.05\times10^3 \text{ A}$$

$$= 100\times\pi\times1495.92\times10^{-6}\times19.05 = \pi\times1495.82\times19.05\times10^{-4} = 8.952 \text{ A}$$

Total charging kVA

$$3V_{ph}I_C = 3\times19.05\times10^3\times8.952 = 511.61\times10^3 \text{ kVAR}$$

8. a) Derive the expression of Dielectric stress of an underground cable and from there find the most economical size of the cable.
b) What are the main reasons of breakdown of a cable.
c) The test results for 10 km long three phase metal sheathed belted cable gave a measured capacitance of 0.7 πF between one conductor and other two conductors bunched together with the earth sheath. Also it has capacitance of 1.2 πF between the three bunched conductors and the sheath. Then calculate:
i) The capacitance between any pair of conductors where the sheath being isolated.
ii) The charging current when the cable is connected to 11 kV, 50 Hz supply.

[WBUT 2019]

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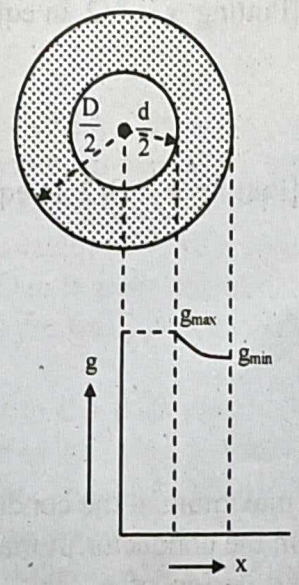
Answer:

a) Under operating conditions, the insulation of a cable is subjected to electrostatic forces. This is known as dielectric stress. The dielectric stress at any point in a cable is infact the potential gradient (or electric intensity) at that point.



Consider a Capacitance of Single Core Cable with core diameter d and internal sheath diameter D. The electric intensity at a point x meters from the centre of the cable is

$$E_x = \frac{Q}{2\pi\varepsilon_o\varepsilon_r x} \text{ volts/m}$$

By definition, electric intensity is equal to potential gradien Therefore, potential gradient g at a point x meters from the centre of cable is

$$g = E_x$$

$$g = \frac{Q}{2\pi\varepsilon_o\varepsilon_r x} \text{ volts/m} \qquad \text{.... (i)}$$

Potential difference V between conductor and sheath is

$$V = \frac{Q}{2\pi\varepsilon_o\varepsilon_r}\log_e\frac{D}{d} \text{ volts}$$

$$Q = \frac{2\pi\varepsilon_o\varepsilon_r V}{\log_e\frac{D}{d}} \qquad \text{.... (ii)}$$

Substituting the value of Q from equation (ii) in (i), we get,

$$g = \frac{\frac{2\pi\varepsilon_o\varepsilon_r V}{\log_e D/d}}{2\pi\varepsilon_o\varepsilon_r x} = \frac{V}{x\log_e\frac{D}{d}} \text{ volts/m} \qquad \text{.... (iii)}$$

It is clear from equation (iii) that potential gradient varies inversely as the distance x. Therefore, potential gradient will be maximum when x is minimum i.e., when $x = d/2$ or at the surface of the conductor. On the other hand, potential gradient will be minimum at $x = D/2$ or at sheath surface.

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Maximum potential gradient is

$$g_{max} = \frac{2V}{d\log_e\frac{D}{d}} \text{ volts/m} \qquad \text{[Putting } x = d/2 \text{ in equation (ii)]}$$

Minimum potential gradient is

$$g_{min} = \frac{2V}{D\log_e\frac{D}{d}} \text{ volts/m} \qquad \text{[Putting } x = D/2 \text{ in equation (iii)]}$$

$$\frac{g_{max}}{g_{min}} = \frac{\frac{2V}{d\log_e D/d}}{\frac{2V}{D\log_e D/d}} = \frac{D}{d}$$

It is clear that dielectric stress is maximum at the conductor surface and its value goes on decreasing as we move away from the conductor. It may be noted that maximum stress is an important consideration in the design of a cable. For instance, if a cable is to be operated at such a voltage that maximum stress is 5 kV/mm, then the insulation used must have a dielectric strength of at least 5 kV/mm, otherwise breakdown of the cable will become inevitable.

It has already been shown that maximum stress in a cable occurs at the surface of the conductor. For safe working of the cable, dielectric strength of the insulation should be more than the maximum stress. Rewriting the expression for maximum stress, we get,

$$g_{max} = \frac{2V}{d \log_e \frac{D}{d}} \text{ volts/m} \qquad \text{.... (i)}$$

The values of working voltage V and internal sheath diameter D have to be kept fixed at certain values due to design considerations. This leaves conductor diameter d to be the only variable in exp. (i) For given values of V and D, the most economical conductor diameter will be one for which g_{max} has a minimum value. The value of g_{max} will be minimum when $d \log_e D/d$ is maximum i.e.

$$\frac{d}{dd}\left[d \log_e \frac{D}{d}\right] = 0$$

or, $\log_e \frac{D}{d} + d \cdot \frac{d}{D} \cdot \frac{-D}{d^2} = 0$

or, $\log_e (D/d) - 1 = 0$

or, $\log_e (D/d) = 1$

or, $(D/d) = e = 2.718$

Most economical conductor diameter is

$$d \simeq \frac{D}{2.718}$$

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and the value of g_{max} under this condition is

$$g_{max} = \frac{2V}{d} \text{ volts/m}$$

b) Breakdown refers to the damage of the insulation layer of the cable due to external force damage. There are several reasons for insulation breakdown of wire and cable:
One is mechanical damage. Due to heavy objects, the excavator accidentally injured the cable. When the cable was bent, the cable was bent too much to injure the insulation.
Second is improper construction. Due to poor construction methods and poor quality of materials used, the cable head and the weak link in the middle are broken, resulting in breakdown of the insulation.
Third, the insulation is damp. Due to the poor construction process of the cable head, moisture is intruded into the interior of the cable, or the inner protective layer of the cable is broken to allow moisture to enter. The lead-clad cable is laid near the source and is fatigue-cracked due to long-term vibration.
The fourth is overvoltage. The insulation layer is broken down due to atmospheric overvoltage or internal overvoltage, especially if the internal overvoltage of the system causes multiple cables to be broken at the same time.

The fifth is insulation aging. In the long-term operation of the cable, the electrical and mechanical properties of the insulating material are deteriorated due to poor heat dissipation or overload, and the insulating layer becomes brittle or broken.

c) $V_{ph} = \frac{11\times10^3}{\sqrt{3}} = 6350.85\text{ V}$

$f = 50\text{ Hz}$

$C_1 = 1.2\ \mu\text{F}$

$C_2 = 0.7\ \mu\text{F}$

$C_1 = 3C_e$

$C_e = \frac{C_1}{3} = \frac{1.2}{3} = 0.4\ \mu\text{F}$

$C_2 = 2C_e + C_c$

$C_c = \frac{C_2 - C_e}{2}$

$C_c = \frac{0.7 - 0.4}{2}$

$C_c = 0.15\ \mu\text{F}$

i) ∴ Core to neutral capacitance is $C_N = C_e + 3C_c = 0.4 + 3\times0.15 = 0.85\ \mu\text{F}$

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ii) Charging current. $I_c = 2\pi f\, V_{ph} C_N = 2\pi\times50\times6350.85\times0.85\times10^{-6} = 1.695\text{ A}$

PERFORMANCE OF LINES

Multiple Choice Type Questions

1. Ferranti effect on long overhead line is experienced when it is [WBUT 2006, 2008, 2011, 2012, 2018, 2019]

a) lightly loaded
b) on full load at unity p.f.
c) on full load at 0.8 p.f. lagging
d) all of these

Answer: (a)

2. The *ac* resistance of a conductor is greater than its *dc* value due to [WBUT 2010, 2011, 2017]

a) Skin effect only
b) Proximity effect only
c) Ferranti effect only
d) Both (a) and (b)

Answer: (d)

3. The values of A, B, C, D parameters for a short transmission line with a series impedance of z are [WBUT 2011, 2016]

a) z, 0, 1 and 1 respectively
b) 0, 1, 1 and 1 respectively
c) 1, z, 0 and 1 respectively
d) 1, 1, z and 0 respectively

Answer: (c)

4. For transmission line which of the following relations is correct? [WBUT 2013]

a) AD – BC = 1
b) AC – BD = 1
c) BA – CD = 1
d) BC – AD = 1

Answer: (a)

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5. In terms of constants A,B,C and D for short transmission lines, which of the following relation(s) is/are valid? [WBUT 2014]

a) A = D = 1
b) C = 0
c) B = Z
d) all of these

Answer: (a)

6 The A, B, C, D constants of transmission line are expressed as follows [WBUT 2015]

a) AD + BC = 1
b) AD – BC = 1
c) AD – BC = 0
d) AB + DC = 1

Answer: (b)

7. Shunt compensation in a transmission line is resorted to [WBUT 2017, 2019]

a) improve the stability
b) improve the voltage profile
c) reduce the fault level
d) as a substitute for synchronous phase modifier

Answer: (b)

Short Answer Type Questions

1. What is Ferranti effect? Explain with phasor diagram. **[WBUT 2010, 2018]**

OR,

Explain with the help of phasor diagram, Ferranti effect. **[WBUT 2013]**

OR,

Explain Ferranti effect. **[WBUT 2014, 2016]**

Answer:

A long transmission line has considerable shunt capacitance effect. During lightly loaded or unloaded condition, this capacitance effect raises the receiving end voltage beyond the sending end voltage and the ratio $(|V_R|/|V_S|)$ increases with line length [figure (a)]. This is known as Ferranti effect.

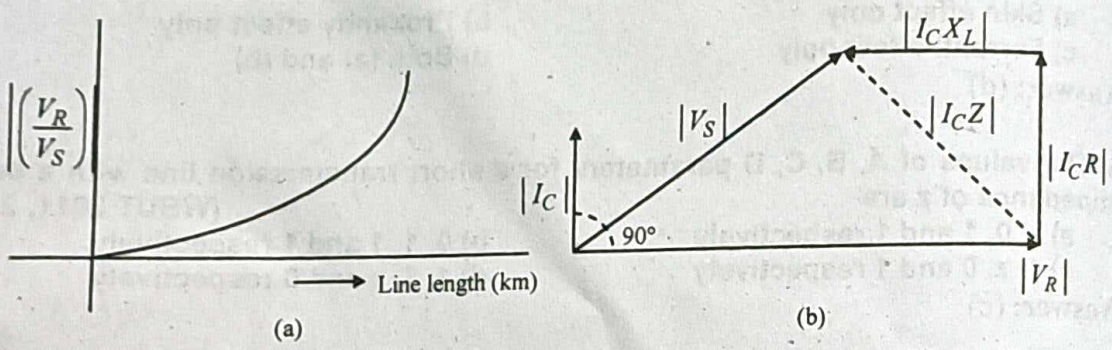

Fig: (a) Profile of $|V_R|/|V_S|$ with line length, (b) Phasor diagram of Ferranti

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Figure (b) represents the phasor diagram of the line during unloaded condition. It is evident from the diagram that $|V_R| > |V_S|$.

With $I_R = 0$, from the expression of $ABCD$ parameter equation,

$$V_S = AV_R + BI_R = AV_R$$

$$\therefore \quad \frac{V_R}{V_S} = \frac{1}{A} \text{ and } \quad I_S = CV_R + DI_R = CV_R$$

$$\therefore \quad \frac{I_S}{V_R} = C$$

Long Answer Type Questions

1. a) Derive the expression for voltage and current distribution over a long transmission line in hyperbolic form and obtain the A, B, C, D parameters. **[WBUT 2008, 2015]**

Answer:

Long Transmission Line

For Lines over 250 km, it is considered that the parameters of a line one not lumped but distributed uniformly throughout its length.

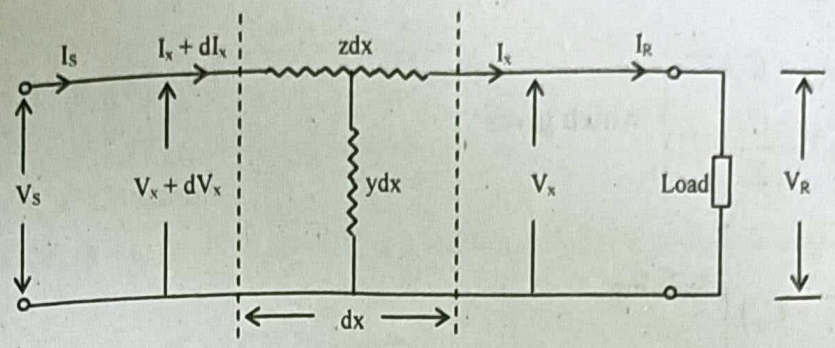

Fig: Long line transmission (Schematic)

This circuit contains one phase and the neutral as return (of zero impedance) of a transmission line. If dx be a receiving – end having a series impedance $z\,dx$ and a shunt admittance ydx, then rise in voltage to neutral over the elemental section in the direction of increasing x is dV_x. As such the following differential relationships across the elemental section; can be written as:

$$dV_x = I_x z dx \quad \text{or,} \quad \frac{dV_x}{dx} = zI_x$$

$$dI_x = V_x y dx \quad \text{or} \quad \frac{dI_x}{dx} = yV_x$$

It may be seen that the kind of connection (e.g. T or Π) assumed for the elemental section, does not affect these first order differential relations.

Differentiating w.r.t x,

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$$\frac{d^2V_x}{dx^2} = \frac{dI_x}{dx} z$$

Substituting the value of $\frac{dI_x}{dx}$

$\frac{d^2V_x}{dx^2} = yzV_x$ Which one is a basic differential equation.

So its general solution is:

$$V_x = C_1 e^{\gamma x} + C_2 e^{-\gamma x}$$

Where $\gamma = \sqrt{yz}$ and C_1 and C_2 are arbitrary constants to be evaluated by differentiating this equation with respect to x

$$\frac{dV_x}{dx} = C_1 \gamma e^{\gamma x} - C_2 \gamma e^{-\gamma x} = zI_x$$

$$I_x = \frac{C_1}{Z_C} e^{\gamma x} - \frac{C_2}{Z_C} e^{-\gamma x}$$

Where $Z_C = \left(z/y\right)^{1/2}$

When $z = 0$, $V_x = V_R$ and $I_x = I_R$ for equations

$$\left\{\begin{aligned} -V_n &= C_1 e^{\gamma n} + C_2 e^{-\gamma n} \\ I_x &= \frac{C_1}{Z_c} e^{\gamma x} - \frac{C_2}{Z_C} e^{-\gamma x} \end{aligned}\right\} \text{ which gives}$$

$$\left.\begin{aligned} V_R &= C_1 + C_2 \\ I_R &= \frac{1}{Z_C}(C_1 - C_2) \end{aligned}\right] \text{Solving}$$

$$C_1 = \frac{1}{2}(V_R + Z_c I_R); \qquad C_2 = \frac{1}{2}(V_R - Z_c I_R)$$

So the solutions are:

$$V_x = \left(\frac{V_R + Z_C I_R}{2}\right) e^{\gamma x} + \left(\frac{V_R - Z_C I_R}{2}\right) e^{-\gamma x}$$

$$I_x = \left(\frac{V_R/Z_C + I_R}{2}\right) e^{\gamma x} - \left(\frac{V_R/Z_C - I_R}{2}\right) e^{-\gamma x}$$

where $Z_C \rightarrow$ Characteristic impedance

$\gamma \rightarrow$ Propagation constant

Rearranging,

$$V_x = V_R\left[\frac{e^{\gamma x} + e^{-\gamma x}}{2}\right] + I_R Z_C\left[\frac{e^{\gamma x} - e^{-\gamma x}}{2}\right]$$

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$$I_x = \frac{V_R}{Z_C}\left[\frac{e^{\gamma x} - e^{-\gamma x}}{2}\right] + I_R\left[\frac{e^{\gamma x} + e^{-\gamma x}}{2}\right]$$

These can be rewritten after introducing hyperbolic functions

$$V_x = V_R \cosh \gamma x + I_R Z_C \sinh \gamma x$$

$$I_x = \frac{V_R}{Z_c} \sinh \gamma x + I_R \cosh \gamma x$$

When $x = l,\ V_x = V_S,\ I_x = I_S$

$$\therefore \quad \begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} \cosh \gamma l & Z_C \sinh \gamma l \\ \frac{1}{Z_C} \sinh \gamma l & \cosh \gamma l \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

Here,

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

$$B = Z_C \sinh \gamma l$$

$$C = \frac{1}{Z_C} \sinh \gamma l$$

So, $\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$

Evaluation of ABCD Constants

It must be noted that $\gamma = \sqrt{yz}$ is in general a complex number and can be expressed as,

$\gamma = \alpha + j\beta$

Procedure for calculation of ABCD Parameter

Mode 1

$\cosh(\alpha l + j\beta l) = \cosh \alpha l \cos \beta l + j \sinh \alpha l \sin \beta l$

$\sinh(\alpha l + j\beta l) = \sinh \alpha l \cos \beta l + j \cos \alpha l \sin \beta l$

From any standard table can easily find out the values of cos and sin terms.

Mode 2

$$\cosh \gamma l = 1 + \frac{\gamma^2 l^2}{2!} + \frac{\gamma^4 l^4}{4!} + \ldots\ldots \approx \left(1 + \frac{YZ}{2}\right)$$

$$\sinh \gamma l = \gamma l + \frac{\gamma^3 l^3}{3!} + \frac{\gamma^5 l^5}{5!} + \ldots\ldots \approx \sqrt{YZ}\left(1 + \frac{YZ}{6}\right)$$

So the corresponding ABCD constant are

$$A = D \approx 1 + \frac{YZ}{2}$$

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$$B \approx Z\left(1 + \frac{YZ}{6}\right)$$

$$C \approx Y\left(1 + \frac{YZ}{6}\right)$$

The above expressions are valid for 400 to 500 Kms long line transmission system.

Mode 3

$$\cosh(\alpha l + j\beta l) = \frac{e^{\alpha l} e^{j\beta l} + e^{-\alpha l} e^{-j\beta l}}{2} = \frac{1}{2}\left(e^{\alpha l} \angle \beta l + e^{-\alpha l} \angle -\beta l\right)$$

$$\sinh(\alpha l + j\beta l) = \frac{e^{\alpha l} e^{-\alpha l} - e^{-j\beta l} e^{-j\beta l}}{2} = \frac{1}{2}\left(e^{\alpha l} \angle \beta l - e^{-\alpha l} \angle -\beta l\right).$$

b) The parameters of a 132 kV, 50 Hz, 3-phase transmission lines are

$$R = 12.84\Omega, \quad L = 0.162\text{H}, \quad C = 1.014\mu\text{F}$$

Calculate the line constants A, B, C and D for nominal π method.

[WBUT 2008, 2015]

Answer:

The parameters of a 132 kv, 50 Hz, 3 phase transmission lines are, $R = 12.84\Omega$, $L = 0.162$ H, $C = 1.014$ μF

For nominal π network,

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

$$C = Y\left(1 + \frac{2Y}{4}\right)$$

$$Z = R + j\omega L = (R + j2\pi f L) = (12.84 + j50.89)$$

$$Y = 2\pi fc = 318.557 \times 10^{-6}$$

$$A = D = 1 + \frac{ZY}{2} = 1 + \frac{(12.84 + j50.89)(j0.00031855)}{2}$$

$$= 1 + j0.002045091 - 0.0081055 = 0.99189 + j0.002045091$$

$$B = Z$$

$$C = Y\left[1 + \frac{ZY}{4}\right] = (j0.00031855)\left(1 + \frac{(12.84 + j50.89).j0.00031855}{4}\right)$$

$$= [j0.00031855]\,[1 + j0.00102254 - 0.00405275]$$

$$= (0.99594 + j0.00102254)(j0.00031855)$$

$$= [j0.00031725 - 0.0000003257]$$

2. a) Determine the generalized constants of a medium transmission line by nominal T method.

b) A 3-phase transmission line, 160 km long, has the following constants:

Resistance / phase / km = 0.2Ω

Reactance / phase / km = 0.3127Ω

Shunt admittance / phase / km = 1.875×10^{-6}s

Determine the sending end voltage and current by rigorous method when the line is delivering a load of 25 MVA at 0.8 pf. Lagging. The receiving end voltage is kept constant at 110kV. **[WBUT 2013]**

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Answer:

a) Performance of Lines

For the line having more than 100 km long, in that case charging currents due to shunt admittance cannot be neglected. For the line ranging from 100 km to 250 km length, it is sufficiently accurate to lump all the line admittance at the receiving-end resulting in the equivalent diagram.

From fundamental circuit equation, the $ABCD$ representation,

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} 1 + YZ & Z \\ Y & 1 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

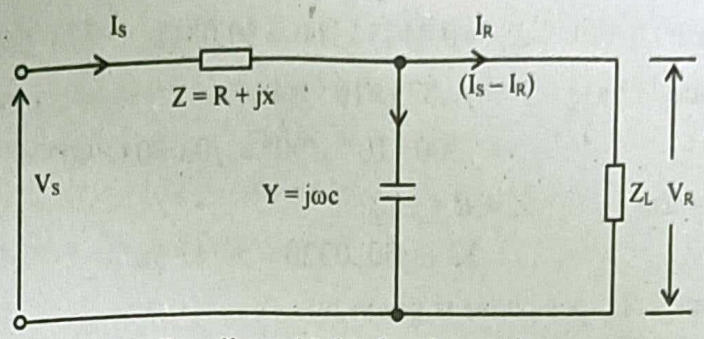

Fig: Medium line with load and capacitance

Nominal – T representation

If it is considered that all the shunt capacitance is lumped at the middle of the line. Then it leads to the nominal T circuit as shown

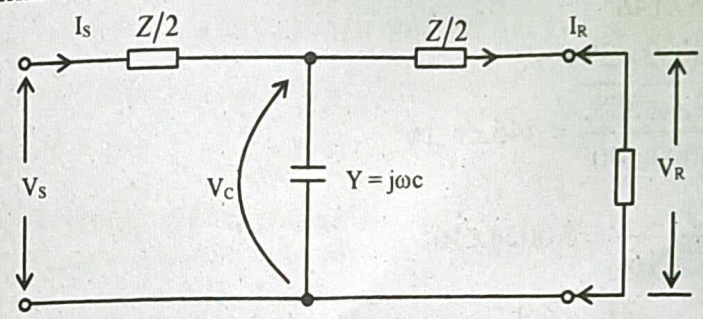

Fig: Medium line with nominal 'T' representation

For the nominal network (T - type), the following circuit equation can be written:

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$$V_C = V_R + I_R\left(Z/2\right)$$

$$I_S = I_R + V_C Y \quad = I_R + YV_R + I_R\left(Z/2\right)Y$$

$$V_S = V_C + I_S\left(Z/2\right)$$

Substituting for V_C and I_S in the last equation, it is obtained as: -

$$V_S = V_R + I_R\left(Z/2\right) + \left(Z/2\right)\left[I_R\left(1+\frac{ZY}{2}\right) + YV_R\right]$$

$$= V_R\left(1+\frac{ZY}{2}\right) + I_R Z\left(1+\frac{YZ}{4}\right)$$

Rearranging the results, the following equations are obtained.

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} 1+\frac{1}{2}ZY & Z\left(1+\frac{1}{4}YZ\right) \\ Y & (1+\frac{1}{2}YZ) \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

b) Performance of Lines

Total resistance / phase $R = 0.2 \times 160 = 32\Omega$

Total reactance / phase $X_L = 0.3127 \times 160 = 50.03\Omega$

Total shunt admittance / phase $Y = j1.875 \times 10^{-6} \times 160$

$= j300 \times 10^{-6} \angle 90° = j0.0003\angle 90°$

Series impedance / phase $Z = R + jX_L$

$= 32 + j50..0320 = 59.4\angle 58°$

The sending end voltage V_S per phase is given by

$$V_S = V_R \cos h\sqrt{YZ} + I_R\sqrt{\frac{Z}{Y}} \sin h\sqrt{ZY} \quad \text{.... (1)}$$

Now $\sqrt{ZY} = \sqrt{59.4\angle 58° + 0.0003\angle 90°} = 0.133\angle 74°$

$ZY = 0.0178\angle 148°$

$Z^2Y^2 = 0.00032\angle 296°$

$$\sqrt{\frac{Z}{Y}} = \sqrt{\frac{59.4\angle 58°}{0.0003\angle 90°}} = 445\angle -16°$$

$$\sqrt{\frac{Y}{Z}} = \frac{1}{445\angle -16°} = 0.0024\angle 16°$$

$$\cos h\sqrt{YZ} = 1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} \text{ approximately}$$

$$= 1 + \frac{0.0178}{2}\angle 148° + \frac{0.00032}{24}\angle 296°$$

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$$= 1 + 0.0089\angle 148° + 0.0000133\angle 296°$$

$$= 1 + 0.0089(-0.848 + j0.529) + 0.0000133(0.438 - j0.9)$$

$$= 0.992 + j0.00469 = 0.992\angle 0.26°$$

$$\sin h\sqrt{YZ} = \sqrt{YZ} + \frac{(YZ)^{3/2}}{6} \text{ approximately}$$

$$= 0.133\angle 74° + \frac{0.0024\angle 222°}{6} = 0.133\angle 74° + 0.0004\angle 222°$$

$$= 0.133(0.275 + j0.961) + 0.0004(-0.743 - j0.67)$$

$$= 0.0362 + j0.1275 = 0.1325\angle 74°6'$$

Receiving end voltage per phase $= \dfrac{110 \times 10^3}{\sqrt{3}} = 63508$ V

Receiving end current $= \dfrac{20 \times 10^6}{\sqrt{3} \times 110 \times 10^3 \times 0.8} = 131$ A

Putting the various values in Eqn. (1) we get

$$V_S = 63508 \times 0.992\angle 0.26° + 131 \times 445\angle -16°0' \times 0.1325\angle 74°6'$$

$$= 63000\angle 0.26° + 7724\angle 58°6'$$

$$= 63000(0.999 + j0.0045°) + 7724(0.5584 + j0.8489)$$
$$= 67108 + j6840 = 67366\angle 5°50' \text{ V}$$

Sending end line-to-line voltage

$$= 67366 \times \sqrt{3} = 116.67 \times 10^3 \times 116.67 \text{ kV}$$

The sending end current I_S is given by

$$I_S = V_R \sqrt{\frac{Y}{Z}} \sin h\sqrt{YZ} + I_R \cos h\sqrt{YZ}$$

Putting the different values we get,

$$I_S = 6.3508 \times 0.0024\angle 16° \times 0.1325\angle 74°6' + 131 \times 0.992\angle 0.26°$$
$$= 18.85\angle 90°6' + 130\angle 0.26°$$
$$= 18.85(-0.0017 + j0.999) + 130(0.999 + j0.0045)$$
$$= 129.83 + j19.42 = 131.1\angle 18° \text{ A.}$$

Sending end current = 131.1 A.

3. A 50km long three phase, 50 Hz transmission line has resistance, reactance and susceptance are 0.1 ohm, 0.5 ohm and 10 × 10^{-6} S per phase per km respectively. If the line supplies load of 20MW at 0.9 p.f. Lagging 66 kV at the receiving end, calculate sending end power factor, regulation and transmission efficiency.

[WBUT 2015]

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Answer:

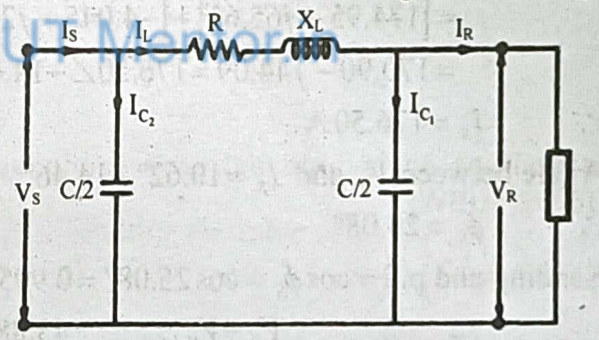


Fig: 1

Total $R = 0.1 \times 100 = 10\Omega$

Total $X_L = 0.5 \times 100 = 50\Omega$

Total $Y_C = 10^{-5} \times 100 = 10^{-3}$ mho

$$\therefore \quad \frac{Y_C}{2} = \frac{10^{-3}}{2}, \; V_R = \frac{66000}{\sqrt{3}} = 38105 \text{ V}$$

Receiving end load current

$$I_R = \frac{\text{Power delivered}}{\sqrt{3} \times V_R \times \cos\phi_R} = \frac{20 \times 10^6}{\sqrt{3} \times 66 \times 10^3 \times 0.9} = 194.39 \text{ A}$$

$$\bar{I}_R = 194.39\angle -\cos^{-1} 0.9 = 194.39\angle -25.84° \text{ A}$$

$$\bar{I}_{C_1} = j(2\pi f)\frac{C}{2}\bar{V}_R = j\omega\frac{C}{2}\bar{V}_R$$

Now, $X_C = \dfrac{1}{\omega C}$; $\omega C = \dfrac{1}{X_C}$

$$\therefore \quad \frac{\omega C}{2} = \frac{1}{2X_C} = \frac{Y_C}{2}$$

$$\bar{I}_{C_1} = j\frac{Y_C}{2}\bar{V}_R = j\left(\frac{10^{-3}}{2}\right)(38105\angle 0°)$$

$$= j19.052\text{ A}$$

$$\overline{I}_L = \overline{I}_R + \overline{I}_{C_1} = [194.39\angle -25.84°] + [j19.052]$$

$$= 174.95 - j65.6747 = 186.87\angle -20.57°\text{ A}$$

$$\therefore \quad I_L = 186.87\text{ A}$$

$$\overline{V}_S = \overline{V}_R + \overline{I}_L\overline{Z} = \overline{V}_R + \overline{I}_L[R + jX_L]$$

$$= [38105 + j0] + [186.87\angle -20.57°][10 + j50]$$

$$= [38105 + j0] + [186.87\angle -20.57°][50.99\angle 78.69°]$$

$$= [38105 + j0] + [5032.39 + j8091.19]$$

$$= 43137.39 + j8091.19 \quad = 43889.65\angle 10.62°\text{ volts}$$

$$V_S = 43.889\text{ kV}$$

Line value of sending end voltage $= \sqrt{3} \times 43.889 = 76\text{ kV}$

$$\overline{I}_{C_2} = j\frac{Y_C}{2}\overline{V}_S = j\left(\frac{10^{-3}}{2}\right)(43137.39 + j8091.19)$$

$$= -4.045 + j21.56$$

$$= 21.94\angle 100.62°\text{ A}$$

$$\overline{I}_S = \overline{I}_L + \overline{I}_{C_2} = [186.87\angle -20.57°] + [21.94\angle 100.62°]$$

$$= [174.95 - j65.65] + [-4.045 + j21.56]$$

$$= 170.90 - j44.09 = 176.50\angle -14.46°\text{ A}$$

$$\therefore \quad I_S = 176.50\text{ A}$$

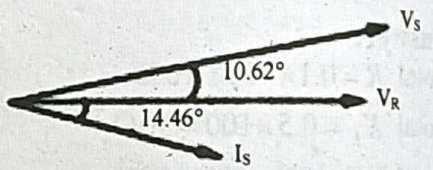


Fig: 1

Angle between V_S and $I_S = 10.62° + 14.46°$

$$\therefore \quad \phi_S = 25.08°$$

Sending end p.f. $= \cos\phi_S = \cos 25.08° = 0.9057$ lagging

$$\%\text{ Voltage regulation} = \frac{V_S - V_R}{V_R} \times 100 = \frac{43.889 - 38.105}{38.105} \times 100 = 15.17$$

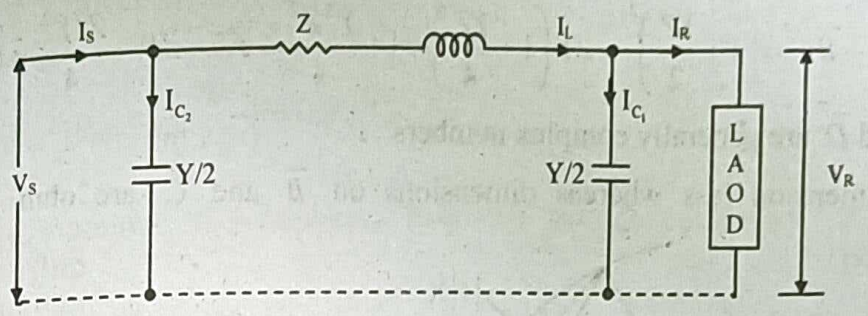
Total line losses $= 3I_L^2R = 3(186.87)^2(10) = 1047.611\text{ kW}$

$$\%\text{ Transmission efficiency} = \frac{\text{Power delivered}}{\text{Power delivered + Losses}} \times 100$$

$$= \frac{20,000}{20,000 + 1047.611} \times 100 = 95.02$$

4. a) For nominal "π" network representation, find the A,B,C,D constants for medium lines. Also draw the phasor diagram. [WBUT 2017, 2019]

Answer:
In nominal π method, line to neutral capacitance is divided into two halves; one half being concentrated at the load end and the other half at the sending end as shown in the figure below:



Here:

$\vec{V_S}$ = Sending end voltage per phase

$\vec{V_R}$ = Receiving end voltage per phase

$\vec{I_S}$ & $\vec{I_R}$ = Sending and receiving end current

Here, $\vec{Z} = R + J \times X_L$ = Series impedance / phase

$\vec{Y} = j\omega C$ = Shunt admittance

$$\vec{I_S} = \vec{I_L} + \vec{V_S}\frac{\vec{Y}}{2} \qquad \text{.... (1)}$$

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Also $\vec{I_L} = \vec{I_R} + \vec{I_{C_1}} = \vec{I_R} + \vec{V_R}\frac{\vec{Y}}{2}$ .... (2)

Now $\vec{V_S} = \vec{V_R} + \vec{I_L}\vec{Z} = \vec{V_R} + \left(\vec{I_R} + \vec{V_R}\frac{\vec{Y}}{2}\right)\vec{Z}$ (Putting the value of $\vec{I_L}$)

$$\vec{V_S} = \vec{V_R}\left(1 + \frac{\vec{Y}\vec{Z}}{2}\right) + \vec{I_R}\vec{Z} \qquad \text{.... (3)}$$

Also $\vec{I_S} = \vec{I_L} + \vec{V_S}\frac{\vec{Y}}{2} = \left(\vec{I_R} + \vec{V_R}\frac{\vec{Y}}{2}\right) + \vec{V_S}\frac{\vec{Y}}{2}$ (Putting the value of $\vec{I_L}$)

Putting the value of $\vec{V_S}$ from Eqn. (3), we get

$$\vec{I_S} = \vec{I_R} + \vec{V_R}\frac{\vec{Y}}{2} + \frac{\vec{Y}}{2}\left\{\vec{V_R}\left(1 + \frac{\vec{Y}\vec{Z}}{2}\right) + \vec{I_R}\vec{Z}\right\} = \vec{I_R} + \vec{V_R}\frac{\vec{Y}}{2} + \frac{\vec{V_R}\vec{Y}}{2} + \vec{V_R}\frac{\vec{Y}^2}{4}\vec{Z} + \frac{\vec{Y}\vec{I_R}\vec{Z}}{2}$$

$$= \vec{I_R}\left(1 + \frac{\vec{Y}\vec{Z}}{2}\right) + \vec{V_R}\vec{Y}\left(1 + \frac{\vec{Y}\vec{Z}}{4}\right) \qquad \text{.... (4)}$$

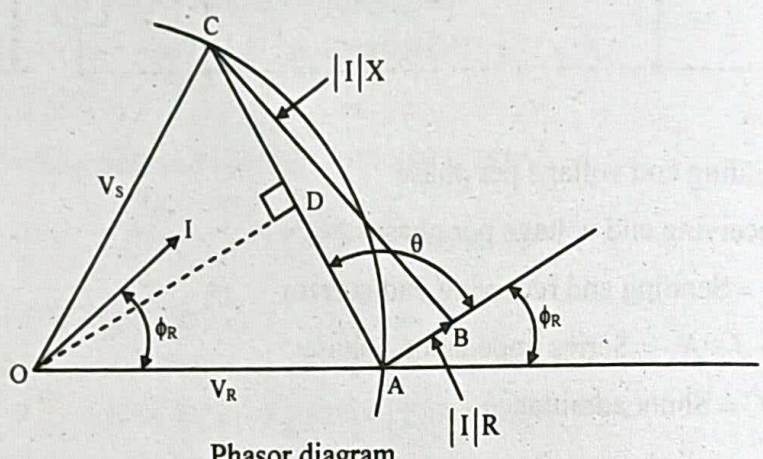
Comparing Eqns. (3) and (4) with these of (1) and (2), we get

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

Also $\quad \vec{A}\vec{D}-\vec{B}\vec{C}=\left(1+\frac{YZ}{2}\right)^2-ZY\left(1+\frac{YZ}{4}\right)=1+\frac{Y^2Z^2}{4}+YZ-ZY-\frac{Z^2Y^2}{4}=1$

$\vec{A}$, $\vec{B}$, $\vec{C}$ and $\vec{D}$ are generally complex numbers.

$\vec{A}$ and $\vec{D}$ dimension less whereas dimensions on $\vec{B}$ and $\vec{C}$ are ohm and siemen respectively.



Phasor diagram

b) The parameters of 220kV, 50Hz, three phase transmission lines are

R = 15.2Ω, L = 0.165H and C = 0.9μF.

Using nominal T method find voltage, current, power factor at the sending end when 70MW at 0.8 power factor lagging load is connected at receiving end. Also calculate the efficiency. **[WBUT 2017, 2019]**

Answer:

$R=15.2\Omega,\ L=0.165\text{H},\ C=0.9\,\mu\text{F},\ f=50\,\text{Hz},\ P_R=70\,\text{MW},\ \cos\phi_R=0.8$

Inductance of the line,

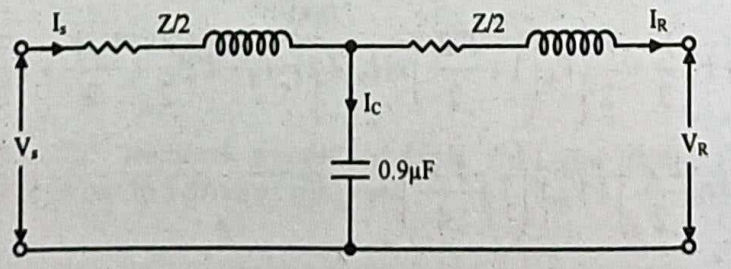
$$L=0.165\,\text{H}$$

Inductive reactance,

$$X_L=2\pi fL=2\pi\times50\times0.165=51.83\Omega$$

Capacitance / phase, $C=0.9\,\mu\text{F}$

Nominal T-method:



$$\frac{Z}{2}=\frac{15.2+j51.83}{2}=(7.6+j25.92)\Omega$$

$$I_R = \frac{70 \times 1000 \times 1000}{\sqrt{3} \times 220 \times 1000 \times 0.8} = 229.62 \text{ A}$$

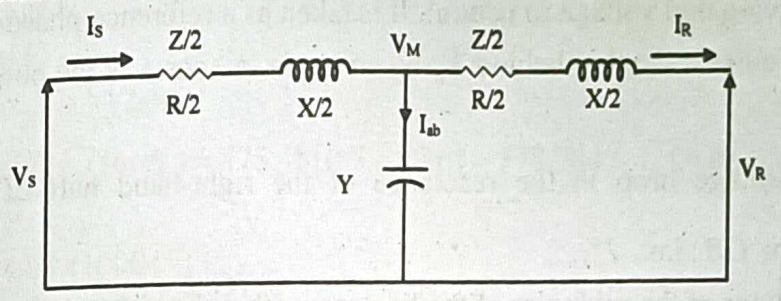
$$V_R = \frac{220 \times 1000}{\sqrt{3}} = 127 \text{ kV}$$

$$\text{Losses} = 3I_R^2 R = 3 \times 229.62^2 \times 15.2 = 2.4 \text{ MW}$$

So, efficiency, $\%\eta_{eff} = \dfrac{70}{70 + 2.4} = 0.97\%$

5. a) For a nominal "T" network, find the ABCD constants of a medium transmission line. **[WBUT 2018]**

Answer:



$$\frac{V_S - V_M}{Z/2} = YV_M + \frac{V_M - V_R}{Z/2}$$

$$V_M = \frac{2}{Yz + 4}(V_S + V_R)$$

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$$I_R = \frac{V_M - V_R}{Z/2}$$

$$V_S = \left(\frac{Yz}{2} + 1\right)V_R + Z\left(\frac{Yz}{4} + 1\right)I_R$$

$$I_S = YV_M + I_R$$

Substituting $-I_R = YV_R + \left(\dfrac{YZ}{2} + 1\right)I_R$

Then ABCD parameters of the T-network are-

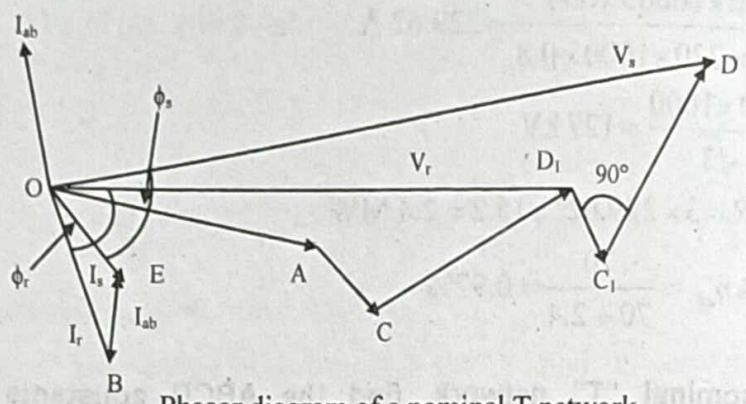
$$A = D = \left(\frac{YZ}{2} + 1\right)$$

$$B = Z\left(\frac{YZ}{4} + 1\right)\Omega$$

$$C = Y_{\text{mho}}$$

b) Draw the required Phasor Diagram. **[WBUT 2018]**

Answer:



Phasor diagram of a nominal T network

In the phasor diagram:

$OA = V_r$ – receiving end voltage to neutral. It is taken as a reference phasor.

$OB = I_r$ – load current lagging behind V_r by an angle ϕ. $\cos\phi$ is the power factor of the load.

$AC = \frac{I_r R}{2}$ – Voltage drop in the reactance of the right-hand half of the line. It is perpendicular to OB, i.e., I_r.

$OD_1 = V_{ab}$ – voltage at the midpoint of the line across the capacitance C.

$BE = I_{ab}$ – current in the capacitor. It leads the voltage V_{ab} by 90.

$OE = I_s$ – sending-end current, the phasor sum of load current and capacitor current.

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$D_1C_1 = \frac{I_s R}{2}$ – voltage drop in the resistance on the left-hand side of the lines. It is perpendicular to I_s.

$C_1D = I_s \frac{X}{2}$ – voltage drop in the reactance in the left half of the line. It is perpendicular to I_s.

$OD = V_s$ – sending end voltage. It is the phasor sum of the V_{ab} and the impedance voltage drop in the left-hand half of the line.

ϕ_s – phase angle at the sending end. $\cos\phi_s$ is the power factor at the sending end of the line.

c) A three phase transmission line 50km long consists of three hard drawn copper conductors is 1.2m delta. Load condition at receiving end are: 10,000kVA at 0.8pf lagging, 33,000V 50Hz. Line is designed so that transmission loss is approximately 10%. Find –

i) The sending end voltage
ii) Power factor
iii) Efficiency and
iv) Regulation

[WBUT 2018]

Answer:

Receiving end power $= \dfrac{10,000}{0.8} = 12,500\,\text{kW}$

Transmission efficiency $= 0.9$

Sending end power $= \dfrac{12,500}{0.9} = 13,888.88\,\text{kW}$

Line losses $= 13,888.88 - 12,500 = 1,388.88\,\text{kW}$

Line current $\text{I} = \dfrac{\text{kW} \times 10^3}{V_R \cos\phi_R} = \dfrac{12,500 \times 10^3}{33,000 \times 0.8} = 473.48\,\text{A}$

$$\cos\phi_R = 0.8$$
$$\sin\phi_R = 0.6$$
$$V_R = V_R + j0 = 33,000\,\text{V}$$
$$I = I(\cos\phi_R - j\sin\phi_R) = 473.48(0.8 - j0.6) = 378.784 - j284.088$$

Line losses $= 2I^2R$

$$R = \frac{1,388.88 \times 1000}{2 \times (473.48)^2} = 3.097\,\Omega$$

Sending end voltage,

$$V_S = V_R + IZ = 33,000 + 3.097(378.784 - j284.088)$$
$$= 33,000 + 1,173.094 - j879.820 = 34,173.094 - j879.820$$

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Magnitude of $V_S = \sqrt{(34,173.094)^2 + (879.820)^2} = 34,184.418\,\text{V}$

Angle between $\overrightarrow{V_S}$ and $\overrightarrow{V_R}$ is

$$\alpha = \tan^{-1}\frac{879.820}{34,173.094} = 1.474°$$

$\therefore$ Sending end power factor angle is

$$\phi_S = \phi_R + \alpha = 36.87° + 1.474° = 38.34°$$

$\therefore$ Sending end power factor angle is $\cos\phi_S = \cos 38.34° = 0.7843$ lagging

Line losses $= I^2R = 1388.88\,\text{kW}$

Output delivered $= 12,500\,\text{kW}$

Power sent $= 13,888.88\,\text{kW}$

$\therefore$ Transmission efficiency $= \dfrac{\text{Power delivered}}{\text{Power sent}} \times 100 = \dfrac{12,500}{13,888.88} \times 100 = 0.9 \times 100 = 90\%$

$\%$ Regulation $= \dfrac{V_S - V_R}{V_R} \times 100 = \dfrac{34,184.418 - 33,000}{33,000} \times 100 = \dfrac{1,184.418}{33,000} \times 100 = 3.5891\%$

6. Write short notes on the following:

a) Ferranti effect [WBUT 2009]

b) Power circle diagram [WBUT 2009]

c) Series compensation of transmission line [WBUT 2019]

d) Skin Effect & Proximity Effect [WBUT 2019]

Answer:

a) Ferranti effect: ***Refer to Question No. 1 of Short Answer Type Questions.***

b) Power circle diagram:

The variation of complex power transferred with variation of the power angle δ can be plotted on a complex plane. This plot is known as power circle diagram and it provides useful information about the performance of a transmission line. In figure (a), the complex power flow at the sending end can be expressed as

$$S_S = V_S I_S^* = |V_S|\angle\delta_S \left[\frac{|V_S|\angle\delta_S - |V_R|\angle\delta_R}{|Z|\angle\theta}\right]$$

$$= |V_S|\angle\delta_S \left[\frac{|V_S|\angle-\delta_S - |V_R|\angle-\delta_R}{|Z|\angle-\theta}\right]$$

$$= \frac{|V_S|^2}{|Z|\angle-\theta} - \frac{|V_S||V_R|\angle(\delta_S-\delta_R)}{|Z|\angle-\theta} \quad \text{.... (1)}$$

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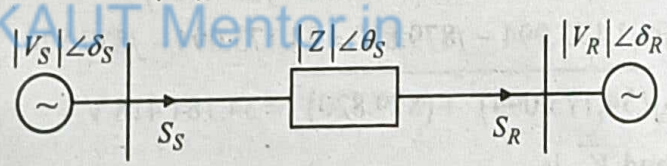

Fig: (a) A two bus system

Substituting δ for $(\delta_S - \delta_R)$ in equation (1), we get

$$S_S = \frac{|V_S|^2}{|Z|}e^{j\theta} - \frac{|V_S||V_R|}{|Z|}e^{j\theta}\cdot e^{j\delta} \quad \text{.... (2)}$$

$$= \frac{|V_S|^2}{|Z|}(\cos\theta + j\sin\theta) - \frac{|V_S||V_R|}{|Z|}\{\cos(\theta+\delta) + j\sin(\theta+\delta)\} = P_S + jQ_S$$

Equating the real and imaginary parts, we get

$$P_S = \frac{|V_S|^2}{|Z|}\cos\theta - \frac{|V_S||V_R|}{|Z|}\cos(\theta+\delta)$$

and $$Q_S = \frac{|V_S|^2}{|Z|}\sin\theta - \frac{|V_S||V_R|}{|Z|}\sin(\theta+\delta)$$

Similarly, for the receiving end complex power, we can write an analogous expression.

$$S_R = -\frac{|V_R|^2}{|Z|}e^{j\theta} + \frac{|V_R||V_S|}{|Z|}e^{j\theta}e^{-j\delta} \qquad \text{.... (3)}$$

$$= -\frac{|V_R|^2}{|Z|}(\cos\theta + j\sin\theta) + \frac{|V_R||V_S|}{|Z|}\{\cos(\theta+\delta) + j\sin(\theta-\delta)\} = P_R + jQ_R$$

$$\therefore \quad P_R = -\frac{|V_R|^2}{|Z|}\cos\theta + \frac{|V_S||V_R|}{|Z|}\cos(\theta-\delta) \qquad \text{.... (4)}$$

and $$Q_R = -\frac{|V_R|^2}{|Z|}\sin\theta + \frac{|V_S||V_R|}{|Z|}\sin(\theta-\delta) \qquad \text{.... (5)}$$

[It may be observed that for lossless lines, with $R = 0, Z = jX_l$ and $\theta = \pi/2$; the power equations for sending and receiving end get simplified as

$$P_S = P_R = \frac{|V_S||V_R|}{|X_l|}\sin\delta$$

$$Q_S = \frac{|V_S|^2}{|X_l|} - \frac{|V_S||V_R|}{|X_l|}\cos\delta$$

and $$Q_R = \frac{|V_S||V_R|}{|X_l|}\cos\delta - \frac{|V_R|^2}{|X_l|}$$

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Equations (2) and (3) ca be written as

$$S_S = K_S - Me^{j\delta}$$

and $$S_R = K_R - Me^{-j\delta}$$

where $K_S = \frac{|V_S|^2}{|Z|}e^{j\theta}$, $K_R = -\frac{|V_R|}{|Z|}e^{j\theta}$

and $$M = \frac{|V_S||V_R|}{|Z|}e^{j\theta}$$

On a complex plane, if the real power is expressed along the *x*-axis and the reactive power along the *y*-axis, it may be observed that with variation of δ, the loci of both S_S and S_R are circles on complex plane. The radius of each is determined by *M*. The circle for S_S is called the sending end power circle diagram while the circle for S_R is called the receiving end power circle diagram (K_S and K_R being the respective centres of the two circles). Figure (b) shows the power circle diagrams.

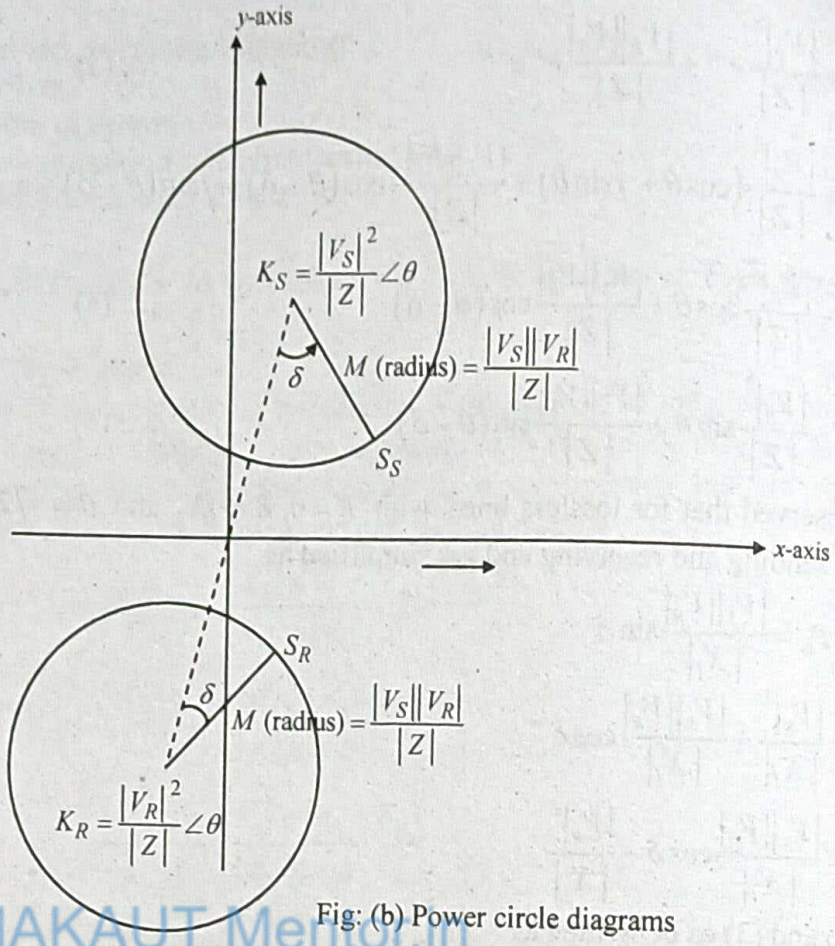

Fig: (b) Power circle diagrams

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The following aspects of power circle diagrams may be noted:

- The maximum power which can be transmitted is limited by the angle $(\theta+\delta)$ while the maximum power received depends on $(\theta-\delta)$. If $\theta-\delta=0$, i.e., $\theta=\delta$, the power received is maximum.
- If $\delta \to 0$, K_S, K_R and M lie on the same straight line.
- The real power flow is controlled by adjusting δ while the reactive power flow can be adjusted by controlling the magnitudes of $|V_S|$ and $|V_R|$.

A more convenient form of a circle diagram is described below:

The expressions for complex power at the receiving and sending ends can be written as

$$S_R = -\left|\frac{A}{B}\right||V_R|^2\angle(\beta-\alpha)+\frac{|V_S||V_R|}{|B|}\angle(\beta-\delta)$$

and $$S_S = -\left|\frac{D}{B}\right||V_R|^2\angle(\beta-\alpha)-\frac{|V_S||V_R|}{|B|}\angle(\beta-\delta).$$

The loci of S_S and S_R are circles with the following parameters:

Receiving end power circle

$$\left.\begin{aligned} &\text{Radius: } \frac{|V_S||V_R|}{|B|} \text{ MVA} \\ &\text{Centre: } -\left|\frac{A}{B}\right||V_R|^2\angle(\beta-\alpha) \end{aligned}\right\} \quad \text{.... (6)}$$

$$\left[\begin{aligned} &\text{Horizontal coordinate: } -\left|\frac{A}{B}\right||V_R|^2\cos(\beta-\alpha)\text{ MW} \\ &\text{Vertical coordinate: } -\left|\frac{A}{B}\right||V_R|^2\sin(\beta-\alpha)\text{ MVAR} \end{aligned}\right]$$

Sending end power circle

$$\left.\begin{aligned} &\text{Radius: } \frac{|V_S||V_R|}{|B|} \text{ MVA} \\ &\text{Centre: } -\left|\frac{D}{B}\right||V_S|^2\angle(\beta-\alpha) \end{aligned}\right\} \quad \text{.... (7)}$$

$$\left[\begin{aligned} &\text{Horizontal coordinate: } -\left|\frac{D}{B}\right||V_S|^2\cos(\beta-\alpha)\text{ MW} \\ &\text{Vertical coordinate: } -\left|\frac{D}{B}\right||V_S|^2\sin(\beta-\alpha)\text{ MVAR} \end{aligned}\right]$$

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Figures (c) and (d) represent the two modified power circle diagrams.

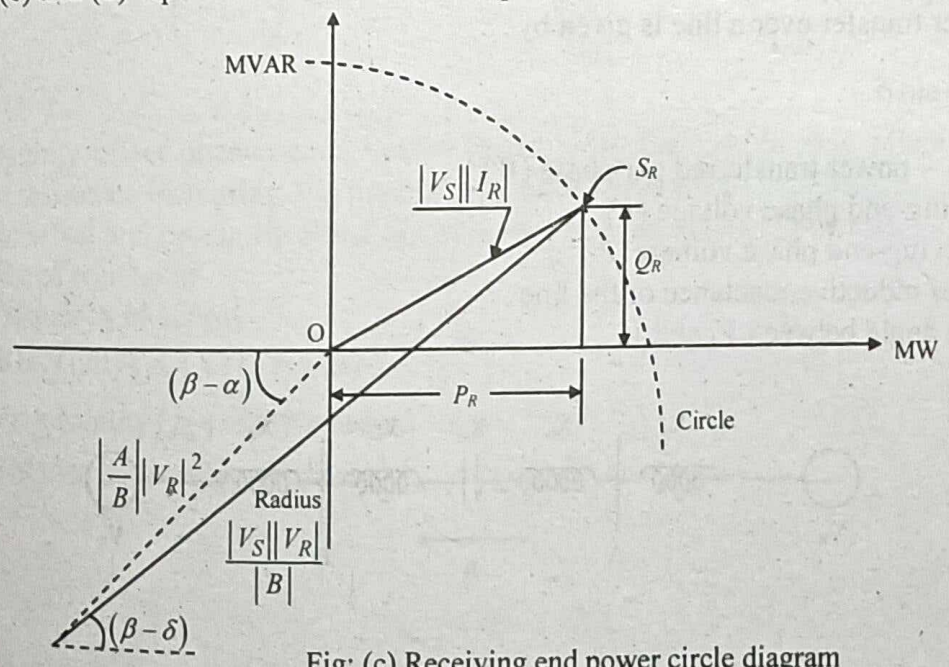

Fig: (c) Receiving end power circle diagram

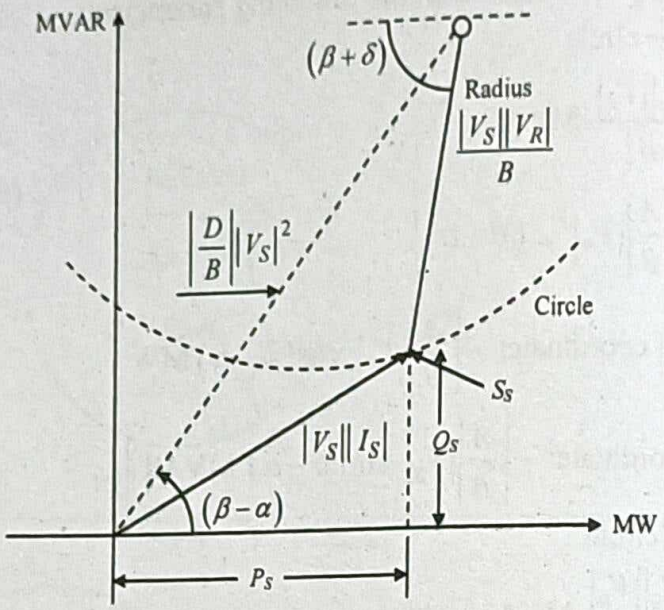

Fig: (d) Sending end power circle diagram

c) Series compensation of transmission line:

Series compensation is the method of improving the system voltage by connecting a capacitor in series with the transmission line. In other words, in series compensation, reactive power is inserted in series with the transmission line for improving the impedance of the system. It improves the power transfer capability of the line. It is mostly used in extra and ultra high voltage line.

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Series compensation has several advantages like it increases transmission capacity, improve system stability, control voltage regulation and ensure proper load division among parallel feeders.

The power transfer over a line is given by

$$P_2 = \frac{V_s V_R}{X_L} \sin\delta$$

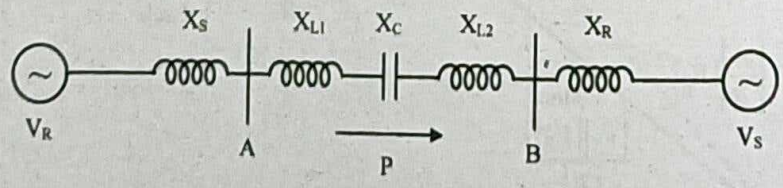
where, P_1 – power transferred per phase (W)

V_s – sending-end phase voltage (V)

V_r – receiving-end phase voltage

X_L – series inductive reactance of the line

δ – phase angle between V_s and V_r



If a capacitor having capacitance reactance X_C is connected in series with the line, the reactance of the line is reduced from X_L to $(X_L - X_C)$. The power transfer is given by

$$P_2 = \frac{V_s V_R}{X_L - X_C} \sin\delta$$

d) Skin Effect &Proximity Effect:

Skin Effect:

The resistance of a conductor is affected by the frequency of the current carried by it. An alternating current passing through a conductor tends to distribute itself non-uniformly throughout the cross – section. Those portions of the conductor situated at or near the surface carry a major portion of the total current. This phenomenon is known as '***Skin Effect***'.

The phenomenon is due to higher reactance of the inner elements in the conductor, with consequent flow of current in the outer surfaces of the conductor, thus reducing the effective area of cross – section. Due to this, losses will be more.

To account for increased losses due to non – uniform current distribution, it is usually to consider the 'effective resistance" (AC resistance) of a conductor and not its "ohmic resistance".

Proximity Effect:

A and B are two conductors placed near each other. When conductor A carries current, its flow links with other conductor B. More flux, however links with the nearer half of the conductor B (shaded) than with the other half removed further away.

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A B

The proximity effect phenomenon causes losses as in the case of skin effect, with the effective resistance increasing and internal reactance decreasing.

Both skin effect and proximity effect are influenced by the following factors:

i) Size of conductor
ii) Frequency of supply
iii) Resistivity (ρ_0) of the material
iv) Permeability (μ_r) of the material
v) Distance between conductors

TARIFF

Multiple Choice Type Questions

1. Running cost of a nuclear power plant is about [WBUT 2013]
   a) 20 paise per unit b) 40 paise per unit
   c) 64 paise per unit d) 48 paise per unit

Answer: (a)

2. The ratio of average demand of energy and energy required according to installed capacity for power system is termed as [WBUT 2015]
   a) diversity factor b) load factor
   c) plant capacity factor d) plant use factor

Answer: (c)

3. As the load factor of a generating plant increases, the generation cost per kW generated [WBUT 2015]
   a) decreases b) increases c) remains same d) none of these

Answer: (a)

4. Diversity factor is always [WBUT 2017]
   a) 1 b) 0 c) greater than 1 d) λ

Answer (c)

5. Daily energy consumption of a plant is 30 units. Maximum demand is 2kW. Then the load factor will be [WBUT 2017, 2019]
   a) 60% b) 50% c) 75% d) 62.5%

Answer: (d)

6. Flat rate tariff can be charged on the basis of [WBUT 2018]
   a) connected load b) units consumed
   c) maximum demand d) both (a) and (b)

Answer: (b)

Short Answer Type Questions

1. The daily load of an industrial corner is as follows: [WBUT 2009, 2016, 2018]
   100 kW for 9 hours
   125 kW for 6 hours
   50 kW for 7 hours
   5 kW for 2 hours

The tariff rate is Rs. 800 per kW of maximum demand per year plus Rs. 2.50 per kWh. Determine the energy consumption per year (365 days) and yearly bill.

Answer:

Daily energy consumption $= 100\text{kW} \times 9 + 125\text{kW} \times 6 + 50\text{kW} \times 7 + 5\text{kW} \times 2$

$= 900 + 750 + 350 + 10 = 2360\text{kW}$

Annual energy consumption $= 2360 \times 365 = 861400\text{kW}$.

Maximum demand = 125 kW.

Total maximum demand charge $= 125 \times 800 = 1,00,000/-$ Rs.

Total Bill = Demand charge + Unit charge $= 1,00,000 + 861400 \times 2.50 = 22,53,000/-$ Rs.

2. A consumer is charged electricity in the following tariff: Rs. 10.40/kVA of maximum demand plus Rs. 5.5 per unit consumed. The consumer has an aggregate motor of load 300 kW at a power factor of 0.8 lagging. Find out the consumer's annual bill for a load factor of 80%. [WBUT 2015]

Answer:

$$\text{Load factor} = \frac{\text{Number of units consumed in a year}}{\text{Maximum demand} \times 8760}$$

$$\text{or,} \quad 0.80 = \frac{\text{Number of units consumed in a year}}{\text{Maximum demand} \times 8760}$$

or, number of units consumed in a year $= 0.80 \times 300 \times 8760$ kWh

Annual cost of energy consumed $= 0.80 \times 300 \times 8760 \times 0.055 =$ ₹115632

$$\text{Maximum demand in kVA} = \frac{300}{0.8} = 375 \text{ kVA}$$

Annual cost of maximum demand $= 375 \times 10.40 =$ ₹3900

Total annual bill $= 115632 + 3900 =$ ₹119532

3. The monthly reading of a consumer's meter is as follows: [WBUT 2017]

Maximum demand = 50kN

Energy consumed = 36000 kW

Reactive energy = 23400 kVARh

If the tariff is Rs. 80 per kW of maximum demand plus 8 paise per unit plus 0.5 paise per unit for each 1% of power factor below 86%, calculate the monthly bill of the consumer.

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Answer:

$$\text{Average load} = \frac{36000}{24 \times 30} = 50 \text{ kW}$$

$$\text{Average reactive power} = \frac{23400}{24 \times 30} = 32.5 \text{ kVAR}$$

If ϕ is the power factor angle then,

$$\tan\phi = \frac{\text{kVAR}}{\text{Active power}} = \frac{32.5}{50} = 0.65$$

$\therefore$ Power factor, $\cos\phi = \cos 33.02 = 0.8384$

$$\text{Power factor surcharge} = ₹\,\frac{36000 \times 0.5}{100}(86 - 83.84) = ₹\,388.8$$

$$\text{Monthly bill} = ₹\,(80 \times 50 + 0.08 \times 36000 + 388.8)$$

$$= ₹\,(4000 + 2880 + 388.8) = ₹\,7268.80 \quad \textbf{(Ans.)}$$

4. An industrial consumer having a maximum demand of 100 KW, maintains a load factor of 60%. The tariff rate is Rs. 900/kVA of maximum demand per annum and Rs. 1.8/kWh of energy consumed. If the average power factor is 0.8 lagging then calculate the annual energy consumed and the yearly electricity bill. [WBUT 2019]

Answer:

$$0.6 = \frac{\text{No. of units consumed in a year}}{\text{Maximum demand} \times 8760}$$

Annual cost of energy consumed $= 0.6 \times 100 \times 8760 \times 1.8 = 946080$

No. of units consumed $= 0.6 \times 100 \times 8760 = 525600\,\text{KWh}$

Maximum demand in kVA $= \frac{100}{0.8} = 125$

Annual cost of maximum demand = 125 × 900 = 112500

Total annual bill = 964080 + 112500 = Rs. 1076580

Yearly bill = Rs. 12918960

Long Answer Type Questions

1. a) What is Availability Based Tariff (ABT)? [WBUT 2006, 2010, 2016, 2018]

b) What is 2-part tariff? Explain how it is determined.[WBUT 2006, 2010, 2016, 2018]

OR,

Write short note on Two part tariff. [WBUT 2009]

Answer:

a) Availability Based Tariff (ABT) is a frequency based pricing mechanism for electric power. The ABT falls under electricity market mechanisms to charge and regulate power to achieve short term and long term network stability as well as incentives and dis-incentives to market participants against deviations in committed supplies as the case may be. ABT Mechanism (Energy policy of India) is adopted in India (ABT Order dated January 2000 of CERC) and in a few other countries for pricing bulk power across various stakeholders. ABT concerns itself with the tariff structure for bulk power and is aimed at bringing about more responsibility and accountability in power generation and consumption through a scheme of incentives and disincentives. As per the notification, ABT was initially made applicable to only central generating stations having more than one SEB/State/Union Territory as its beneficiary. Through this scheme, the Central Electricity Regulatory Commission (CERC) looks forward to improve the quality of power and curtail the following disruptive trends in power sector:

i) Unacceptably rapid and high frequency deviations (from 50 Hz) causing damage and disruption to large scale industrial consumers

ii) Frequent grid disturbances resulting in generators tripping, power outages and power grid disintegration.

ABT Features

- ABT brings about enhanced grid discipline
- Economically viable power with right pricing
- Promote competition and efficiency and also
- Encourage use of Merit Order Dispatch / Economic Dispatch in India.

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b) When the rate of electrical energy is charged on the basis of maximum demand of the consumer and the units consumed, it is called a two-part-tariff.

In two-part-tariff, the total charge to be made from the consumer is split into two components viz. fixed charges and running charges. The fixed charges depend upon the maximum demand of the consumer while the running charges depend upon the number of units consumed by the consumer. Thus the consumer is charged at a certain amount per kW of maximum demand plus a certain amount per kWh of energy consumed i.e

$$\text{Total charges} = Rs\left(b \times kW + c \times kWh\right)$$

where, $b =$ Charges per kW of maximum demand

$c =$ Charge per kWh of energy consumed

This type of tariff is mostly applicable to industrial consumers who have appreciable maximum demand.

Advantages

(i) It is understood by the consumers,

(ii) It recovers the fixed charges which depend upon the maximum demand of the consumer but are independent of the

(iii) units consumed.

2. a) What is meant by the term "tariff"? [WBUT 2011, 2013]

Answer:

The rate at which electrical energy is supplied to a consumer is known as tariff. The supply company has to ensure that the tariff is such that it not only recovers the total cost of producing electrical energy but also earns profit against the capital investment.

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Objectives

The tariff must have the following objectives:

(a) Recovery cost of producing electrical energy at the power station.

(b) Recovery of cost on the capital investment in transmission and distribution systems.

(c) Recovery of cost of operation and maintenance of supply of electrical energy i.e. metering equipment, billing etc.

(d) Reasonable profit against capital investment.

b) Explain the following: [WBUT 2011, 2013]

i) Two-part tariff

ii) Maximum Demand tariff

iii) Availability based tariff.

Answer:

i) The total charge to be made to the consumer is split into two components namely fixed charge and running charge. Since fixed charge is independent of energy consumed and proportional to the maximum demand so the fixed charge is made at a certain amount per kW of maximum demand, which can be assessed on the basis of the ratable value of the premises or on the number of rooms excluding bath rooms or on the connected load or on the total combined KW capacity of all the consuming devices owned by a particular consumer.

Total energy charges, e = Rs a kW + b kWh where Rs a is the charge per kW of maximum demand assessed and Rs b is the charge per KWh of energy consumed.

ii) Typically daytime demand is higher than at night, weekday demand higher than at weekends and winter demand much higher than in summer. Because electricity cannot be stored there must be sufficient generation, transmission and distribution capacity to meet the highest demand. For these reasons most tariffs for larger user are designed to encourage customers to control electricity demand at daytime peaks.
It is similar to two-part with the only difference that the maximum demand is actually measured by installing maximum demand meter in the premises of the consumer. This removes the objection of two-part tariff where the maximum demand is assumed merely on the basis of the ratable value. This type of tariff is mostly applied to big consumers. However, it is not suitable for a small consumer (e.g. residential consumer) as a separate maximum demand meter is required.

iii) ABT has been under discussion since 1994 when M/s ECC, an ADB consultant, first supported it. GOI constituted a National Task Force in February 1995.It had ten meetings till end 1998 where all the related issues were discussed. A draft notification wads prepared for issue by government. With effect from May 15, 1999 the jurisdiction was vested in the CERC. Papers were sent to the commission in June 1999 by the MOP. The proceedings were held in the Commission from July 26 to 28 1999. The ABT order dated January 4, 2000 of the Commission depends significantly from the draft notification as also from the prevailing tariff design.

c) A consumer has a maximum demand of 250 kW at 45% load factor. If the tariff is Rs.100 per kW of maximum demand plus 10 paise per kWh, find the overall cost per kWh. **[WBUT 2011, 2013]**

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Answer:

250 kWat 45% load factor

tariff Rs. 100/kW_{ot} maximum demand + 10 paise/kWh

Units consumed / year = maximum demand × L.F. × Hours in a year

$= 250 \times 0.45 \times 8760$ kWh $= 985500$

Annual charges = Annual M.D. charges + Annual energy charges

$= \text{Rs. } (100 \times 250 + 0.1 \times 985500)$

$= \text{Rs. } (25000 + 98550) = 123550$

Overall cost / kWh = Rs. $\dfrac{123550}{985500}$ = Re. 0.1253 = 12.53 paise

3. Write short notes on Two-part Tariff. **[WBUT 2019]**

Answer:

Refer to Question No. 2(b)(i) of Long Answer Type Questions.

MISCELLANEOUS

Multiple Choice Type Questions

1. A synchronous compensator absorbs inductive reactive power. It is [WBUT 2009, 2010, 2015]
   a) over excited
   b) normally excited
   c) under excited
   d) none of these

Answer: (a)

2. As the load factor of a generating plant increases, the generation cost per kWh generated [WBUT 2009, 2010]
   a) decreases
   b) increases
   c) remains same
   d) none of these

Answer: (b)

3. A lightning arrester connecting a line and earth in a sub-station [WBUT 2011]
   a) protects the transmission line against direct lightning stroke
   b) suppresses high frequency oscillation
   c) protects the terminal equipment from travelling surges
   d) none of these

Answer: (a), (c)

4. What is the approximate efficiency of a normal thermal power plant? [WBUT 2015]
   a) 30 – 40%
   b) 20 – 25%
   c) 40 – 50%
   d) 60 – 70%

Answer: (a)

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5. The quantity of raw materials used for generating a given quantity of power is the least in the case of [WBUT 2015]
   a) thermal power plant
   b) hydel power plant
   c) nuclear power plant
   d) MHD

Answer: (c)

6. Load factor is defined as the ratio of [WBUT 2016]
   a) average demand to plant capacity
   b) average load to maximum demand
   c) maximum demand to connected load
   d) average load to connected load

Answer: (c)

7. Nuclear power plant is invariably used as a/an [WBUT 2016]
   a) peak load point
   b) base load point
   c) stand by plant
   d) emergency plant

Answer: (a)

8. In thermal power plants, the pressure in the working fluid cycle is developed by [WBUT 2018]
   a) condenser
   b) superheater
   c) feed water pump
   d) turbine

Answer: (a)

9. In a stream power plant heat from the flue gases is recovered in **[WBUT 2018]**

a) condenser **b) chimney**
c) economizer and air preheater **d) desuperheater**

Answer: (c)

10. Nuclear power plant is invariably used as a/an **[WBUT 2018]**

a) Peak load plant **b) Base load plant**
c) Stand by plant **d) Emergency plant**

Answer: (a)

11. Which of the following materials is not used as control rods of nuclear power plant? **[WBUT 2019]**

a) cadmium **b) helium**
c) boron **d) hafnium**

Answer: (a)

Short Answer Type Questions

1. What is load curve? What are the information we can get from 'Load Curve'? **[WBUT 2006, 2007]**

Answer:

The curve showing the variation of load on the power station with respect to (w.r.t) time is known as load curve.

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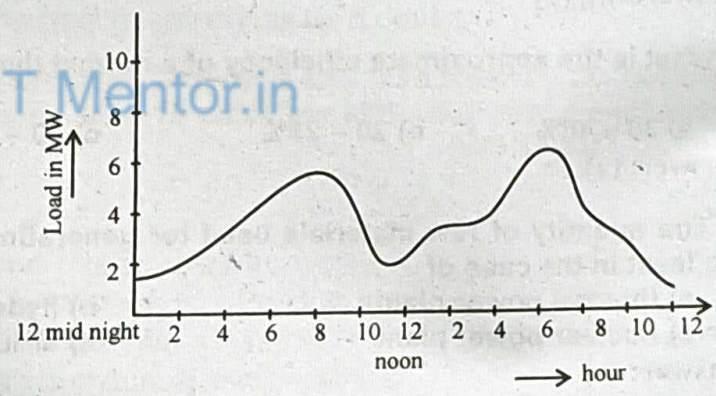

The load on a power station is never constant; it varies from time to time. These load variations during the 24 hours are recorded hourly or half hourly and are plotted against time on the graph.

As daily load curves gives sufficient information about the total load demand, so it has great importance in generation.

a) It gives the power demand for different hours of the day.
b) The area under the daily load curve gives the number of units generated in the day.
   i.e., Total units generated/day = Area under daily load curve.
c) The top point of the daily load curve represents the maximum demand on the station on that day.
d) The area under the daily load curve divided by the total number of hours gives the average load on the station in the day.

$$\text{Average load} = \frac{\text{Area (in Kwh) under daily load curve}}{\text{24 hours.}}$$

e) The ratio of the area under the load curve to the total area of rectangle in which it is continued gives the load factor.

$$\text{Load factor} = \frac{\text{Average load}}{\text{Max. demand}} = \frac{\text{Average load} \times 24}{\text{Max. demand} \times 24}$$

$$= \frac{\text{Area under daily load curve}}{\text{Total area of rectangle in which the load curve is contained.}}$$

f) Load curve is helpful in selecting the nos. of generator units.

g) It also helps preparing generator operation schedule.

2. Explain different methods of power factor correction. **[WBUT 2006]**

OR,

Explain different methods adopted for power factor correction. **[WBUT 2007]**

Answer:

Power factor correction

Power factor correction can be achieved by the following equipment:

1. Static capacitor
2. Synchronous condenser
3. Phase advancers

1. Static Capacitor: By connecting capacitors in parallel with the equipment operating at lagging power factor. The capacitor draws a leading current and partly or completely neutralizes the lagging reactive component of load current. This rises the power factor of the load.

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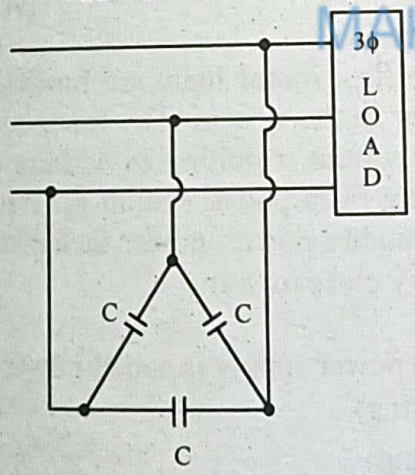
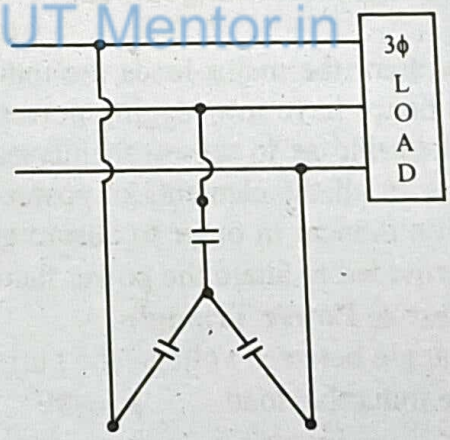
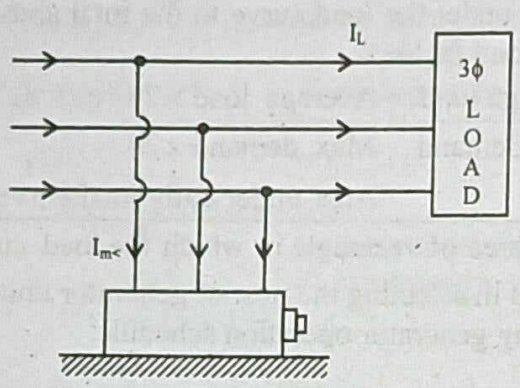


Delta connected static compensator



Star connected static compensator

2. Synchronous Condenser: Synchronous motor takes a leading current when over-excited and, therefore, behaves as a capacitor. An over-excited synchronous motor running on no load is known as synchronous condenser. When such a machine is connected in parallel with the supply, it takes a leading current which partly neutralizes the lagging reactive component of the load. Thus the power factor is improved.



3. Phase advancers: Phase advancers are used to improve the power factor of induction motors. The low power factor of an induction motor is due to the fact that its stator winding draws exciting current which lags behind the supply voltage by 90°. If the exciting ampere turns can be provide from some other a.c. source, then the stator winding will be relieved of exciting current and the power factor of the motor can be improved.

Long Answer Type Questions

1. Discuss the various methods of controlling reactive power at load end to keep consumer's terminal voltage fixed. **[WBUT 2007, 2014]**

OR,

Discuss in brief various methods of controlling reactive power at load end to keep consumers' terminal voltage fixed. **[WBUT 2016]**

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Answer:

In power system the major loads are inductive (i.e., motor load, arc furnace, lamps) in nature and hence have low lagging power factor in the system. The low power factor is highly undesirable as it causes an increase in current, resulting in additional losses of active power in all the elements of power system from power station generator down to the utilization device. In order to ensure good quality power, power factor improvement should be provided to attain the power factor very close to unity.

Power Factor & Power Triangle

The cosine angle between voltage and current in power supply is called power factor.

(a) For pure inductive load $\phi = -90°$ (lagging)

(b) For pure capacitive load $\phi = +90°$ (leading)

(c) For Resistive load $\phi = 0°$

The analysis of power factor can also be made in terms of power drawn by the a.c circuit.

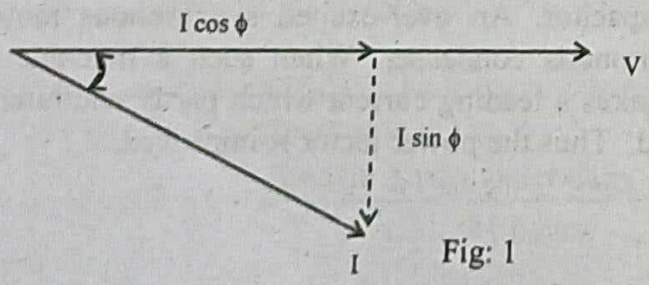

Fig: 1

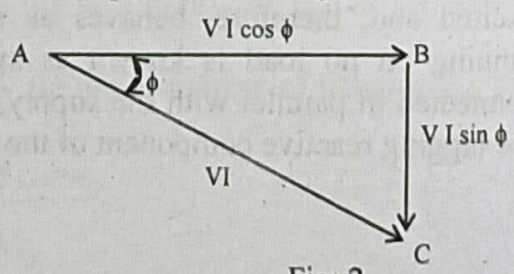

Fig: 2

$AB \rightarrow$ Active power in watts or Kwatt
$BC \rightarrow$ Reactive power in VAR or KVAR
$AC \rightarrow$ Apparent power in VA or KVA

i.e., $(AC)^2 = (AB)^2 + (BC)^2$

i.e., $(\text{Apparent Power})^2 = (\text{Active Power})^2 + (\text{Reactive Power})^2$

i.e., $KVAR = KVA\sin\phi = KW\tan\phi$

Discharges of low power factor

It is known, power Active power is given as,

$$W = V_L I_L \cos\phi$$

or, $$I_L = \frac{W}{V_L \cos\phi}$$

i.e., $$I_L \propto \frac{1}{\cos\phi}$$

So for low $\cos\phi$ (power factor), load current will increase i.e., power systems have to face some problems:

(a) Requirement of KVA rating should be high for a particular system

$$KVA = \frac{KW}{\cos\phi} \quad [\cos\phi \downarrow \text{so, } KVA \uparrow \text{ for fixed } KW]$$

(b) As I_L increased for low $\cos\phi$, so the dimension of the conductor material should be kept large, to maintain low transmission loss.

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(c) The large current at low lagging power factor causes greater voltage drops in alternators, transformers, transmission lines and distributors.

(d) The lagging power factor reduces the handling capacity of all the elements of the system. It is because; the reactive component of current prevents the full utilization of installed capacity.

Types of Compensators

(a) Shunt capacitors
(b) Synchronous compensator
(c) Series capacitors
(d) Static VAR system

(a) Shunt capacitors compensation

Small banks of static capacitors are usually connected in star/ delta and used in substations for supplying reactive power (Q) to the system. It improves the power factor of the load and hence has got wide application in industrial bus of distribution system and in sub transmission systems. By supplying reactive power to the bus it remains its voltage profile. In transmission systems, the static capacitor banks are often connected to the tertiary delta winding of the substation transformer.

The reactive power supplied by the capacitors (Q_c) is given by:

$$Q_c = VI_c = \frac{V^2}{X_c} = V^2 \omega C MVAR/\text{phase}$$

where X_c = shunt capacitive reactance/phase

V = phase voltage

C = Capacitance/phase

Shunt connected inductors are frequently used at the load end of the transmission line to control the over voltage of the receiving end at light load condition (Ferranti effect). The inductors are usually coreless type and possess linear type characteristics. If X_L be the reactance/phase of the inductor with phase voltage V, the reactive power absorbed by these inductors, Q_L (obviously in star or in delta connection) is given by

$$Q_L = VI_1 = -\frac{V^2}{X_L} = -\frac{V^2}{\omega L} \text{MVAR per phase.}$$

where, V = phase voltage

X_L = Reactance of inductor/phase $= \omega L$ ohms

L = Inductance/phase

$-ve$ sign indicates reactive power absorption]

(b) Synchronous compensator

It is basically a synchronous motor running at no load. Depending on the value of excitation, it can absorb or generate reactive power. However, the losses within the motor are more and wear and tear is high. A great flexibility of operation for all load condition (lagging or leading) is thus achieved. Thus, its use in high voltage transmission lines helps in either absorption of reactive power or supply of reactive power under light load or heavy load conditions respectively.

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Additional advantages of this device include improvement in system stability, reduction of the effect of sudden change in load, arresting voltage dips and supply of heavy amount of reactive power during short period. Moreover, the control is continuous. Disadvantages include high cost of installation, contribution of more short circuit current in the system, more loss and higher maintenance.

(c) Series capacitors

It is powerful device to improve the power transfer capability as well as the voltage profile of the line as well as the receiving end bus.

Series capacitors are connected in series with the line conductors and hence reduce the net inductive reactance between the two ends of the line. It improves the voltage stable state and supplies reactive power to the receiving end such that voltage profile is maintained.

In addition to this benefit, due to net decrease of series inductive reactance, the steady state stability improves. Power transfer also increases and switched series capacitors can

be used in order to improve transient stability. However, its use is still limited except for EHV systems because of the following reasons:

(1) Severe over voltage during line fault.

(2) Ferro resonance in series compensated lightly loaded line with transformer at the receiving end.

(3) Sub-synchronous resonance with the electro-mechanical system of the turbine generator with the line causing high torsional stress.

(4) Economy is affected and its installation is not justified when the load reactive power requirement is small.

(5) Series capacitor compensation may lead to mal-operation of distance relays in the transmission line when the degree of compensation is high.

(d) Static Var compensation

Shunt capacitor compensation is required to enhance the system voltage during heavy load condition of transmission line while reactors are needed to reduce the over voltage of the line at light load condition. A static VAR system (SVS) can perform these two tasks together utilizing the static VAR compensator.

A static VAR compensator (SVC) is basically a parallel combination of controlled reactor and fixed static capacitor (as shown in the Fig. 3).

The reactor control is done by an anti-parallel thyristors switch assembly. The firing angle of the thyristors governs the voltage across the inductor thus controlling the reactor current. Thus the reactive power absorption by the inductor can be controlled. The capacitor, in parallel with the reactor, supplies reactive power to the system. Assuming Q_C as the reactive power charging by the capacitor and Q_l the reactive power absorption by the inductor, the reactive power injection to the bus becomes $Q = Q_c - Q_l$

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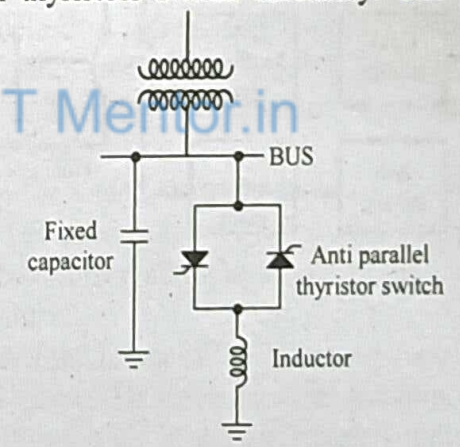


Fig: 3 Schematic of a static VAR compensator

In SVC Q_l is varied and thus Q is controllable. The bus voltage is thus controllable by SVC. During light load period, Q_l is greater than Q_c while during heavy load condition, Q_c is greater than Q_l. This equipment has got high application in transmission, sub-transmission and even in distribution bus voltage control.

2. Draw a general layout of modern thermal power plant and explain the working of different circuits and components. [WBUT 2013]

OR,

Draw the schematic diagram of a steam power plant. Explain the function of different constituents of the steam power plant. [WBUT 2015]

OR,

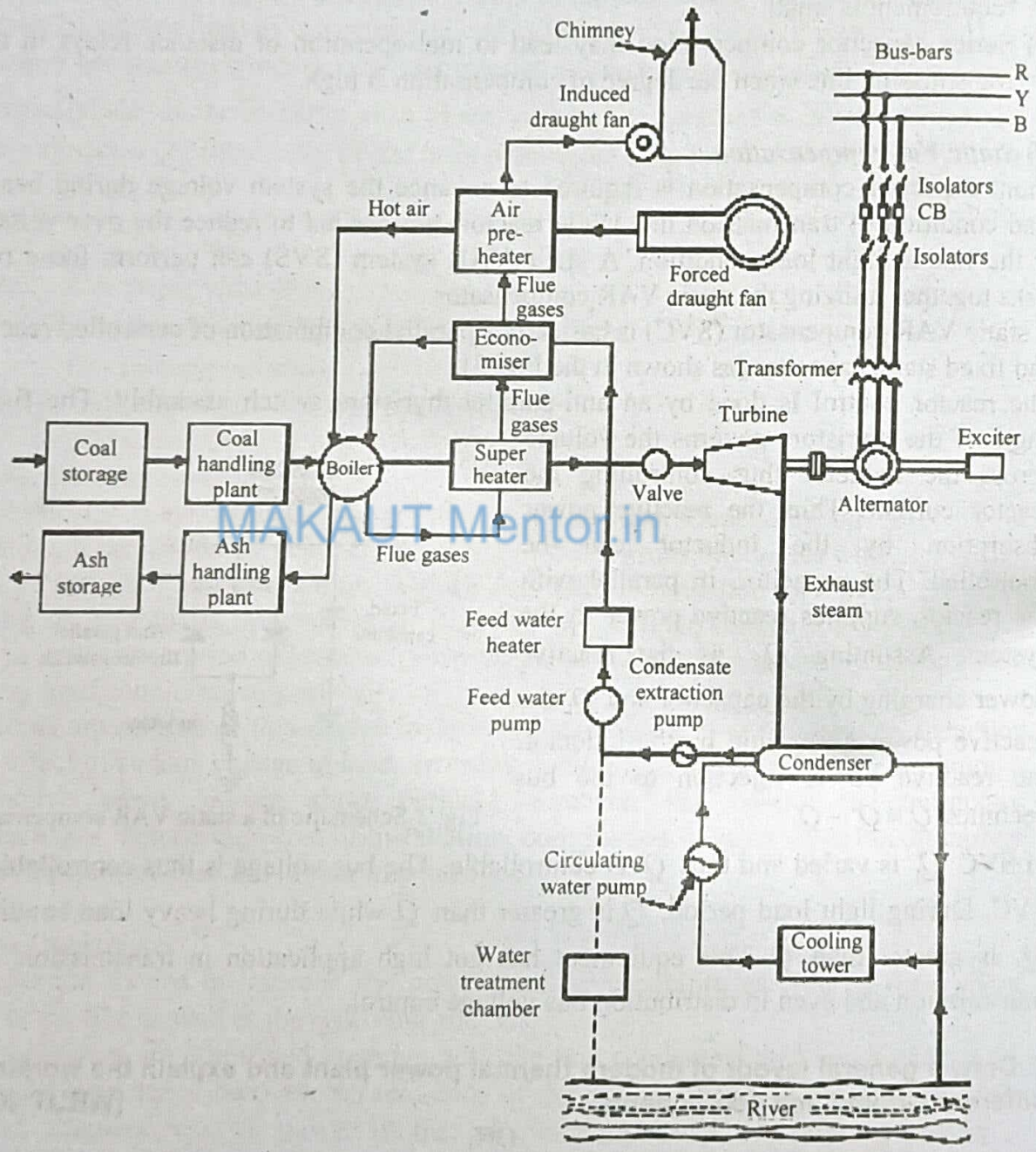
Draw the layout of diagram of a thermal power plant. Give the function of each part of thermal power plant. **[WBUT 2017]**

OR,

Draw the layout diagram of a thermal power plant. Give detail working principle of the thermal power plant. **[WBUT 2018]**

Answer:

The schematic arrangement of a modern Thermal Power Plant is shown below:



Schematic arrangement of thermal power plant

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The function of each part of thermal power plant is briefly explained as under:

1. **Coal and ash handling plant:** The coal is transported to the power station by road or railway and is stored in the coal storage plant. Storage of coal is primarily a matter of protection against coal strikes, failure of transportation system and general coal shortages. From the coal storage plant, coal is delivered to the coal handling plant where it is pulverized (i.e., crushed into small pieces) in order to increase its surface exposure, thus promoting rapid combustion without using large quantity of excess air. The pulverized coal is fed to the boiler by belt conveyors. The coal is burnt in the boiler and the ash produced after the complete combustion of coal is removed to the ash handling plant and then delivered to the ash storage plant for disposal. The removal of the ash from the boiler furnace is necessary for proper burning of coal.
2. **Steam generating plant:** The steam generating plant consists of a boiler for the production of steam and other auxiliary equipment for the utilization of flue gases.
   i) **Boiler:** the heat of combustion of coal in the boiler is utilized to convert water into steam in high temperature and pressure. The flue gases from the boiler make their journey through super heater, economizer, air pre-heater and are finally exhausted to atmosphere through the chimney.
   ii) **Superheater:** The steam produced in the boiler is wet and is passed through a superheater where it is dried and superheated (i.e., steam temperature increased above that of boiling point of water) by the flue gases on their way to chimney. Superheating provides two principal benefits. Firstly, the overall efficiency is increased. Secondly, too much condensation in the last stages of turbine (which would cause blade corrosion) is avoided. The superheated steam from the super heater is fed to steam turbine through the main valve.
   iii) **Economiser:** An economiser is essentially a feed water heater and derives heat from the flue gases for this purpose. The feed water is fed to the economiser before supplying to the boiler. The economiser extracts a part of heat of flue gases to increase the feed water temperature.
   iv) **Air preheater:** An air preheater increases the temperature of the air supplied for coal burning by deriving heat from flue gases. Air is drawn from the atmosphere by a forced draught fan and is passed through air preheater before supplying to the boiler furnace. The air preheater extracts heat from flue gases and increases the temperature of air used for coal combustion. The principal benefits of preheating the air are: increased thermal efficiency and increased steam capacity per square meter of boiler surface.
3. **Steam turbine:** The dry and superheated steam from the superheater is fed to the steam turbine through main valve. The heat energy of steam when passing over the blades of turbine converted into mechanical energy. After giving heat energy to the turbine, the steam is exhausted the condenser which condenses the exhausted steam by means of cold water circulation.
4. **Alternator:** The steam turbine is coupled to an alternator. The alternator converts mechanical energy of turbine into electrical energy. The electrical output from the alternator is delivered the bus bars through transformer, circuit breakers and isolators.

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5. **Feed water:** The condensate from the condenser is used as feed water to the boiler. Some water may be lost in the cycle which is suitably made up from external source. The feed water on the way to the boiler is heated by water heater and economiser. This helps in raising the overall efficiency of the plant.
6. **Cooling arrangement:** In order to improve the efficiency of the plant, the steam exhausted from the turbine is condensed by means of a condenser. Water is drawn from the natural source of supply viz., river and is circulated through the condenser. The circulating water takes up the heat of the exhausted steam and itself become hot. During the scarcity of water in the river, hot water from the condenser is passed on to the cooling towers where it is cooled. The cold water from the cooling tower is reused in the condenser.

3. A 3-phase line having an impedance of (5+j20) ohm per phase delivers a load of 30 MW at a p.f. of 0.8 lagging and voltage 33 kV. Determine the capacity of the phase modifier required to install at the receiving end if the voltage at the sending end is to be maintained at 33 kV. **[WBUT 2014, 2016]**

Answer:

$\alpha = 0°$ $\qquad \beta = 73.3°$

$A = 1$ $\qquad B = \sqrt{20^2 + 5^2} = 20.61\Omega$

Using equation & substituting 3 phase quantities we have

$$33^2 = 33^2 + 20.61^2\left[\left(\frac{30}{33}\right)^2 + \left(\frac{Q_r}{33}\right)^2\right] + 2\times1\times20.61\times30\cos73.3°$$

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$$+2\times1\times20.61\times Q_r\sin73.3°$$

$$\Rightarrow 0 = 20.61^2\left[.826 + \left(\frac{Q_r}{33}\right)^2\right] + 2\times20.61\times30\times.287 + 2\times20.61\times Q_r\times.9578$$

$$\Rightarrow 0 = 20.61^2\left[.826 + \left(\frac{Q_r}{33}\right)^2\right] + 41.22\times30\times.287 + 41.22\times.9578\times Q_r$$

$$\Rightarrow 0 = 424.7721\left[.826 + \left(\frac{Q_r}{33}\right)^2\right] + 354.9042 + 39.48Q_r$$

$$\Rightarrow 0 = 350.8617 + \frac{424.7721}{33^2}\times Q_r^2 + 354.9042 + 39.48Q_r$$

$$\Rightarrow 0 = 350.8617 + .39Q_r^2 + 354.9042 + 39.48Q_r$$

$$\Rightarrow 0 = 705.7659 + .39Q_r^2 + 39.48Q_r$$

$$\Rightarrow 0 = 1809.656 + Q_r^2 + 101.23Q_r$$

$$\Rightarrow 0 = Q_r^2 + 101.23Q_r + 1809.656$$

$$\sqrt{b^2-4ac}=\sqrt{101.23^2-4\times1\times1809.656}$$
$$=\sqrt{10,247.5129-7238.624}$$
$$=\sqrt{3008.8889}=54.85$$
$$Q_r=\frac{-101.23+54.85}{2}=-23.19$$

Since Q_r is negative, the phase modifier supplies 23.19MVAr in addition to the MVAr requirements of the load i.e., the phase modifier capacity is

$$=23.19+\frac{30}{0.8}\times.6=23.19+22.5=45.69MVAr$$

4. Draw the layout diagram of a Hydel power plant. Give detailed working principle of the Hydel power plant. [WBUT 2016]

Answer:

Layout And Working Of Hydropower Stations

In hydroelectric power plants, water power in the form of velocity/potential is used to run the hydraulic turbines (Fig. 1). The generator connected to the turbine converts the mechanical shaft power into electrical power. It is a renewable and non-polluting source of energy. Site selection for a hydroelectric plant has already been discussed. *A* few terms frequently used in hydropower are discussed here below:

(a) Gross head (H_g): Gross head is defined as the distance between head race and tail race, as shown in Fig 1.

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Effective head, $H=H_g-h_f-h$ ... (1)

where h is the height of the nozzle above the tail race, and h_f is the frictional head loss in penstock.

(b) Water power: Water power is defined as the capacity of water to produce work. It is equal to *mgh*, i.e., potential energy of water, where, *m*, *g*, & *h* are mass of fluid, gravitational acceleration and head available, respectively.

(c) Bucket power: power developed by the turbine or bucket power $=m(V_{w1}-V_{w2})u$

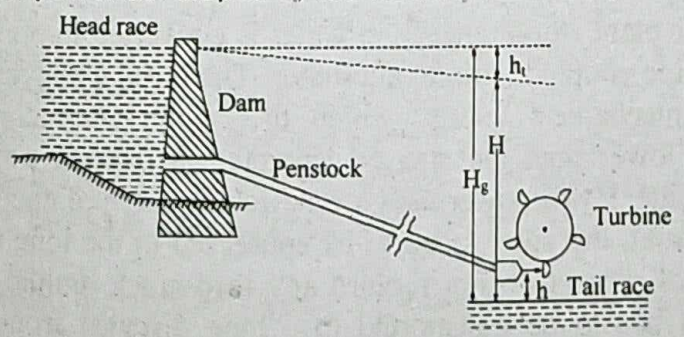

Fig. 1 Layout diagram of a hydroelectric power plant

V_{w1} and V_{w2} are whirl velocity at inlet and outlet respectively and u is the bucket peripheral velocity.

Overall efficiency, $(\eta)_0 = \dfrac{\text{Shaft power}}{\text{Water power}} = \dfrac{P}{wQH}$ ... (2)

w = Specific weight

Q = Volume flow rate of water

Volumetric efficiency (η_v), is to account for water, which does not strike the bucket.

$$= \frac{\text{Volume water actually striking the bucket } (Q_a)}{\text{Total water supplied by the nozzle} (Q)} \quad \text{... (3)}$$

Thus, $\boxed{\eta_v = \dfrac{Q_a}{Q}} = \dfrac{Q-q}{Q}$ ... (4)

where q is the loss or leakage.

Hydraulic efficiency,

$$\eta_h = \frac{\text{Bucket power}}{\text{Water power}} = \frac{\rho Q_a (V_{w1} \pm V_{w2}) u}{(\rho Q_a) gH} = \frac{H_e}{H} \quad \text{... (5)}$$

$$\left[H_e = \text{Euler head} = \frac{(V_{w1} \pm V_{w2}) u}{g} \right]$$

$$= \frac{H - \Delta H}{H} \quad \text{... (6)}$$

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ΔH = Head loss within the turbine

Mechanical efficiency, $\eta_m = \dfrac{\text{Shaft power}}{\text{Bucket power}} = \dfrac{P}{WQ_u H_e}$ ... (7)

Overall efficiency, $\eta_0 = \eta_v \times \eta_h \times \eta_m = \dfrac{Q_a}{Q} \cdot \dfrac{H_e}{H} \times \dfrac{P}{wQ_a H_e} = \dfrac{P}{wQH}$ ... (8)

If generative efficiency is also considered, then

$$\boxed{\eta_0 \times \eta_{generator} = \eta_{plant}}$$

In a hydroelectric power plant stored energy in water is converted into electrical energy by the use of water turbine coupled with an alternator. The turbine converts the potential energy of water into mechanical energy which drives the alternator. The cost of generation per kWh is lower than the energy generated at thermal power stations or combined cycle gas turbine. Hydropower uses a renewable source of energy where fossil fuel are finite in nature and, therefore, need to be conserved in the long term interest of the country. This type of project do not require any feed stock, unlike thermal power projects for which coal has to be transported to a long distance from coal mines to thermal plant sites. While the life of a hydro plant is very long of the order of 35-40 years and its efficiency does not reduce much with age, the generation of power is dependent upon the availability of water in its reservoir. Since more than 70% of the annual run-off in India takes place during 3-4 monsoon months, it is necessary to build suitable storage

reservoir schemes so as to store water during monsoon period for utilization in non-monsoon months. While selecting the site for hydroelectric power station, it is the prime consideration that there must be large quantity of availability of water.

5. Write short notes on the following:

a) Synchronous condenser **[WBUT 2007]**

b) Step and touch potential **[WBUT 2013]**

c) Load curve and information obtained from load curves **[WBUT 2013]**

d) Working principle of Nuclear power plant **[WBUT 2019]**

Answer:

a) Synchronous condenser:

Refer to Question No. 1(b) Part of Long Answer Type Questions.

b) Step and Touch potential:

Step potential is the voltage difference between a person's feet and is caused by the voltage gradient in the soil at the point where a fault enters the earth. The potential gradient is steepest near the fault location and thereafter reduces gradually. Just 75cm away from the entry point, voltage usually will have been reduced by 50%. Thus at a point of 75cm from the fault (which is less than the distance of a normal step), a fatal potential of a few kilovolts can exist.

The touch potential represents the same basic hazard, except the potential exists between the person's hand and his or her feet. This happens when a person standing on the ground touches a structure of the substation which is conducting the fault current into ground. Since the likely current path within the human body runs through the arm and heart region instead of through the lower extremities, the danger of injury or death is far greater in this case. For this reason the safe limit of touch potential usually much lower than that of step potential.

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c) Load Curves: ***Refer to Question No. 1 of Short Answer Type Questions.***

d) Working principle of Nuclear power plant:

1. A nuclear power plant works pretty much like a conventional power plant, but it produces heat energy from atoms rather than by burning coal, oil, gas, or another fuel. The heat it produces is used to boil water to make steam, which drives one or more giant steam turbines connected to generators.

First, uranium fuel is loaded up into the reactor—a giant concrete dome that's reinforced in case it explodes. In the heart of the reactor (the core), atoms split apart and release heat energy, producing neutrons and splitting other atoms in a carefully controlled nuclear reaction.

2. Control rods made of materials such as cadmium and boron can be raised or lowered into the reactor to soak up neutrons and slow down or speed up the chain reaction.

3. Water is pumped through the reactor to collect the heat energy that the chain reaction produces. It constantly flows around a closed loop linking the reactor with a heat exchanger.

4. Inside the heat exchanger, the water from the reactor gives up its energy to cooler water flowing in another closed loop, turning it into steam. Using two unconnected loops of water and the heat exchanger helps to keep water contaminated with radioactivity safely contained in one place and well away from most of the equipment in the plant.
5. The steam from the heat exchanger is piped to a turbine. As the steam blows past the turbine's vanes, they spin around at high speed.
6. The spinning turbine is connected to an electricity generator and makes that spin too.
7. The generator produces electricity that flows out to the power grid—and to our homes, shops, offices, and factories.

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QUESTION 2015

Group – A
(Multiple Choice Type Questions)

1. Answer any *ten* questions:

i) The size of conductors of modern EHV lines is obtained based on
✓a) voltage drop b) current density c) corona d) skin effect

ii) As the load factor of a generating plant increases, the generation cost per kW generated
✓a) decreases b) increases c) remains same d) none of these

iii) A synchronous compensator absorbs inductive reactive power. It is
✓a) over excited b) normally excited c) under excited d) none of these

iv) Stringing chart is used in transmission lines for
a) designing the tower
✓b) calculating the sag in the conductor
c) determining the distance between the conductor
d) design of insulator string

v) The surge impedance of a 100 km long underground cable is 50Ω. The surge impedance of a 40 km long cable of similar type is
a) 20Ω ✓b) 50Ω c) 80Ω d) 125Ω

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vi) The ratio of average demand of energy and energy required according to installed capacity for power system is termed as
a) diversity factor b) load factor
✓c) plant capacity factor d) plant use factor

vii) The quantity of raw materials used for generating a given quantity of power is the least in the case of
a) thermal power plant b) hydral power plant
✓c) nuclear power plant d) MHD

viii) The A, B, C, D constants of transmission line are expressed as follows
a) AD + BC = 1 ✓b) AD – BC = 1 c) AD – BC = 0 d) AB + DC = 1

ix) When the effective resistance of a conductor increases due to the presence of current carrying conductor nearby, then the effect is called
a) skin effect ✓b) proximity effect c) Ferranti effect d) corona effect

x) At the time of transposition of three phase line, the equivalent equilateral spacing between the conductors is

✓a) $\sqrt[3]{d_1 d_2 d_3}$ b) $\sqrt{d_1 d_2 d_3}$ c) $d_1 d_2 d_3$ d) $\frac{1}{3}(d_1 d_2 d_3)$

xi) A string of insulator has 4 insulators. The voltage across the bottom unit is 30% of the total voltage. The string efficiency of insulator is

a) 30% b) 60% c) 75% ✓d) 83.33%

xii) What is the approximate efficiency of a normal thermal power plant?

✓a) 30 – 40% b) 20 – 25% c) 40 – 50% d) 60 – 70%

Group – B

(Short Answer Type Questions)

2. A transmission line conductor at a river crossing is supported from two towers at heights of 50m and 80m from water level. The horizontal distance between the towers is 300m. If the tension in the Conductor is 200kg, find the clearance between the conductor and water level at a point midway between the towers. Weight of the conductor per meter is 0.844kg.

See Topic: OVERHEAD LINE CONSTRUCTION, Short Answer Type Question No. 2.

3. What is grading of cable? Why is it necessary? How many types of grading are there?

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See Topic: UNDERGROUND CABLES, Short Answer Type Question No. 3.

4. Derive an expression of inductance for single phase two wire line.

See Topic: OVERHRAD TRANAMISSION LINE, Short Answer Type Question No. 5.

5. A consumer is charged electricity in the following tariff:

Rs. 10.40/kVA of maximum demand plus Rs. 5.5 per unit consumed. The consumer has an aggregate motor of load 300 kW at a power factor of 0.8 lagging. Find out the consumer's annual bill for a load factor of 80%.

See Topic: TARIFF, Short Answer Type Question No. 2.

6. Discuss main features of Indian Electricity rule – 1956.

See Topic: INDIAN ELECTRICITY RULES, Short Answer Type Question No. 1.

Group – C

(Long Answer Type Questions)

7. a) Define string efficiency. Briefly explain one method of improving the efficiency.

b) Each conductor of a 33 kV, 3 phase system is suspended by a string of three similar insulators. If the capacitance of each disc unit is five times the capacitance to ground of each unit, calculate

i) The voltage across each unit,

ii) String efficiency.

See Topic: INSULATORS, Long Answer Type Question No. 4(a) & (b).

8. a) A 50km long three phase, 50 Hz transmission line has resistance, reactance and susceptance are 0.1 ohm, 0.5 ohm and 10 × 10–6 S per phase per km respectively. If the line supplies load of 20MW at 0.9 p.f. Lagging 66 kV at the receiving end, calculate sending end power factor, regulation and transmission efficiency.

See Topic: PERFORMANCE OF LINES, Long Answer Type Question No. 3.

b) Write down the different factors affecting corona loss of transmission line.

See Topic: CORONA, Long Answer Type Question No. 1(b).

9. a) Derive the expression for voltage and current distribution over a long transmission line in hyperbolic form and obtain the A, B, C, D parameters.

b) The parameters of a 132 kV, 50 Hz, 3-phase transmission lines are

$R = 12.84\Omega$ $L = 0.162H$, $C = 1.014\mu F$.

Calculate the line constants A, B, C and D for nominal π method.

See Topic: PERFORMANCE OF LINES, Long Answer Type Question No. 1(a) & (b).

10. a) A single core cable has an inner diameter of 6 cm and a core diameter of 20 cm. Its paper dielectric has a working dielectric stress of 60 kV/cm. Calculate the maximum permissible line voltage when such cables are used on a three phase power system.

b) Find the most economical value of the diameter of single core cable to be used on 66 kV three phase system. Find also the overall diameter of the insulation if the maximum permissible stress is not to exceed 5 kV/mm.

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c) What is insulation resistance of a single core cable? Prove that the insulation resistance is inversely proportional to the length of the cable.

a) See Topic: UNDERGROUND CABLES, Long Answer Type Question No. 5.

b) See Topic: UNDERGROUND CABLES, Long Answer Type Question No. 4(b).

c) See Topic: UNDERGROUND CABLES, Long Answer Type Question No. 2(b).

11. Draw the schematic diagram of a steam power plant. Explain the function of different constituents of the steam power plant.

See Topic: MISCELLANEOUS, Long Answer Type Question No. 2.

QUESTION 2016

Group – A
(Multiple Choice Type Questions)

1. Choose the correct alternatives for any ten of the following:

i) The presence of earth in case of overhead lines

✓✓a) increases the capacitance b) increases the inductance

c) decreases the capacitance d) decreases the inductance

ii) Use of bundle conductors in EHV transmission system provides
a) increased line reactance
b) decreased capacitance
✓c) reduced voltage gradient
d) increased corona loss

iii) Transposition of transmission line is done to
a) reduce line loss
b) reduce skin effect
✓c) balance line voltage drop
d) reduce corona

iv) The transmission efficiency of a line is
a) directly proportional to the load power factor
✓b) inversely proportional to the load power factor
c) does not depend on load power factor
d) proportional to the square of load power factor

v) For a stranded conductor, the ratio of GMR to actual radius is
a) equal to 1
b) greater than 1
c) equal to 0.7788
✓d) less than 0.7788

vi) The electric stress in a cable is maximum at
a) centre of conductors
b) interface of sheath and conductors
✓c) lead sheath
d) armour

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vii) The A, B, C, D parameters for short transmission line with a series impedance z are
a) z, 0, 1, 1
b) 0, z, 1, 1
✓c) 1, z, 0, 1
d) 1, 1, z, 0

viii) Load factor is defined as the ratio of
a) average demand to plant capacity
b) average load to maximum demand
✓c) maximum demand to connected load
d) average load to connected load

ix) Nuclear power plant is invariably used as a/an
✓a) peak load point
b) base load point
c) stand by plant
d) emergency plant

x) The a.c. resistance of a conductor is greater than its d.c. value due to
a) skin effect
b) proximity effect
c) Ferranti effect
✓d) both (a) & (b)

xi) 25% of the line of neutral voltage appears across the bottom-most unit in a string insulators with 5 identical discs. The string efficiency is
✓a) 80%
b) 75%
c) 50%
d) 25%

xii) By increasing the sag on the transmission line, the tension
a) increases
✓b) decrease
c) not affected
d) may increase or decrease

Group – B
(Short Answer Type Questions)

2. A 3-phase, 50 Hz line consists of three conductors, each of diameter 21 mm. the spacing between the conductors are 3 m, 5 m & 3.6 m. Find the inductance & inductive reactances per phase per km of the line.
See Topic: OVERHEAD TRANSMISSION LINE, Short Answer Type Question No. 6.

3. For a single core lead sheathed cable derive the expressions for (i) maximum dielectric stress and (ii) capacitance.
See Topic: UNDERGROUND CABLES, Short Answer Type Question No. 4.

4. What is corona? Explain the principle of corona formation. What is critical disruptive voltage? What is air density factor?
See Topic: CORONA, Short Answer Type Question No. 5.

5. A single core cable of conductor diameter 2 cm and lead sheath of diameter 5.3 cm is to be used on a 66 kV, 3-phase system. Two inter-sheaths of diameter 3.1 cm and 4.2 cm are introduced between the core and lead sheath. If the maximum stress in the layers is the same, find the voltages on the intersheaths.[37.1 KV,18.87 kV]
See Topic: UNDERGROUND CABLES, Short Answer Type Question No. 5.

6. The towers of height 30 m and 90 m respectively support a transmission line conductor at water crossing. The horizontal distance between the towers is 500 m. If the tension in the conductor is 1600 kg, find the minimum clearance of the conductor and 3water and clearance mid-way between the supports. Weight of the conductor is 1.5 kg/m. bases of the towers can be considered to be at water level.
See Topic: OVERHEAD LINE CONSTRUCTION, Short Answer Type Question No. 3.

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Group – C
(Long Answer Type Questions)

7. a) Discuss in brief various methods of controlling reactive power at load end to keep consumers' terminal voltage fixed.
b) A 3-phase line having an impedance of (5+j20) ohm per phase delivers a load of 30 MW at a p.f. of 0.8 lagging and voltage 33 kV. Determine the capacity of the phase modifier required to install at the receiving end if the voltage at the sending end is to be maintained at 33 kV.
c) Explain Ferranti effect.
a) See Topic: MISCELLANEOUS, Long Answer Type Question No. 1.
b) See Topic: MISCELLANEOUS, Long Answer Type Question No. 3.
c) See Topic: PERFORMANCE OF LINES, Short Answer Type Question No. 1.

8. a) What are the methods of equalizing potential distribution over a string of insulator?

b) In a string of three insulator unit, the self-capacitance of each unit is C, from each connector to ground is C/3 and from each connector to line is C/5. Calculate the voltage across each unit as a percentage of total voltage.

c) Name the different types of insulators. What is string efficiency?

See Topic: INSULATORS, Long Answer Type Question No. 5(a), (b) & (c).

9. a) What is availability based tariff?

b) What is two part tariff? Explain how it is determined.

c) The daily load of an industrial corner is as follows:

100 kW for 9 hours
125 kW for 6 hours
50 kW for 7 hours
5 kW for 2 hours

The tariff rate is Rs. 800 per kW of maximum demand per year plus Rs. 2.50 per kWh. Determine consumption per year & yearly bill.

a) & b) See Topic: TARIFF, Long Answer Type Question No. 1(a) & (b).

c) See Topic: TARIFF, Short Answer Type Question No. 1.

10. a) Derive the expression of capacitance of a single phase line considering the effect of earth. Hence deduce the capacitance without the effect of earth.

b) A 3-phase, 400 kV, 50 Hz, 350 km overhead transmission line has flat horizontal spacing with three identical conductors. The conductors have an outside diameter of 3.28 cm with 12 m between adjacent conductors.

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Determine the capacitive reactance to neutral in ohms/m/ph and the capacitive reactance for the line in ohms/ph.

c) Why is surge impedance of overhead line more than underground cable?

See Topic: OVERHEAD TRANSMISSION LINE, Long Answer Type Question No. 8(a), (b) & (c).

11. Draw the layout diagram of a Hydel power plant. Give detailed working principle of the Hydel power plant.

See Topic: MISCELLANEOUS, Long Answer Type Question No. 4.

12. a) Point out the difference between the nominal π equivalent and equivalent π circuit model of a transmission line.

b) Find A, B, C, D constants for nominal π circuit of a medium transmission line. Also derive the expression for sending end voltage & current.

c) A 3-phase, 132 kV, 50 Hz transmission line has resistance, reactance and capacitance of 0.1 Ω, 5.0 Ω and 0.01 μF per km. Determine the series and shunt parameter and draw the nominal π circuit model of the line.

See Topic: OVERHEAD TRANSMISSION LINE, Long Answer Type Question No. 9(a), (b) & (c).

QUESTION 2017

Group – A
(Multiple Choice Type Questions)

1. Choose the correct alternatives for any *ten* of the following:

i) The function of earth wire in a transmission line is to
a) prevent earth fault
b) provide a safety measure for any high flying objects
✓c) provide a shield to the phase conductors from direct lightning stroke
d) provide mechanical strength to the tower

ii) The thickness of the layer of insulation on the conductor, in cables, depends upon
a) reactive power
b) power factor
✓c) voltage
d) current carrying capacity

iii) Which of the following insulators is used in transmission lines at a river and road crossings
a) Pen type
b) Suspension type
✓c) Strain type
d) Shackle type

iv) Diversity factor is always
a) 1
b) 0
✓c) greater than 1
d) λ

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v) A 3-phase, 4-wire system is commonly used for
a) primary distribution
✓b) secondary distribution
c) primary transmission
d) secondary transmission

vi) Shunt compensation in a transmission line is resorted to
a) improve the stability
✓b) improve the voltage profile
c) reduce the fault level
d) as a substitute for synchronous phase modifier

vii) Daily energy consumption of a plant is 30 units. Maximum demand is 2kW. Then the load factor will be
a) 60%
b) 50%
c) 75%
✓d) 62.5%

viii) In a 3-core cable, the capacitance between two conductors is 3mF. What will be the capacitance per phase?
a) 1.5μF
b) 3μF
✓c) 6μF
d) 12μF

ix) Stringing chart is useful for
✓a) finding the sag in the conductor
b) the design of insulator string
c) the design of tower
d) finding the distance between towers

x) The leakage resistance of a 50km long cable is 1MΩ. For a 100 km long cable, it will be

✓a) 1MΩ b) 0.66MΩ c) 2MΩ d) 0.5MΩ

xi) The economic size of a conductor is determine by

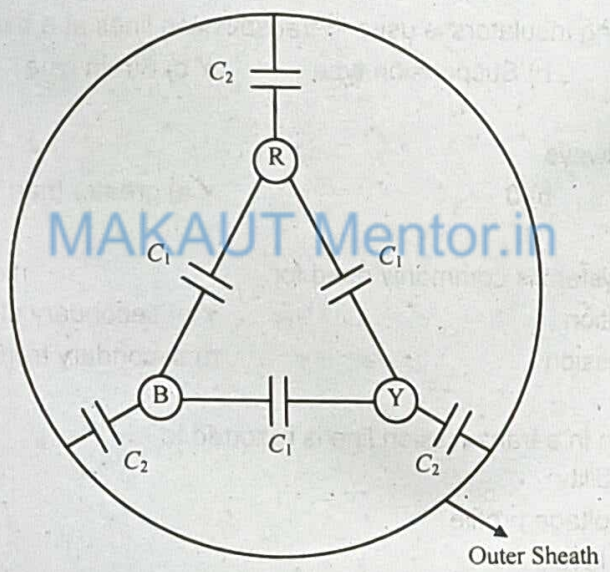
✓a) Kelvin's law b) Kirchhof's law c) Faraday's law d) Gauss's law

xii) The AC resistance of a conductor is greater than its DC value due to

✓a) Skin effect only b) Proximity effect only c) Ferranti effect only d) both (a) & (b)

Group – B
(Short Answer Type Questions)

2. Consider a three-core, three-phase, 50Hz, 11kV cable whose conductors are denoted as *R*, *Y* and *B* in the figure. The inter-phase capacitance (C_1) between each line conductor is 0.2μF and the capacitance (C_2) between core and sheath is 0.4μF. Determine the per-phase charging current.



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See Topic: OVERHEAD TRANSMISSION LINE, Short Answer Type Question No. 7.

3. The *A*, *B*, *C*, *D* constants of a 220kV line are: $A = D = 0.94\angle 10$, $B = 130\angle 73°$, $C = 0.001\angle 90°$. If the sending end voltage of the line for a given load delivered at nominal voltage is 240kV, what is the percentage voltage regulation of the line?

See Topic: OVERHEAD TRANSMISSION LINE, Short Answer Type Question No. 8.

4. The monthly reading of a consumer's meter is as follows:
Maximum demand = 50kN
Energy consumed = 36000 kW
Reactive energy = 23400 kVARh
If the tariff is Rs. 80 per kW of maximum demand plus 8 paise per unit plus 0.5 paise per unit for each 1% of power factor below 86%, calculate the monthly bill of the consumer.
See Topic: TARIFF, Short Answer Type Question No. 3.

5. An overhead transmission line conductor is subjected to a horizontal wind load of 1.78 kg/m & vertical ice loading of 1.08kg/m. If the maximum permissible sag is 6 metres, then calculate the permissible span between two supports allowing a factor of safety of 2. Weight of conductor is 0.849kg/m.
See Topic: OVERHEAD TRANSMISSION LINE, Short Answer Type Question No. 9.

6. Derive an expression of inductance for single phase two wire lines.
See Topic: OVERHEAD TRANSMISSION LINE, Short Answer Type Question No. 5.

Group – C
(Long Answer Type Questions)

7. a) For nominal "π" network representation, find the ABCD constants for medium lines. Also draw the phasor diagram.
b) The parameters of 220kV, 50Hz, three phase transmission lines are

$$R = 15.2\Omega,\ L = 0.165H \text{ and } C = 0.9\mu F.$$

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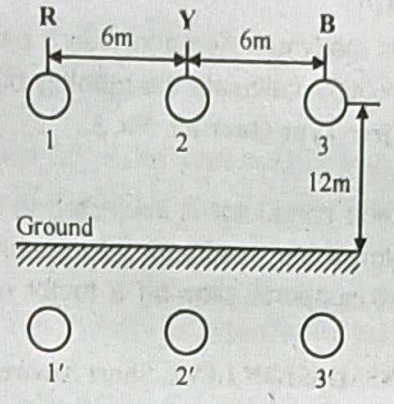
Using nominal T method find voltage, current, power factor at the sending end when 70MW at 0.8 power factor lagging load is connected at receiving end. Also calculate the efficiency.
See Topic: PERFORMANCE OF LINES, Long Answer Type Question No. 4(a) & (b).

8. a) A 66-kV, single core, lead sheathed cable is graded by using two dielectrics of relative permittivities 5 and 3 respectively, thickness of each being 1cm. The core diameter is 2 cm. Determine the maximum stress in the two dielectrics.
See Topic: UNDERGROUND CABLES, Long Answer Type Question No. 6.

b) The self capacitance of each unit in a string of three suspension insulator is C. The shunting capacitance of the connecting metal work of each insulator to earth is 0.15C while for line it is 0.1C. Calculate (i) the voltage across each insulator as a percentage of line voltage to earth and (ii) string efficiency.
See Topic: INSULATORS, Long Answer Type Question No. 6.

9. Draw the layout of diagram of a thermal power plant. Give the function of each part of thermal power plant.
See Topic: MISCELLANEOUS, Long Answer Type Question No. 2.

10. a) Derive the expression for inductance of a 3-phase completely transposed line.
b) Determine the capacitance per km per phase to neutral of a 3-phase line arranged as shown in the figure. The diameter of the conductor is 2.8cm. The line is transposed. Take the effect of ground into account.



a) See Topic: OVERHEAD TRANSMISSION LINE, Long Answer Type Question No. 2.
b) See Topic: OVERHEAD TRANSMISSION LINE, Long Answer Type Question No. 10.

11. a) What is corona? What are the advantages and disadvantages of corona? How can corona be minimized?
b) A 3-phase, 220 kV, 50Hz transmission line consists of 1.5cm radius conductor spaced 2m apart in equilateral triangular formation. If the temperature is 40°C and atmospheric pressure is 76cm, calculate the corona loss per km of the line. Assume roughness factor as 0.85.
c) Derive the expression of critical disruptive voltage of corona.
a) See Topic: CORONA, Long Answer Type Question No. 6.
b) See Topic: CORONA, Short Answer Type Question No. 2.
c) See Topic: CORONA, Short Answer Type Question No. 1.

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QUESTION 2018

Group – A
(Multiple Choice Type Questions)

1. Choose the correct alternative for *any ten* of the following:
i) The function of steel wire in an ACSR conductor is to
a) compensate for skin effect
b) take care of surges
c) reduce inductance
✓d) provide additional mechanical strength

ii) When is the Ferranti effect on long over head lines experienced?
✓a) The line is lightly loaded
b) The line is heavily loaded
c) The line is fully loaded
d) The power factor is unity

iii) The sag of a transmission line is least effected owing to
a) weight of the conductor
✓b) current through the conductor
c) atmospheric temperature
d) ice deposition on the conductor

iv) Transposition of transmission line is done to
a) reduce line loss
b) reduce skin effect
✓c) balance line voltage drop
d) reduce corona

v) The surge impedance of a 400kV, 100km transmission line is 300Ω. For a 200km length the line surge impedance will be
✓a) 300Ω
b) 150Ω
c) 600Ω
d) 400Ω

vi) Bundle conductor are used to
a) reduce inductance of the line
b) reduce corona loss
c) reduce both inductance and capacitance
✓d) reduce corona loss and line inductance

vii) Corona occurs between two transmission conductors when they
a) have high potential difference
b) are closely spaced
c) carry dc power
✓d) both (a) and (b)

viii) If the frequency of a transmission system is changed from 50Hz to 100Hz, the string efficiency
a) will increase
b) will decrease
✓c) remain unchanged
d) may increase or decrease depending on the parameter

ix) In a cable the sheath radius is R and conductor radius is r. As r changes from 0.5R to 0.25 R to maximum voltage gradient in the dielectric.
a) decrease by about 6%
✓b) increase by about 6%
c) decrease by about 15%
d) increase by about 15%

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x) In thermal power plants, the pressure in the working fluid cycle is developed by
✓a) condenser
b) superheater
c) feed water pump
d) turbine

xi) In a stream power plant heat from the flue gases is recovered in
a) condenser
b) chimney
✓c) economizer and air preheater
d) desuperheater

xii) Flat rate tariff can be charged on the basis of
a) connected load
✓b) units consumed
c) maximum demand
d) both (a) and (b)

xiii) Nuclear power plant is invariably used as a/an
✓a) Peak load plant
b) Base load plant
c) Stand by plant
d) Emergency plant

Group – B
(Short Answer Type Questions)

2. A three phase 50Hz line consists of three conductor, each of diameter 21 mm. The spacing between the conductor are 3m, 4m and 3.6m. Find the inductance and inductive reactance per phase per km of the line.

See Topic: OVER HEAD TRANSMISSION LINE, Short Answer Type Question No. 6.

3. What is grading of cable? Why is it necessary? How many types of grading are there?

See Topic: UNDERGROUND CABLES, Short Answer Type Question No. 3.

4. Derive the expression for critical disruptive voltage during corona.

See Topic: CORONA, Short Answer Type Question No. 1.

5. What is Ferranti Effect? Explain with the help of Phasor Diagram.

See Topic: PERFORMANCE OF LINES, Short Answer Type Question No. 1.

6. A single phase load of 200kVA is delivered at 2500V over a transmission line having R = 1.4Ω, X = 0.8Ω. Calculate the current and voltage at the sending end when the power factor of the load is unity.

See Topic: OVERHEAD TRANSMISSION LINE, Short Answer Type Question No. 10.

Group – C
(Long Answer Type Questions)

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7. a) What is availability based tariff?

b) What is two part tariff? Explain how it is determined.

c) The daily load of an industrial corner is as follows:

100kW for 9 hours
125kW for 6 hours
50kW for 7 hours
5kW for 2 hours

The tariff rate is Rs. 800 per kW of maximum demand per year plus Rs. 2.50 per kWh. Determine consumption per year and yearly bill.

a) & b) See Topic: TARIFF, Long Short Answer Type Question No. 1(a) & (b).

c) See Topic: TARIFF, Short Answer Type Question No. 1.

8. a) Derive the expression of inductance of a single phase line.

b) Explain the effect of earth on conductor capacitance.

c) A three phase 50Hz line consists of three conductors each of diameter 21mm. The spacing between the conductors is as follows:

A-B = 3m, B-C = 5m, C-A = 3.6m.

Find the capacitance and capacitive reactance per phase per km of the line. If the line operates at 132kV, find the charging current per km and the reactive volt-amperes generated by the line per km.

a) See Topic: OVERHEAD TRANSMISSION LINE, Short Answer Type Question No. 5.
b) & c) See Topic: OVERHEAD TRANSMISSION LINE, Long Answer Type Question No. 11(a) & (b).

9. Draw the layout diagram of a thermal power plant. Give detail working principle of the thermal power plant.
See Topic: MISCELLANEOUS, Long Answer Type Question No. 2.

10. a) For a nominal "T" network, find the ABCD constants of a medium transmission line.
b) Draw the required Phasor Diagram.
c) A three phase transmission line 50km long consists of three hard drawn copper conductors is 1.2m delta. Load condition at receiving end are: 10,000kVA at 0.8pf lagging, 33,000V 50Hz. Line is designed so that transmission loss is approximately 10%. Find –
i) The sending end voltage
ii) Power factor
iii) Efficiency and
iv) Regulation
See Topic: PERFORMANCE OF LINES, Long Answer Type Question No. 5(a), (b) & (c).

11. a) Derive the expression of Receiving End Power Circle Diagram in terms of General Circuit Constant.
b) Draw the Receiving End Power Circle Diagram.
c) Derive the expression of dielectric strength in a single core cable.
d) A 33kV, 3 phase, 50Hz underground line, 3.4 km long, uses three single core cable. Each cable has a core diameter of 2.5cm and the radial thickness of insulation is 0.6cm. The relative permittivity of the dielectric is 3.1. Find –
i) maximum stress and
ii) total charging kVAR.
See Topic: UNDERGROUND CABLES, Long Answer Type Question No. 7(a), (b) & (c).

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QUESTION 2019

Group – A
(Multiple Choice Type Questions)

1. Choose the correct alternatives for any *ten* of the following:
i) The surge impedance of a 50 miles long underground cable is 25 Ω. For a 25 miles length it will be

✓a) 50 Ω b) 100 Ω c) 25 Ω d) 200 Ω

ii) Shunt compensation in a transmission line is resorted to
a) improve the stability
✓b) improve the voltage profile
c) reduce the fault level
d) as a substitute for synchronous phase modifier

iii) The presence of earth in case of overhead lines

✓a) increases the capacitance
b) decreases of capacitance
c) increases the inductance
d) decreases the inductance

iv) Stringing chart is useful for

a) the designing of tower
✓b) finding the sag in the conductor
c) the designing of insulator string
d) finding the distance between the towers

v) Daily energy consumption of a plant is 30 units. Maximum demand is 2 kW. Then load factor will be

a) 60%
b) 50%
c) 75%
✓d) 62.5%

vi) The breakdown strength of air at STP is 21 kV / cm. Its breakdown strength at 30°C and 72 cm of Hg will be

✓a) 21.25 kV/cm
b) 20.2 kV/cm
c) 23 kV/cm
d) 19.5 kV/cm

vii) Ferranti effect on long overhead lines is experienced when it is

✓a) lightly loaded
b) on full load at 0.8 p.f. lagging
c) on full load at 0.8 p.f. lagging
d) all of these

viii) If r is the radius of the conductor and R is the radius of the sheath of the cable, the cable operates stably from the view point of dielectric strength is

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a) $\frac{r}{R} > 1.0$
b) $\frac{r}{R} < 1.0$
c) $\frac{r}{R} < 0.632$
✓d) $\frac{r}{R} < 0.368$

ix) If δ is the loss angle of the cable, its power factor is

a) independent of δ
b) $\cos\delta$
✓c) $\sin\delta$
d) none of these

x) Which of the following materials is not used as control rods of nuclear power plant?

✓a) cadmium
b) helium
c) boron
d) hafnium

xi) Which insulator is used on locations where there is a change in direction of the line?

a) pin type
✓b) strain type
c) shackle type
d) suspension type

xii) If the corona loss for 25 Hz frequency is 100 kW, then for 75 Hz it will be

a) 100 kW
✓b) 200 kW
c) 50 kW
d) 25 kW

Group – B
(Short Answer Type Questions)

2. An industrial consumer having a maximum demand of 100 KW, maintains a load factor of 60%. The tariff rate is Rs. 900/kVA of maximum demand per annum and Rs. 1.8/kWh of energy consumed. If the average power factor is 0.8 lagging then calculate the annual energy consumed and the yearly electricity bill.

See Topic: TARIFF, Short Answer Type Question No. 4.

3. Derive the expression of capacitance for single phase overhead line by considering the effect of earth.

See Topic: OVERHEAD TRANSMISSION LINE, Short Answer Type Question No. 11.

4. Derive the expression of insulation resistance of an underground cable.

See Topic: UNDERGROUND CABLES, Short Answer Type Question No. 6.

5. An overhead transmission line conductor is subjected to a horizontal wind load of 1.78 kg/m and vertical ice loading of 1.08 kg/m. If the maximum permissible sag is 6 metres then calculate the permissible span between two supports allowing a factor of safety of 2. Weight of conductor is 0.844 kg/m.

See Topic: OVERHEAD TRANSMISSION LINE, Short Answer Type Question No. 9.

6. Briefly explain the factors effecting corona loss.

See Topic: CORONA, Short Answer Type Question No. 6.

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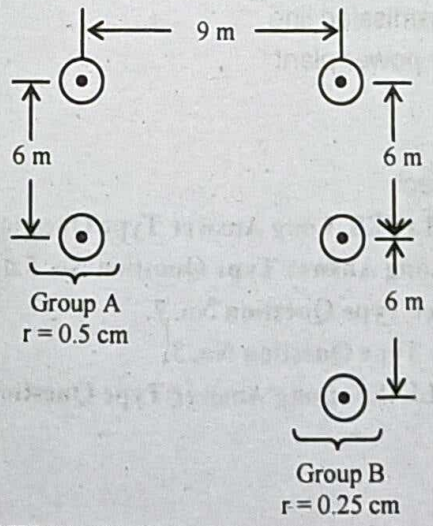
Group – C
(Long Answer Type Questions)

7. a) What do you mean by transposition of a three phase line. Derive the expression of inductance for a three phase transposition line with unsymmetrical spacing.

b) Find L_A and L_B of figure below. Also find the total inductance in H/m.



See Topic: OVERHEAD TRANSMISSION LINE, Long Answer Type Question No. 12.

8. a) For nominal π network representation find the A, B, C, D constants for medium lines. Also draw the phasor diagram.

b) The parameters of 220 kV, 50 Hz, three phase transmission lines are

$R = 15.2\Omega$, $L = 0.165H$ and $C = 0.9\pi F$

Using nominal T method find voltage, current, power factor at the sending end when 70 MW at 0.8 power factor lagging load is connected at receiving end. Also calculate the efficiency.

See Topic: PERFORMANCE OF LINES, Long Answer Type Question No. 4.a) & b).

9. a) What are the different types of insulator and where are they used?

b) Briefly explain the method of equalizing potential distribution of each disc of an string insulator.

c) Each of the three insulators forming a string has a self capacitance of C farads. The shunting capacitance of the connecting metal work of each insulator is 0.2C to earth and 0.1C to line. Calculate the voltage across each insulator as a percentage of the line voltage to earth and also the string efficiency of the arrangement.

See Topic: INSULATORS, Long Answer Type Question No. 7.

10. a) Derive the expression of Dielectric stress of an underground cable and from there find the most economical size of the cable.

b) What are the main reasons of breakdown of a cable.

c) The test results for 10 km long three phase metal sheathed belted cable gave a measured capacitance of 0.7 πF between one conductor and other two conductors bunched together with the earth sheath. Also it has capacitance of 1.2 πF between the three bunched conductors and the sheath. Then calculate:

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i) The capacitance between any pair of conductors where the sheath being isolated.

ii) The charging current when the cable is connected to 11 kV, 50 Hz supply.

See Topic: UNDERGROUND CABLES, Long Answer Type Question No. 8.

11. Write short notes on any *three* of the following:

a) Series compensation of transmission line

b) Working principle of Nuclear power plant

c) Critical disruptive voltage

d) Two-part tariff

e) Skin effect and Proximity effect.

a) See Topic: PERFORMANCE OF LINES, Long Answer Type Question No. 6.c).

b) See Topic: MISCELLANEOUS, Long Answer Type Question No. 5.d).

c) See Topic: CORONA, Long Answer Type Question No. 7.

d) See Topic: TARIFF, Long Answer Type Question No. 3.

e) See Topic: PERFORMANCE OF LINES, Long Answer Type Question No. 6.d).