Lec 1 Tutorial Questions

1) Compare the pros and cons of overhead lines, gas insulated lines and underground cables.

2) What are the functionalities of a bushing?

3) Which two purposes are served by the oil in a transformer?

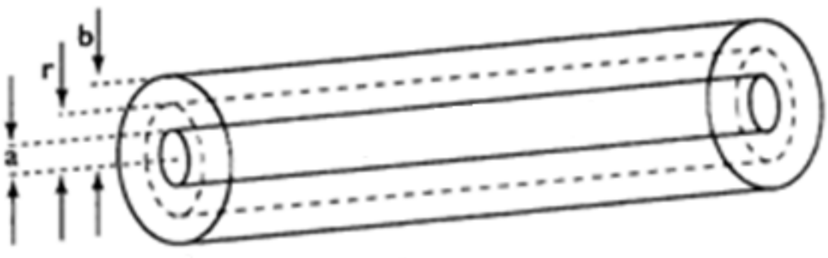
4) What are the pros and cons of AC and DC transmission?

5) Define electric field and discuss its significance in HV system design.

6) Using the electric field theory as underpinning, explain why an air filled void in a solid insulation may experience partial discharge.

7) A simple coaxial cable is made out of a central cylindrical conductor of 5mm diameter, with an outer conducting sheath, also cylindrical, coaxial with the central conductor. The internal diameter of the outer sheath is 20mm. The space between the two cylinders is empty. Determine the electric strength at the surface of the inner conductor when the potential difference between the conductors is 500V.

8) The inner conductor of a concentric cable has a diameter of 3cm, the diameter over the insulator being 8.5cm. The cable is insulated with two materials having permittivity of 5 and 3 respectively, with corresponding safe working stresses of 38kV/cm and 26kV/cm. Calculate the radial thickness of each insulating layer and the design voltage of the cable.



8. A capacitor bushing with three layers of conductors is designed for the power transformer as data tabulated below.

Internal diameter of the conductor: 20mm
Internal diameter of the earthed flange: 80mm
Internal diameter of the other two layers of copper foils are: 40mm and 60mm respectively.
Length of earthed flange: 100cm
Relative permittivity of the mica insulator: 3.5

(i) calculate the axial length of the conducting foils to withstand maximum stress in the insulator layer.

(ii) Develop the 66kV capacitor bushing with labelling of relevant dimensions and showing the place of conductive foils used.

(iii) determine the voltage V1, V2 and V3 across each layer.

(Note: Capacitance between concentric cylinders $C= [\varepsilon r \times L]/[18 \ln (R/r)]$ nF)

Lec 2 Tutorial Questions

1. Provide definition of dielectric loss angle tanδ and relative permittivity in HV systems and explain their significance in HV plant design and condition monitoring.

2. List the advantages and disadvantages of gaseous insulation, solid insulation, and liquid insulation respectively, and provide two breakdown mechanisms with brief explanations for each of them.

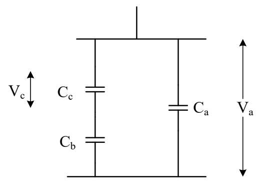
3. Define and contrast Townsend discharge, Streamer discharge and Corona discharge.

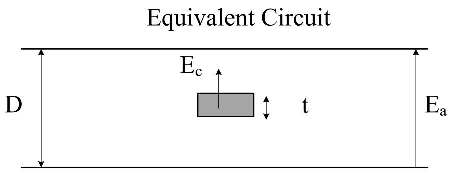
4. Explain the concept of PD inception voltage and apparent discharge.

5. Show that for a solid insulating material of relative permittivity ε_r containing a cylindrical air-filled void of depth *t* which is small in relation to the thickness *D* of the dielectric, that

$$E_c = E_a\left[\frac{\epsilon_r}{1+\frac{t}{D}(\epsilon_r-1)}\right]$$

Where E_c is the stress of the void and E_a the stress in the solid dielectric.



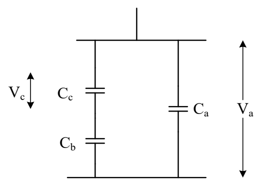


6. A solid insulating material of relative permittivity 2.2 is used in a capacitor between two metal electrodes. The thickness of the insulating sheet is 0.22 cm. Voids are known to occur in the sheet and their sizes are small relative to the insulation. The depth of each void lies in between 0.02 cm and 0.05 cm. The breakdown characteristics of the gas in void (equivalent to Parchen's curve) is as follows.

Gap length (cm)	0.02	0.03	0.04	0.05	0.06
Electric field at breakdown (kV_{pk}/cm)	125	110	105	100	95

Estimates the 50Hz root mean square inception voltage.

7. A dielectric containing a single discharge cavity can be represented by the equivalent circuit below.



Where C_c represents the cavity. If C_a=0.1μF, C_b=0.001pF and C_c=0.01pF. The voltage across the cavity at the instant of breakdown is 950V, calculate

(i) the rms discharge inception voltage, assuming a sinusoidal waveform

(ii) the apparent discharge magnitude, and

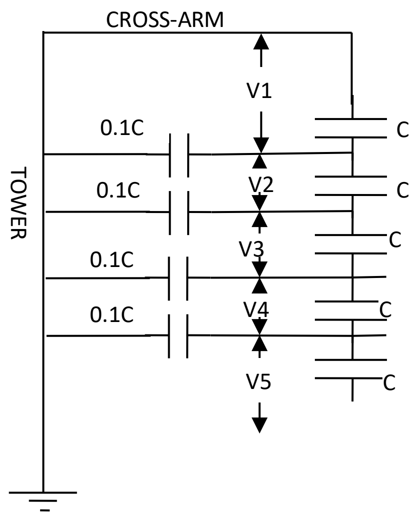
(iii) the energy dissipated by a single discharge

8. Explain, with the aid of an electrical equivalent circuit, the mechanisms of PD occurring in a solid insulation containing a air voids. Using sketches to illustrate the voltage waveform across the void, the applied voltage and the PD current waveforms during an ac cycle.

Lec 3: HV Plant Insulation

1. Briefly describe the four types of stresses high voltage power plant insulation systems are subjected in operation.
2. Discuss the electrical and mechanical stresses which may appear in a rotating machine, include the likely locations and causes.
3. Describe the mechanisms and symptoms of thermal aging to core insulation and winding insulations in a rotating machine respectively.
4. Contrast the advantages and disadvantages of Oil insulated CB, ABCB, SF6 and Vacuum CB in HV applications.
5. State the considerations which must be made when designing overhead line insulators.
6. Explain the process of insulator flashover and provide three methods which can help alleviate the problem.
7. (i) A 33kV overhead line string insulator can be described electrically as shown in Figure below. A string of 5 insulator units each possessing a capacitance C is used to suspend a transmission line. The air capacitance between each of the unit cap/pin junctions to the earthed tower is 0.1C. Given that the wet surge flashover voltage is 70kV (peak) for each unit, determine whether any individual unit would flash over when the whole unit is subjected to a surge of 250kV (peak) on a rainy day.

   (ii) With the design shown, the string efficiency is low due to non-uniform distribution of voltage. Provide one measure, with the aid of a sketch, that can help improve the string efficiency and explain how the improvement is achieved.



8. **(i)**A 33kV overhead line string insulator is made of 5 insulator units each possessing a capacitance C is used to suspend a transmission line. The air capacitance between each of the unit cap/pin junctions to the earthed tower is 0.1C. Given that the wet surge flashover voltage is 65kV (peak) for each unit, determine whether any individual unit would flash over when the whole unit is subjected to a surge of 250kV (peak) on a rainy day.

   (ii) Determine the string efficiency in (a)(i). Explain what has been the cause of the non-linear voltage distribution across the insulators and what role the ring guard has played in voltage distribution.

Lec 4: Insulation Coordination

1. Give the three types of overvoltages which need to be considered in insulation design and coordination for HV power plant. Explain their source and their manifestation
2. Provide the definition of the basic insulation level (BIL) of an insulation system, and explain its significance in HV system design
3. Describe and explain respectively how the conventional and statistical method of insulation coordination are applied in HV insulation system design.
4. A transformer has an impulse insulation level of 1000kV and is to be operated with a margin of 15% under lightning impulse conditions. The transformer has a surge impedance of 1600Ω and is connected to a transmission line having a surge impedance of 360Ω. A short length of overhead earth wire is to be used for shielding the line near transformer from direct strikes. Beyond the shielded length, direct strokes on the phase conductor can give rise to voltage waves of the form $820e^{-0.05t}$ kV (where t is expressed in μs). if the corona distortion in the line is represented by the expression $\frac{\Delta t}{x} = \frac{1}{B}[1 - \frac{e_o}{e}] \quad \mu s$, where B=120m/μs and e_o=180kV, determine the minimum length of shielding wire necessary in order that the transformer insulation will not fail due to lightning surges.

5. A 3-phase 132 kV line having BIL of 300 kV is supported on steel towers and protected by a circuit breaker. The earthing resistance at each tower is 20 **Ω** whereas the neutral of the lines is solidly grounded at the transformer just ahead of the circuit breaker. During an electric lightning, one of the towers is hit by lightning stroke of 20 kA.

   (i) Calculate the voltage across each insulator string under normal conditions and during the process of lightning. Describe the sequence of events during and after the lightning stroke.

   (ii) Determine the maximum earthing resistance with which the line will not be tripped under the same lightening condition.

6. A lightning arrestor having a flashover voltage of 650 kV is located on a main 132-kV busbar providing protection to a 132/33kV transformer having a surge impedance of 1600Ω. The arrestor is subject to a surge of 500kV rising at 1000kV/μs originating on a 132-kV line, of surge impedance 400Ω, connected to the transformer via a busbar. The transformer is effectively earthed.

(i) Assuming the arrestor is 90 meters away from the transformer, determine the time required to travel between the two plant items, transmission and reflection coefficient for the lightning impulse.
(ii) Sketch the voltage waveform at the location of arrestor and the location of transformer.
(iii) The lightning impulse insulation level of the transformer on the 132kV side is 900kV. Determine, stating any assumptions made, the maximum possible voltage at the transformer terminal.
(iv) What would have been the maximum separation permissible between the transformer and the lightning arrestor, if the BIL of the transformer was 1000 kV and a protective margin of 15 % is required, for the above case?

[Note: $E_t = E_a + \beta(de/dt) \times 2l/300$]

Lec 5 – HV Generation and Testing

1. List three types of techniques which can be adopted for HV voltage measurement, contrast their principles of operation.

2. A resistor divider has a high voltage arm of 39.6MΩ and a low voltage arm of 0.4 MΩ. Determine the reading on an electrostatic voltmeter (measuring rms value) connected across the low voltage arm when the following voltages are applied.

(i) $40000+10000\sin 100\pi t$,

(ii) $40000\sin 100\pi t+10000\sin(200\pi t)$

3. For Q2, if capacitors of 4000pF and 196,000pF are connected in parallel with the resistors across the high voltage and low voltage arms respectively, determine the reading of the electrostatic voltmeter.

4. It is important to determine the dielectric strength of solid insulants in HV design. Outline the procedures, with the aid of schematic diagrams, for carrying out such tests. Explain also how the maximum safe working voltage is determined from test results.

5. Explain why HVDC are often applied to test AC cables. Discuss why DC test can result in failures when cables are reinstated for operation after test.

6. Explain why HV tests need to be carried out on HV materials and equipment. Lists the various types of tests often carried out on (i) insulation materials, and (ii) completed equipment.

7. Explain why switching and lightning impulse tests are often carried out on HV equipment and describe the test waveforms required for the tests.

8. Lists the factors that may affect the dielectric loss.

9. Polarisation index (PI) is often applied to rotating machine insulation tests. Explain what is PI, and how it is applied to a winding insulation test.