UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 8 Examination in Engineering: September 2023

Module Number: EE8308 **Module Name: High Voltage Engineering (C/18)**

[Three Hours]

[Answer **all questions**, each question carries 10 marks]

All notations have their usual meanings.

Technical Information for candidates

- Permeability of free space $\mu_0 = 4\pi \times 10^{-7}$ H/m
- Permittivity of free space $\varepsilon_o = 8.854 \times 10^{-12}$ F/m
- Velocity of light in free space = 2.998×10^8 m/s
- Air density correction factor $\delta = \frac{p}{760}\frac{273+20}{273+t}$

Q1 a) i) Describe briefly with the aid of suitable diagrams, "Electro-mechanical breakdown process" of solid dielectric materials.

ii) Plot the variation of voltage and current waveforms during the breakdown process of solid dielectrics with voids, due to internal discharge.

iii) A transformer oil having a dielectric constant of 2.5 and a dielectric strength of 32 kV/mm is used as an insulation in a spacing of 10 mm. Determine the maximum permissible voltage across the electrodes, using a safety factor of 2.
A barrier of thickness 4 mm of transformer board with a dielectric strength of 80 kV/mm which has a dielectric constant of 4.5 is used in this space to increase the strength. Using a safety factor of 2, determine the new maximum voltage that is permissible and comment on the decision.

[5 Marks]

b) i. What is meant by "Basic Lightning Impulse Insulation Level (BIL)" in a system?

ii. Differentiate "Statistical BIL" and "Conventional BIL".

iii. With suitable diagrams, show how corona distorts the waveshape of a voltage surge.

iv) A transformer has an impulse insulation level of 1225 kV. It is to be operated with an insulation margin of 20% under lightning conditions. The transformer has a surge impedance of 2370 Ω and is connected to a transmission line with a surge impedance of 520 Ω. It is planned to use an overhead earth wire from the transformer up to a certain distant, to protect it from direct lightning strikes. Beyond this shielding length, direct strikes can cause voltage waves of the form $940\ e^{-0.04t}$ kV (with t expressed in μs).
If the corona discharge in the line is given by the expression, $\frac{\Delta t}{x} = K\left[1 - \frac{e_o}{e}\right]$

μs/m, where k= 0.01 μs/m and $e_o = 240\ V$, determine the minimum length of shielding wire required to protect the transformer from lightning strikes.

[5 Marks]

Q2 a) i) Describe briefly, with the aid of suitable diagrams, the mechanism of lightning stroke generation.

ii) Briefly explain the areas indicated as (1), (2) and (3) in Figure Q2.a) of the geometric model of earth wire shielding. In the figure, "e" represents the earth wire and "c" represents the phase conductor.

iii) Using a suitable geometric configuration, derive an expression for the radius of protection of a lightning conductor. State any assumptions used in the derivation.

[5 Marks]

b) i) Figure Q2.b) shows a substation P, where three transmission lines A, B, and C are connected. The surge impedances of the lines are as indicated on the figure. If a surge voltage of magnitude 100 kV arrives along line AP, determine the magnitude of surges transmitted to PC and reflected back to AP.

ii) Three substations, A, B, and C are connected via overhead lines: Line AB and Line BC. The velocity of propagation for these lines is 3×10^8 ms^{-1}, and the characteristics of these overhead lines are listed below.
Line AB: length – 300 km, surge impedance – 320 Ω, attenuation factor – 0.95
Line BC: length – 150 km, surge impedance – 440 Ω, attenuation factor – 0.85
Surge impedance of the overhead line which feeds substation A is 800 Ω.
Substation C feeds a terminal equipment with surge impedance of 1350 Ω at end C. If a voltage surge reaches substation A with a magnitude of 100 kV from outside, sketch Bewley Lattice diagram indicating significant values on it up to 2 ms. Calculate the voltage at B at 2 ms.

[5 Marks]

Q3 a) Define the followings.

i) Critical Flashover Voltage
ii) Statistical Withstand Voltage
iii) Statistical Flashover Voltage

[3 Marks]

b) Table Q3.b) gives the results of insulation breakdown test of a sample of self-restoring liquid insulation material at standard temperature (20°C) and pressure (101.3 kPa). The liquid sample is placed between two electrodes which are kept 3 mm apart. Calculate the following at 31°C and 98 kPa for the gap. Assume that breakdowns are distributed according to standard normal curve.

i) Critical Flashover Voltage
ii) Statistical Withstand Voltage
iii) Statistical Flashover Voltage
iv) What is the dielectric strength of air sample at 31°C and 98 kPa?

[7 Mark]

Q4 a) An electrostatic voltmeter has a vertical movable circular plate (electrodes) having 8 cm in diameter. The movable plate moves only horizontally. A light beam, emitted at 30^0 angle to the vertical, is reflected by a vertical mirror fixed to the movable plate and set to be on a vertical wall.
The movable plate is connected to a spring having spring constant of 4.9×10^{-4} N/mm. The spring is originally at equilibrium (unstretched) length. When a voltage is applied between the two plates, it is observed that the light beam moves 13.86 mm. If the distance between the plates after movement is 4 mm, determine the potential difference applied between the plates by deriving all the formulas used.

[5 Marks]

b) When the 3 cores of a cable are strapped together, the capacitance between this bundle and the sheath is measured as 12 μF. When the two of the cores are connected to the sheath and the capacitance measured between the remaining core and the sheath is 9 μF. Based on above measurements, calculate the followings by deriving any formula used.

i) Charging current of the cable.

ii) Reactive power taken by capacitance of the cable, when it is connected to a 33 kV, 50 Hz frequency supply.

[5 Marks]

Q5 a) i) Explain the practical existence of chopped surge waveforms and how we can generate them for high voltage testing purposes.

ii) Using suitable diagrams, define following for an unchopped surge.

I. Surge front time

II. Surge tail time

[6 Marks]

b) Unchopped 800 kV surge has 0.18 μs wave front time and 49.87 μs wave tail time. Derive the equation of the surge.

[4 marks]

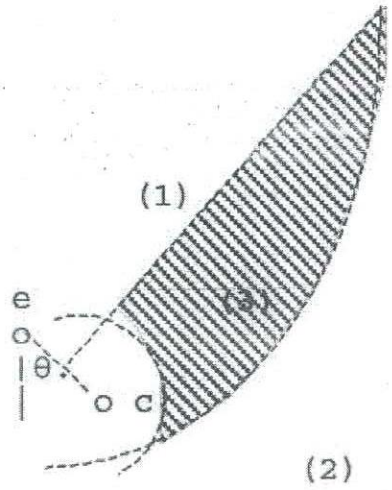

Figure Q2.a).

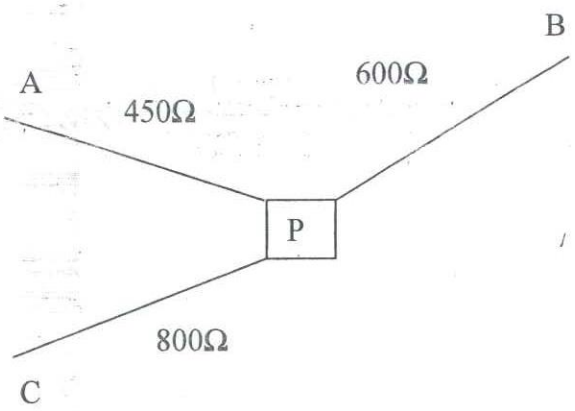

Figure Q2.b).

Table Q3.b)

Applied voltage in kV	75	80	85	90	95	100	105	110
Number of shots applied	95	115	100	110	90	95	90	85
Number of times failed	6	18	31	55	62	80	84	84