18EE501

Hall Ticket Number:

III/IV B.Tech (Regular\Supplementary) DEGREE EXAMINATION (SET-1)

March, 2021 **Electrical and Electronics Engineering**

Fifth Semester **Power Systems-II**

Time: Three Hours **Maximum:** 50 Marks

Answer ALL Questions from PART-A. (1X10 = 10 Marks)
Answer ***ANY FOUR*** *questions from PART-B.* (4X10=40 Marks)

PART-A

1.a) List any four different types of sub stations
b) What is a single line diagram?
c) What is the need of base values?
d) Define kelvins law.
e) Define Grading of cables.
f) What is maximum momentary short circuit current?
g) What is the wave velocity of travelling wave?
h) Write any two types of Lightning Arresters.
i) Compare indoor and outdoor substations.
j) What are the usual insulating materials for cables?

PART-B

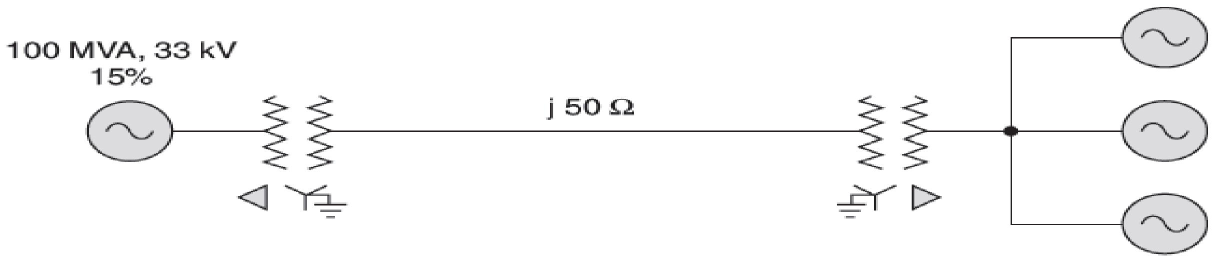
2. a)Explain in detail about Kelvin's law for most economical cross section and its limitations. **5M**

b) A 2-wire DC distributor cable AB is 2 km long and supplies loads of 100A, 150A, 200A and 50A situated 500 m, 1000 m, 1600 m and 2000 m from the feeding point A. Each conductor has a resistance of 0·01 Ω per 1000 m. Calculate the potential difference at each load point if a potential difference of 300 V is maintained at point A. **5M**

3. Explain substation bus bar arrangements by comparing each with neat sketches. **10M**

4. Classify grading methods of cables and explain them. **10M**

5. A 100 MVA, 33 kV 3-phase generator has a sub-transient reactance of 15%. The generator is connected to the motors through a transmission line and transformers as shown in Fig. The motors have rated inputs of 30 MVA, 20 MVA and 50 MVA at 30 kV with 20% sub-transient reactance. The 3-phase transformers are rated at 110 MVA, 32 kV, Δ/110 kV Y with leakage reactance 8%. The line has a reactance of 50 ohms. Selecting the generator rating as the base quantities in the generator circuit, determine the base quantities in other parts of the system and evaluate the corresponding p.u. values. **10M**



6. Discuss the effect of synchronous machine excitation in detail with the help of phasor diagrams? **10M**

7. a)Derive the fault current expressions for a LLG fault of an unloaded generator? **5M**

b) A 25 MVA, 13.2 kV alternator with solidly grounded neutral has a sub-transient reactance of 0.25 p.u. The negative and zero sequence reactance's are 0.35 and 0.1p.u. respectively. A single line to ground fault occurs at the terminals of an unloaded alternator; determine the fault current. Neglect resistance. **5M**

8. a) Derive the expression for velocity of a travelling wave through a loss less line. **5M**

b) Derive the coefficient of reflection and refraction of voltage and current for open ended line. **5M**

9. Explain types of lightning arresters with neat sketches. **10M**

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Answer ALL Questions from PART-A. (1X10 = 10 Marks)

Answer ***ANY FOUR*** *questions from PART-B.* (4X10=40 Marks)

Scheme of Evaluation

PART-A

1. a) Transformer substation, indoor substation, outdoor substation, Underground Substation

b) As per the definition of the single line diagram, it is specified as the diagram that uses single line and symbols to represent the path and the components of an electrical circuit.

c) The components or various sections of power system may operate at different voltage and power levels. It will be convenient for analysis of power system if the voltage power, current and impedance ratings of components of power system are expressed with reference to a common value called base value. Hence for analysis purpose a base value is chosen for voltage, power, current and impedance.

d) The Kelvin's law states that the most economical size of a conductor is that for which annual interest and depreciation on the capital cost of the conductor is equal to the annual cost of energy loss.

e) Grading of cable is the process of achieving uniform distribution of dielectric stress or voltage gradient in a dielectric of cable.

f) The maximum momentary short circuit current I_{mm} corresponds to the first peak of short circuit current of transmission line.

g) Velocity of light i.e. 3×10^8 m/sec.

h) Rod gap, Horn Gap Lightning arresters

i)

Indoor substation	Outdoor substation
Less because all the components are insulated.therefore clearance required between them is less.	More as some components such as bus bar, O.H. line are not insulated hence clearance between them is more.
More because additional building construction is required.	Less because no building construction is required
Difficult due to less space available.	Easy due to more space is available.

j) Rubber, Impregnated Paper, Polyvinyl Chloride etc…

PART-B

2. a) Explain in detail about Kelvin's law for most economical cross section and its limitations. 5M

Kelvins Law def. and explanation:3M diagrams:2M

The cost of conductor material is generally a very considerable part of the total cost of a transmission line. Therefore, the determination of proper size of conductor for the line is of vital importance. The most economical area of conductor is that for which the total annual cost of transmission line is minimum*. This is known as Kelvin's Law after Lord Kelvin who first stated it in 1881. The total annual cost of transmission line can be divided broadly into two parts viz., annual charge on capital outlay and annual cost of energy wasted in the conductor.

(i) **Annual charge on capital outlay:** This is on 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 X-section and the cost of supports and their erection is partly constant and partly proportional to area of X-section of the conductor. Therefore, annual charge on an overhead† transmission line can be expressed as :

$$\text{Annual charge} = P_1 + P_2\, a$$

where P1 and P2 are constants and a is the area of X-section of the conductor.

(ii) **Annual cost of energy wasted:** This is on account of energy lost mainly‡ in the conductor due to I2R losses. Assuming a constant current in the conductor throughout the year, the energy lost in the conductor is proportional to resistance. As resistance is inversely proportional to the area of Xsection of the conductor, therefore, the energy lost in the conductor is inversely proportional to area of X-section. Thus, the annual cost of energy wasted in an overhead transmission line can be expressed as :

Annual cost of energy wasted = P3a ...(ii) where P3 is a constant.

Total annual cost, C = exp. (i) + exp. (ii) = $(P_1 + P_2\, a) + P_3/a$

$\therefore C = P_1 + P_2\, a + P_3/a$ ...(iii)

In exp. (iii), only area of X-section a is variable. Therefore, the total annual cost of transmission line will be minimum if differentiation of C w.r.t. a is zero i.e. d/da(C) = 0

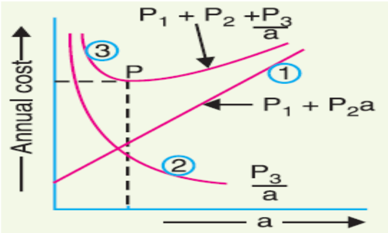
or $d/da(P_1 + P_2\, a + P_3/a) = 0$

or $P_2 - P_3/a^2 = 0$

or $P_2 = P_3/a^2$

or $P2\ a = P_3/a$

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

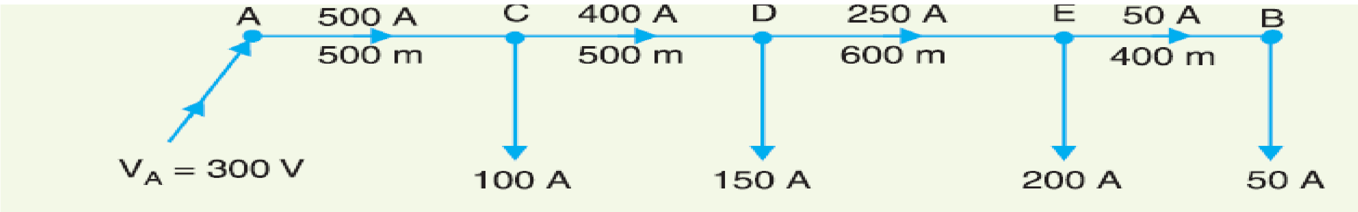


Therefore Kelvin's Law can also be stated in an another way i.e. the most economical area of conductor is that for which the variable part* of annual charge is equal to the cost of energy losses per year.

Graphical illustration of Kelvin's law. Kelvin's law can also be illustrated graphically by plotting annual cost against X-sectional area 'a'of the conductor as shown in Fig. . In the diagram, the straight line (1) shows the relation between the annual charge (i.e., P1 + P2a) and the area of X-section a of the conductor. Similarly, the rectangular hyperbola (2) gives the relation between annual cost of energy wasted and X-sectional area a. By adding the ordinates of curves (1) and (2), the curve (3) is obtained. This latter curve shows the relation between total annual cost (P1 + P2a + P3a) of transmission line and area of X-section a. The lowest point on the curve (i.e., point P) represents the most economical area of X-section.

b) A 2-wire DC distributor cable AB is 2 km long and supplies loads of 100A, 150A, 200A and 50A situated 500 m, 1000 m, 1600 m and 2000 m from the feeding point A. Each conductor has a resistance of 0·01 Ω per 1000 m. Calculate the potential difference at each load point if a potential difference of 300 V is maintained at point A. 5M

Diagram: 2M Solution and Result: 3M



Resistance per 1000 m of distributor $= 2 \times 0{\cdot}01 = 0{\cdot}02\ \Omega$

Resistance of section AC, $R_{AC} = 0{\cdot}02 \times 500/1000 = 0{\cdot}01\ \Omega$

Resistance of section CD, $R_{CD} = 0{\cdot}02 \times 500/1000 = 0{\cdot}01\ \Omega$

Resistance of section DE, $R_{DE} = 0{\cdot}02 \times 600/1000 = 0{\cdot}012\ \Omega$

Resistance of section EB, $R_{EB} = 0{\cdot}02 \times 400/1000 = 0{\cdot}008\ \Omega$

Referring to Fig. 13.6, the currents in the various sections of the distributor are :

$I_{EB} = 50$ A ; $I_{DE} = 50 + 200 = 250$ A

$I_{CD} = 250 + 150 = 400$ A ; $I_{AC} = 400 + 100 = 500$ A

P.D. at load point C, V_C = Voltage at A − Voltage drop in AC

$$= V_A - I_{AC} R_{AC}$$

$$= 300 - 500 \times 0{\cdot}01 = \mathbf{295\ V}$$

P.D. at load point D, $V_D = V_C - I_{CD} R_{CD}$

$$= 295 - 400 \times 0{\cdot}01 = \mathbf{291\ V}$$

P.D. at load point E, $V_E = V_D - I_{DE} R_{DE}$

$$= 291 - 250 \times 0{\cdot}012 = \mathbf{288\ V}$$

P.D. at load point B, $V_B = V_E - I_{EB} R_{EB}$

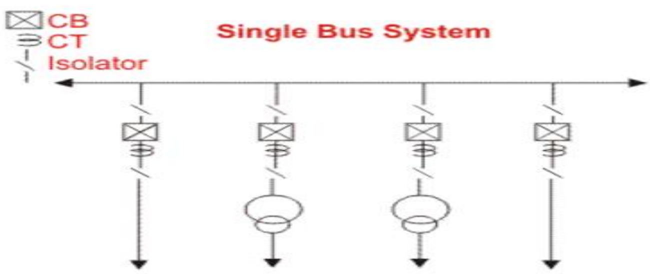
$$= 288 - 50 \times 0{\cdot}008 = \mathbf{287{\cdot}6\ V}$$

3. Explain substation bus bar arrangements by comparing each with neat sketches. 10M

Four Bus bar schemes (4 X 2.5M each)=10M

a) Single Bus System

Single Bus System is simplest and cheapest one. In this scheme all the feeders and transformer bay are connected to only one single bus as show.



Advantages of Single Bus System

1) This is very simple in design.

2) This is very cost effective scheme.

3) This is very convenient to operate.

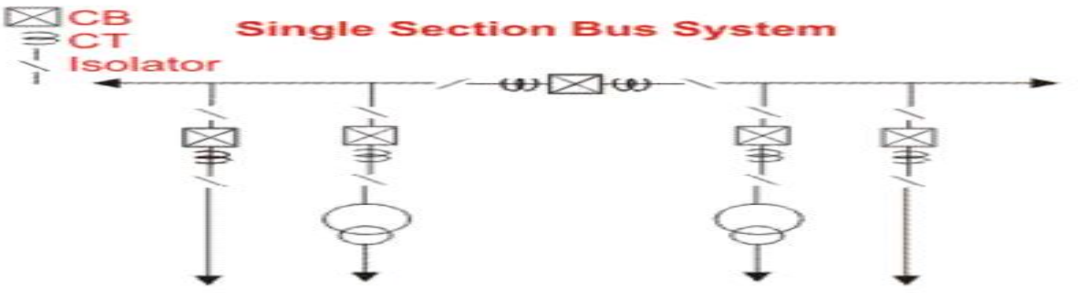
Disadvantages of Single Bus System

1) One but major difficulty of these type of arrangement is that, maintenance of equipment of any bay cannot be possible without interrupting the feeder or transformer connected to that bay.

2) The indoor 11KV switchboards have quite often single bus bar arrangement.

b) **Single Bus System with Bus Sectionalizer**

Some advantages are realized if a single bus bar is sectionalized with circuit breaker. If there are more than one incoming and the incoming sources and outgoing feeders are evenly distributed on the sections as shown in the figure, interruption of system can be reduced to a good extent.



Advantages of Single Bus System with Bus Sectionalizer

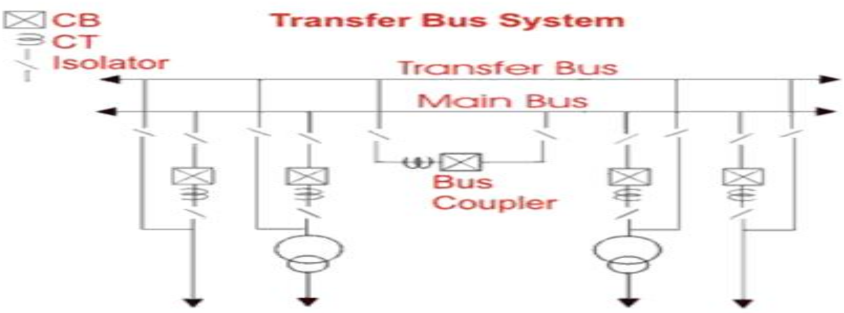
If any of the sources is out of system, still all loads can be fed by switching on the sectional circuit breaker or bus coupler breaker. If one section of the bus bar system is under maintenance, part load of the substation can be fed by energizing the other section of bus bar.

Disadvantages of Single Bus System with Bus Sectionalizer

1) As in the case of single bus system, maintenance of equipment of any bay cannot be possible without interrupting the feeder or transformer connected to that bay.

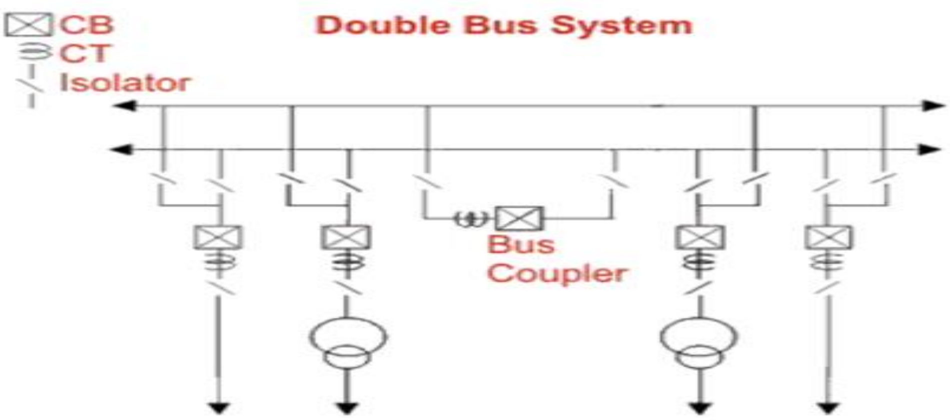
2) The use of isolator for bus sectionalizing does not fulfill the purpose. The isolators have to be operated ‘off circuit’ and which is not possible without total interruption of bus – bar. So investment for bus-coupler breaker is required.

c) **Main and Transfer Bus System**



- This is an alternative of double bus system. The main conception of Main and Transfer Bus System is, here every feeder line is directly connected through an isolator to a second bus called transfer bus. The said isolator in between transfer bus and feeder line is generally called bypass isolator. The main bus is as usual connected to each feeder through a bay consists of circuit breaker and associated isolators at both side of the breaker. There is one bus coupler bay which couples transfer bus and main bus through a circuit breaker and associated isolators at both sides of the breaker. If necessary the transfer bus can be energized by main bus power by closing the transfer bus coupler isolators and then breaker. Then the power in transfer bus can directly be fed to the feeder line by closing the bypass isolator. If the main circuit breaker associated with feeder is switched off or isolated from system, the feeder can still be fed in this way by transferring it to transfer bus.

d) **Double Bus System**



In double bus bar system two identical bus bars are used in such a way that any outgoing or incoming feeder can be taken from any of the bus. Actually every feeder is connected to both of the buses in parallel through individual isolator as shown in the figure.

Advantages of Double Bus System

Double Bus Bar Arrangement increases the flexibility of system.

Disadvantages of Double Bus System

The arrangement does not permit breaker maintenance without interruption

4. Classify grading methods of cables and explain them. 10M

Capacitance grading:5M Inter heath grading;5M

The process of achieving uniform electrostatic stress in the dielectric of cables is known as **grading of cables.**

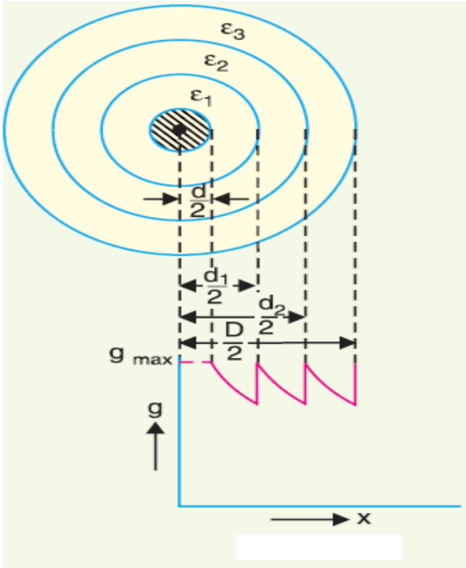
It has already been shown that electrostatic stress in a single core cable has a maximum value (g_{max}) at the conductor surface and goes on decreasing as we move towards the sheath. The maximum voltage that can be safely applied to a cable depends upon g_{max} *i.e.,* electrostatic stress at the conductor 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

i) Capacitance grading:**(5M)**

The process of achieving uniformity in the dielectric stress by using layers of different dielectrics is known as **capacitance grading.**



In capacitance grading, the homogeneous dielectric is replaced by a composite dielectric. The composite dielectric consists of various layers of different dielectrics in such a manner that relative permittivity ε_r of any layer is inversely proportional to its distance from the centre. Under such conditions, the value of potential gradient at any point in the dieletric is *constant and is independent of its distance from the centre. In other words, the dielectric stress in the cable is same everywhere and the grading is ideal one. However, ideal grading requires the use of an infinite number of dielectrics which is an impossible task. In practice, two or three dielectrics are used in the decreasing order of permittivity ; the dielectric of highest permittivity being used near the core.

The capacitance grading can be explained beautifully by referring to Fig. There are three dielectrics of outer diameter d_1, d_2 and D and of relative permittivity ε_1, ε_2 and ε_3 respectively. If the permittivities are such that $\varepsilon_1 > \varepsilon_2 > \varepsilon_3$ and the three dielectrics are worked at the same maximum stress, then,

$$\frac{1}{\varepsilon_1 d} = \frac{1}{\varepsilon_2 d_1} = \frac{1\dagger}{\varepsilon_3 d_2}$$

or
$$\varepsilon_1 d = \varepsilon_2 d_1 = \varepsilon_3 d_2$$

Potential difference across the inner layer is

$$V_1 = \int_{d/2}^{d_1/2} g\,dx = \int_{d/2}^{d_1/2} \frac{Q}{2\pi\varepsilon_0\varepsilon_1 x}dx$$

$$= \frac{Q}{2\pi\varepsilon_0\varepsilon_1}\log_e\frac{d_1}{d} = \frac{g_{max}}{2}d\log_e\frac{d_1}{d}\left[\because \frac{Q}{2\pi\varepsilon_0\varepsilon_1} = {}^{*}\frac{g_{max}}{2}d\right]$$

Similarly, potential across second layer (V_2) and third layer (V_3) is given by ;

$$V_2 = \frac{g_{max}}{2}d_1\log_e\frac{d_2}{d_1}$$

$$V_3 = \frac{g_{max}}{2}d_2\log_e\frac{D}{d_2}$$

Total p.d. between core and earthed sheath is

$$V = V_1 + V_2 + V_3$$

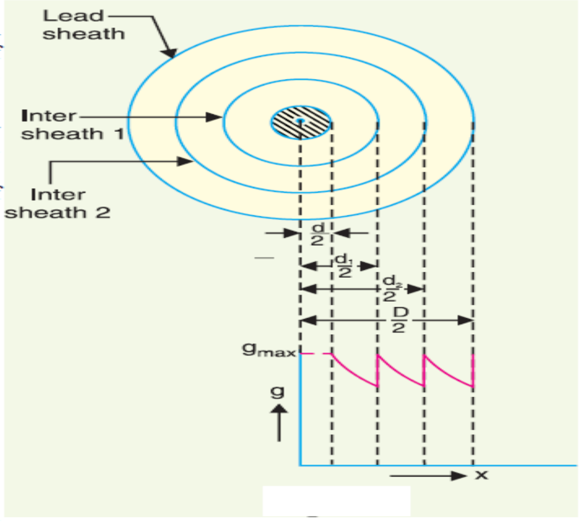
$$= \frac{g_{max}}{2}\left[d\log_e\frac{d_1}{d} + d_1\log_e\frac{d_2}{d_1} + d_2\log_e\frac{D}{d_2}\right]$$

If the cable had homogeneous dielectric, then, for the same values of d, D and g_{max}, the permissible potential difference between core and earthed sheath would have been

$$V' = \frac{g_{max}}{2}d\log_e\frac{D}{d}$$

ii)Intersheath Grading: **(5M)**

In this method of cable grading, a homogeneous dielectric is used, but it is divided into various layers by placing metallic intersheaths between the core and lead sheath. The intersheaths are held at suitable potentials which are inbetween the core potential and earth potential. This arrangement improves voltage distribution in the dielectric of the cable and consequently more uniform potential gradient is obtained.



Consider a cable of core diameter d and outer lead sheath of diameter D. Suppose that two intersheaths of diameters d_1 and d_2 are inserted into the homogeneous dielectric and maintained at some fixed potentials. Let V_1, V_2 and V_3 respectively be the voltage between core and intersheath 1, between intersheath 1 and 2 and between intersheath 2 and outer lead sheath. As there is a definite potential difference between the inner and outer layers of each intersheath, therefore, each sheath can be treated like a homogeneous single core cable.

Maximum stress between core and intersheath 1 is

$$g_{1max} = \frac{V_1}{\frac{d}{2}\log_e\frac{d_1}{d}}$$

Similarly,

$$g_{2max} = \frac{V_2}{\frac{d_1}{2}\log_e\frac{d_2}{d_1}}$$

$$g_{3max} = \frac{V_3}{\frac{d_2}{2}\log_e\frac{D}{d_2}}$$

Since the dielectric is homogeneous, the maximum stress in each layer is the same *i.e.*,

$$g_{1max} = g_{2max} = g_{3max} = g_{max} \text{ (say)}$$

$$\therefore \quad \frac{V_1}{\frac{d}{2}\log_e\frac{d_1}{d}} = \frac{V_2}{\frac{d_1}{2}\log_e\frac{d_2}{d_1}} = \frac{V_3}{\frac{d_2}{2}\log_e\frac{D}{d_2}}$$

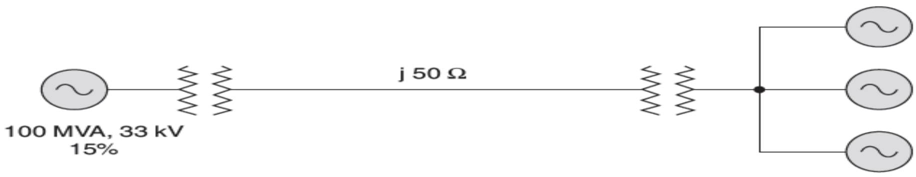
As the cable behaves like three capacitors in series, therefore, all the potentials are in phase *i.e.* Voltage between conductor and earthed lead sheath is

$$V = V_1 + V_2 + V_3$$

Intersheath grading has three principal disadvantages. Firstly, there are complications in fixing the sheath potentials. Secondly, the intersheaths are likely to be damaged during transportation and installation which might result in local concentrations of potential gradient. Thirdly, there are considerable losses in the intersheaths due to charging currents. For these reasons, intersheath grading is rarely used.

5. Problem on One Line Diagram: **10M**

Solution:6M Formulae:2M Reactance Diagram:2M



Assuming base values as 100 MVA and 33 kV in the generator circuit, the p.u. reactance of generator will be 15%. The base value of voltage in the line will be

$$33 \times \frac{110}{32} = 113.43 \text{ kV}$$

In the motor circuit,

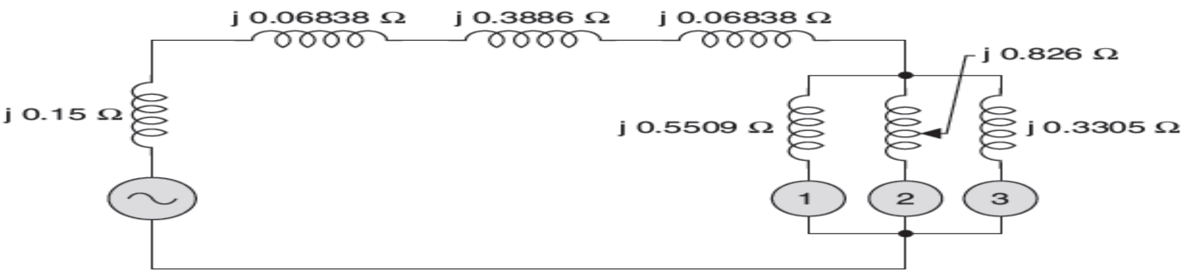
$$113.43 \times \frac{32}{110} = 33 \text{ kV}$$

The reactance of the transformer given is 8% corresponding to 110 MVA, 32 kV. Therefore, corresponding to 100 MVA and 33 kV the p.u. reactance will be (using Eq. 1.23).

$$0.08 \times \frac{100}{110} \times \left(\frac{32}{33}\right)^2 = 0.06838 \text{ p.u.}$$

The p.u. impedance of line $= \dfrac{50 \times 100}{(113.43)^2} = 0.3886$ p.u.

The reactance diagram for the system is shown in :



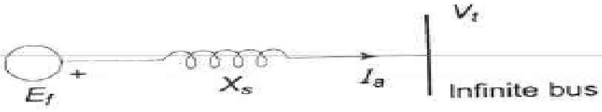
6. Discuss the effect of synchronous machine excitation in detail with the help of phasor diagrams? 10M

Normal Over and Under excitation explanation: 5M Phasor Diagrams:5M

Normally, a synchronous generator operates in parallel with other generators connected to the power system. For simplicity of operation we shall consider a generator connected to an *infinite bus* as shown in Fig. As infinite bus means a large system whose voltage and frequency remain constant independent of the power exchange between the synchronous machine and the bus, and independent of the excitation of the synchronous machine.

Consider now a synchronous generator feeding constant active power into an infinite bus bar. As the machine excitation is varied, armature current I_a and its angle θ, i.e. power factor, change in such a manner as to keep

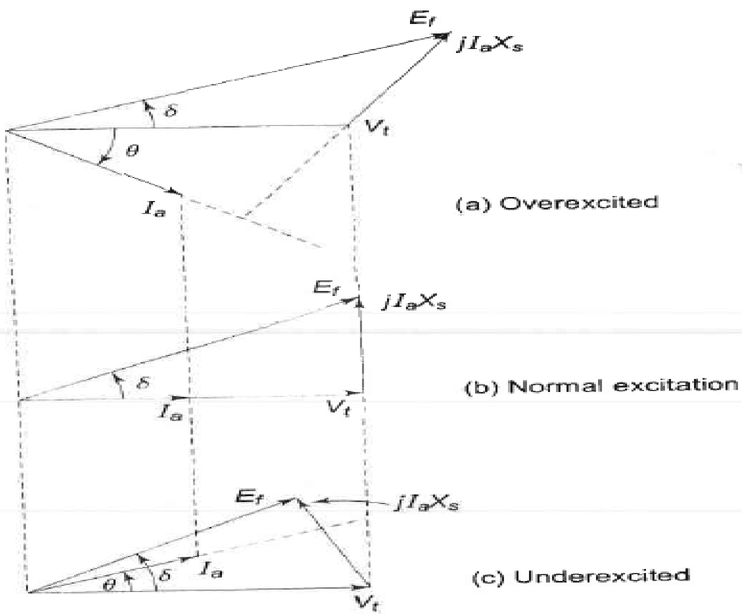
$$|V_t|\,|I_a| \cos\,\theta = \text{constant} = \text{active power output}$$



Synchronous machine connected to infinite bus

It means that since $|V_t|$ is fixed, the projection $|I_a| \cos\,\theta$ of the phasor I_a on V_t remains constant, while the excitation is varied. Phasor diagrams corresponding to high, medium and low excitations are presented in Fig. The phasor diagram of Fig. 4.23(b) corresponds to the unity power factor case. It is obvious from the phasor diagram that for this excitation

$$|E_f| \cos\,\delta = |V_t|$$



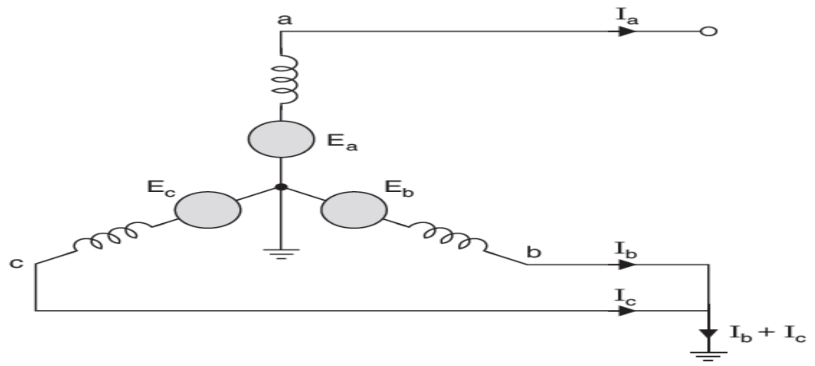
Phasor diagrams of synchronous generator feeding constant power as excitation is varied

This is defined as *normal excitation*. For the *overexcited* case $|E_f| \cos\,\delta > |V_t|$, I_a lags behind V_t so that the generator feeds positive reactive power into the bus (or draws negative reactive power from the bus). For the

underexcited case i.e. $|E_f| \cos\,\delta < |V_t|$, I_a leads V_t so that the generator feeds negative reactive power into the bus (or draws positive reactive power from the bus).

7. a)Derive the fault current expressions for a LLG fault of an unloaded generator? **5M**

Derivation 3M Diagram 2M



A solidly grounded, unloaded alternator, L-L-G fault.

Double line to ground fault takes place on phases b and c

The boundary conditions are

$$I_a = 0$$
$$V_b = 0$$
$$V_c = 0$$

The solution of these six equations will give the six unknown symmetrical components.
Using the equations and substituting for V_a, V_b and V_c

$$\begin{aligned} V_{a_0} &= \tfrac{1}{3}(V_a + V_b + V_c) \\ &= V_a/3 \\ V_{a_1} &= \tfrac{1}{3}(V_a + \lambda V_b + \lambda^2 V_c) \\ &= V_a/3 \\ V_{a_2} &= \tfrac{1}{3}(V_a + \lambda^2 V_b + \lambda V_c) \\ &= V_a/3 \end{aligned}$$

i.e., $$V_{a_0} = V_{a_1} = V_{a_2}$$

Using this relation of voltages and substituting in the sequence network equations

$$V_{a_0} = V_{a_1}$$
$$-I_{a_0}Z_0 = E_a - V_{a_1}Z_1$$

$\therefore$ $$I_{a_0} = -\frac{E_a - I_{a_1}Z_1}{Z_0}$$

Similarly $$V_{a_2} = V_{a_1}$$
$$-I_{a_2}Z_2 = E_a - I_{a_1}Z_1$$

$\therefore$ $$I_{a_2} = -\frac{E_a - I_{a_1}Z_1}{Z_2}$$

Now from equation

$$I_a = I_{a_1} + I_{a_2} + I_{a_0} = 0$$

Substituting values of I_{a_2} and I_{a_0}

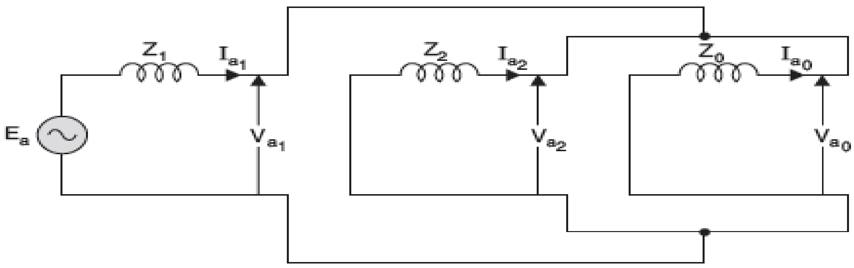
$$I_{a_1} - \frac{E_a - I_{a_1}Z_1}{Z_2} - \frac{E_a - I_{a_1}Z_2}{Z_0} = 0$$

Rearranging the terms gives

$$I_{a_1} = \frac{E_a}{Z_1 + \dfrac{Z_0Z_2}{Z_0 + Z_2}}$$

it is clear that all the three sequence networks are required to simulate *L-L-G* fault and also that the negative and zero sequence networks are connected in parallel.

From equation it is clear that the zero and negative sequence networks are first connected in parallel and then in opposition with the positive sequence network. The same has been shown in Fig.

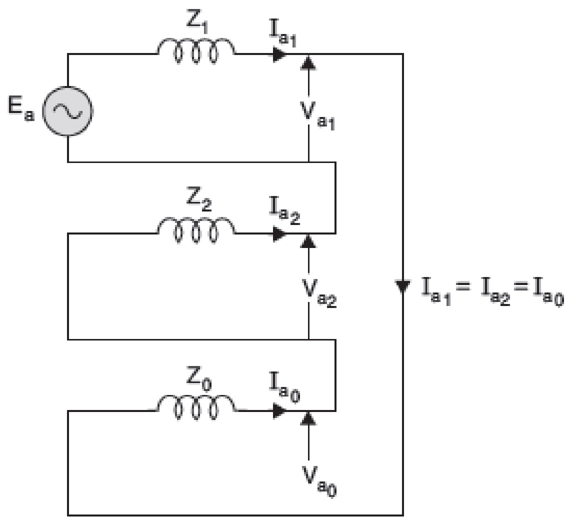


Interconnection of sequence networks for L-L-G fault.

7.b) problem on LG fault: **5M**

Solution methodology: 3M Formulae: 2M

Normally the positive sequence impedance is greater than the negative sequence but since the given positive sequence impedance corresponds to the subtransient state, it may be less than the negative sequence impedance. The sequence network for a line-to-ground fault current is shown



Interconnection of sequence network.

Let the line-to-neutral voltage at the fault point before the fault be 1.0 + *j*0.0 p.u. For a line-to-ground fault the fault impedance is

$$j0.25 + j0.35 + j0.1 = j0.7$$

$$\therefore \quad I_{a_1} = \frac{E_a}{Z_1 + Z_2 + Z_0} = \frac{1 + j0.0}{j0.7} = -j1.428$$

For a *L-G* fault

$$I_{a_1} = I_{a_2} = I_{a_0} = -j1.428$$

$\therefore$ The p.u. fault current $\quad I_a = I_{a_1} + I_{a_2} + I_{a_0} = 3I_{a_1} = -j4.285$

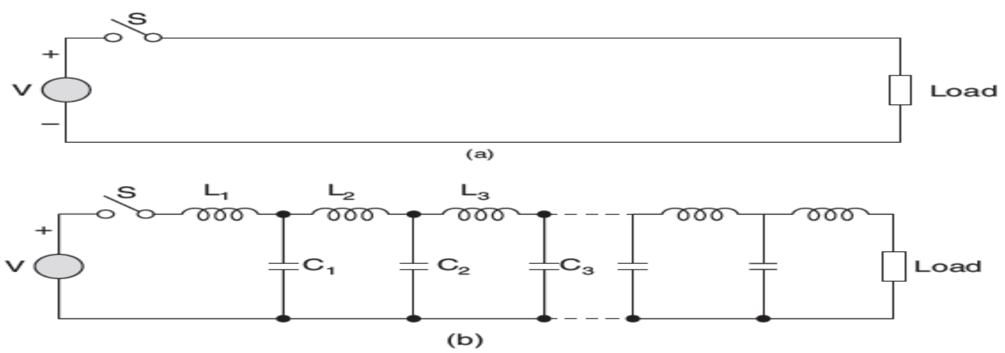
Let the base quantities be 25 MVA, 13.2 kV, and hence

$$\text{the base current} = \frac{25 \times 1000}{\sqrt{3} \times 13.2} = 1093 \text{ amps}$$

$\therefore$ The fault current in amperes = 1093 × 4.285 = 4685 amps

8. a) Derive the expression for velocity of a travelling wave through a loss less line. **5M**

Dervation: 3M Diagram: 2M



(*a*) Long transmission line, (*b*) Equivalent π-section of a long transmission line.

Now it is desired to find out expressions for the relation between the voltage and current waves travelling over the transmission lines and their velocity of propagation.

Suppose that the wave after time t has travelled through a distance x. Since we have assumed lossless lines whatever is the value of voltage and current waves at the start, they remain same throughout the travel. Consider a distance dx which is travelled by the waves in time dt. The electrostatic flux is associated with the voltage wave and the electromagnetic flux with the current wave. The electrostatic flux which is equal to the charge between the conductors of the line up to a distance x is given by

$$q = VCx$$

The current in the conductor is determined by the rate at which the charge flows into and out of the line.

$$I = \frac{dq}{dt} = VC\frac{dx}{dt}$$

Here dx/dt is the velocity of the travelling wave over the line conductor and let this be represented by v. Then

$$I = VCv$$

Similarly the electromagnetic flux linkages created around the conductors due to the current flowing in them up to a distance of x is given by

$$\psi = ILx$$

The voltage is the rate at which the flux linkages link around the conductor

$$V = IL\frac{dx}{dt} = ILv$$

$$\frac{V^2}{I^2} = \frac{L}{C}$$

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

The expression is a ratio of voltage to current which has the dimensions of impedance and is therefore here designated as surge impedance of the line. It is also known as the natural impedance because this impedance has nothing to do with the load impedance. It is purely a characteristic of the transmission line. The value of this impedance is about 400 ohms for overhead transmission lines and 40 ohms for cables.

$$VI = VCv \cdot ILv = VILCv^2$$

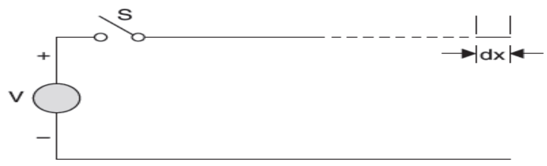
$$v^2 = \frac{1}{LC}$$

$$v = \frac{1}{\sqrt{LC}}$$

8. b) Derive the coefficient of reflection and refraction of voltage and current for open ended line. **5M**

Diagram: 2M Explanation: 3M

Consider a line with the receiving end open-circuited as shown in



Case of an open-ended line.

When switch S is closed, a voltage and current wave of magnitudes V and I respectively travel towards the open-end. These waves are related by the equation:

$$\frac{V}{I} = Z$$

where Z is the characteristic impedance of the line. Consider the last element dx of the line, because, it is here where the wave is going to see a change in impedance, an impedance different from Z (infinite impedance as the line is open-ended).

The electromagnetic energy stored by the element dx is given by $\frac{1}{2}LdxI^2$ and electrostatic energy in the element dx, $\frac{1}{2}CdxV^2$. Since the current at the open-end is zero, the electromagnetic energy vanishes and is transformed into electrostatic energy. As a result, let the change in voltage be e; then

$$\frac{1}{2}LdxI^2 = \frac{1}{2}Cdxe^2$$

or
$$\left(\frac{e}{I}\right)^2 = \frac{L}{C}$$

or
$$e = IZ = V$$

This means the potential of the open-end is raised by V volts; therefore, the total potential of the open-end when the wave reaches this end is

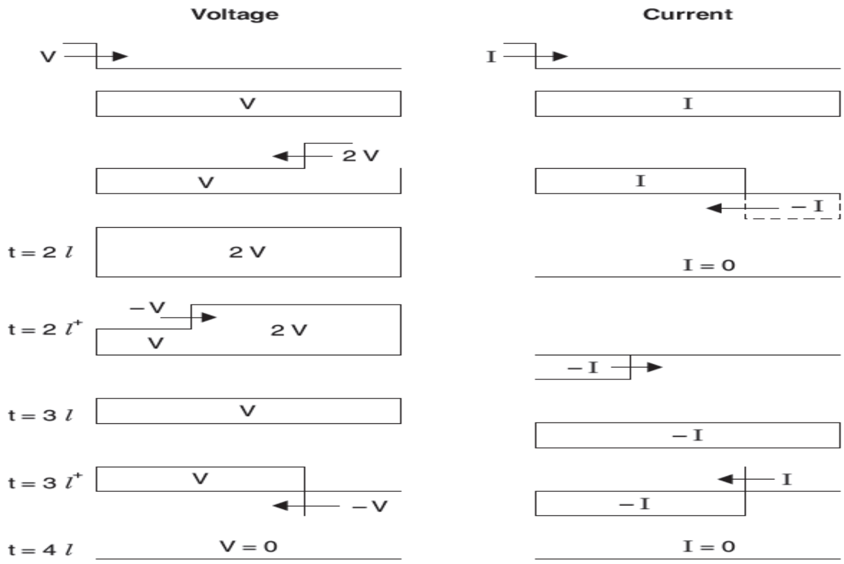
$$V + V = 2V$$

The wave that starts travelling over the line when the switch S is closed, could be considered as the incident wave and after the wave reaches the open-end, the rise in potential V could be considered due to a wave which is reflected at the open-end and actual voltage at the open-end could be considered as the refracted or transmitted wave and is thus

Refracted wave = Incident wave + Reflected wave

We have seen that for an open-end line a travelling wave is reflected back with positive sign and coefficient of reflection as unity.

over the transmission line. This means for an open-end line, a current wave is reflected with negative sign and coefficient of reflection unity. The variation of current and voltage waves over the line is explained in Fig.



Variation of voltage and current in an open-ended line.

After the voltage and current waves are reflected back from the open-end, they reach the source end, the voltage over the line becomes $2V$ and the current is zero. The voltage at source end cannot be more than the source voltage V therefore a voltage wave of $-V$ and current wave of $-I$ is reflected back into the line . It can be seen that after the waves have travelled through a distance of $4l$, where l is the length of the line, they would have wiped out both the current and voltage waves, leaving the line momentarily in its original state. The above cycle repeats itself.

9. Explain types of lightning arresters with neat sketches. **10M**

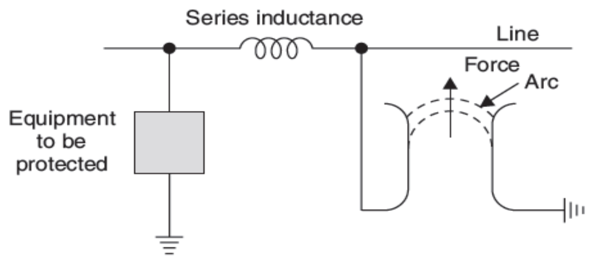
Diagrams: 5M Explanation: 5M

Horn Gap

The horn gap consists of two horn shaped rods separated by a small distance. One end of this is connected to the line and the other to the earth as shown in Fig. with or without a series resistance. The choke connected between the equipment to be protected and the horn gap serves two purposes: (*i*) The steepness of the wave incident on the equipment to be protected is reduced. (*ii*) It reflects the voltage surge back on to the horn.

Whenever a surge voltage exceeds the breakdown value of the gap a discharge takes place and the energy content in the rest part of the wave is by-passed to the ground. An arc is set up between the gap, which acts like a flexible conductor and rises upwards under the influence of the electromagnetic forces, thus increasing the length of the arc which eventually blows out.

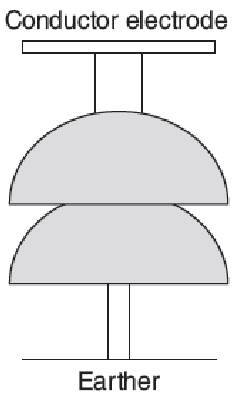
There are two major drawbacks of the horn gap: (*i*) The time of operation of the gap is quite large as compared to the modern protective gear. (*ii*) If used on isolated neutral the horn gap may constitute a vicious kind of arcing ground. For these reasons, the horn gap has almost vanished from important power lines.



Horn gap connected in the system for protection.

Rod Gap

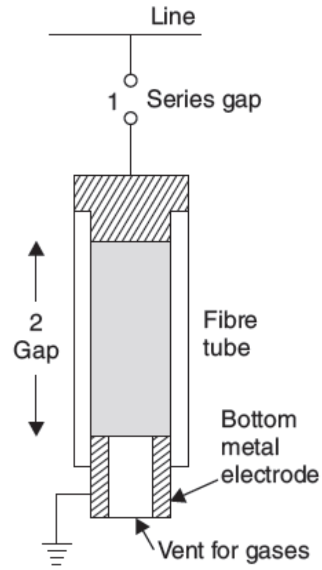
This type of surge diverter is perhaps the simplest, cheapest and most rugged one. shows one such gap for a breaker bushing. This may take the form of arcing ring. shows the breakdown characteristics (volt-time) of a rod gap. For a given gap and wave shape of the voltage, the time for breakdown varies approximately inversely with the applied voltage.



A rod gap.

The times to flashover for positive polarity are lower than for negative polarities. Also it is found that the flashover voltage depends to some extent on the length of the lower (grounded) rod. For low values of this length there is a reasonable difference between positive (lower value) and negative flashover voltages. Usually a length of 1.5 to 2.0 times the gap spacing is good enough to reduce this difference to a reasonable amount. The gap setting normally chosen is such that its breakdown voltage is not less than 30% below the voltage withstand level of the equipment to be protected.

Even though rod gap is the cheapest form of protection, it suffers from the major disadvantage that it does not satisfy one of the basic requirements of a lightning arrester listed at no. (*iv*) *i.e.*, it does not interrupt the power frequency follow current. This means that every operation of the rod gap results in a *L-G* fault and the breakers must operate to de-energize the circuit to clear the flashover. The rod gap, therefore, is generally used as back up protection.



Expulsion type lightning arrester.

Expulsion Type of Lightning Arrester: An improvement of the rod gap is the expulsion tube which consists of (*i*) a series gap (1) external to the tube which is good enough to withstand normal system voltage, thereby there is no possibility of corona or leakage current across the tube; (*ii*) a tube which has a fibre lining on the inner side which is a highly gas evolving material; (*iii*) a spark gap (2) in the tube; and (*iv*) an open vent at the lower end for the gases to be expelled

It is desired that the breakdown voltage of a tube must be lower than that of the insulation for which it is used. When a surge voltage is incident on the expulsion tube the series gap is spanned and an arc is formed between the electrodes within the tube. The heat of the arc vaporizes some of the organic material of the tube wall causing a high gas pressure to build up in the tube. The resulting neutral gas creates lot of

Valve Type Lightning Arresters: An improved but more expensive surge diverter is the valve type of lightning arrester or a non-linear surge diverter. A porcelain bushing contains a number of series gaps, coil units and the valve elements of the non-linear resistance material usually made of silicon carbide disc, the latter possessing low resistance to high currents and high resistance to low currents. The characteristic is usually expressed as $I = KV^n$, where n lies between 2 and 6 and K is constant, a function of the geometry and dimension of the resistor. The non-linear characteristic is attributed to the properties of the electrical contacts between the grains of silicon carbide. The discs are 90 mm in dia and 25 mm thick. A grading ring or a high resistance is connected across the disc so that the system voltage is evenly distributed over the discs. The high resistance keeps the inner assembly dry due to some heat generated.