UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 8 Examination in Engineering: August 2022

Module Number: EE8308 **Module Name: High Voltage Engineering**

[Three Hours]

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

All notations have their usual meanings.
The values of the constants are given as in the following.

- 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 $\delta = \frac{p}{760}\left(\frac{273+20}{273+t}\right)$

Q1 a) Corona discharge is considered as a significant phenomenon in breakdown of gases. It is responsible for considerable power loss in transmission lines and give rise to radio interference.

i) Explain what is meant by disruptive critical voltage and mention the difference between visual corona inception voltage and disruptive critical voltage.

ii) Derive an expression for the corona inception in a two-conductor system with the radius of each conductor r and the spacing between the conductors d. Thereby, get an expression for disruptive critical voltage if the air breakdown stress is 30 kV/cm, irregularity factor is m_o and correction factor is δ.

iii) Explain with the aid of suitable diagrams, how the expression derived in part ii) can be extended to a three-phase transmission line with equilateral spacing.

iv) Find the disruptive critical voltage for a 150 km long 3 phase, 132 kV line consisting of roughened conductors (m_o = 0.85) of diameter 1.2 cm, arranged in an equilateral triangle configuration with 5 m spacing. The actual ambient temperature is 32 °C and the atmospheric pressure is 765 torr.

[5.0 Marks]

b) Insulation Coordination is a necessary study in High Voltage Engineering which supports the existence of a healthy electrical power system.

i) List 3 significant advantages of insulation coordination in a power system.

ii) A lightning arrestor is to be located on the main 33 kV busbar, away from a 33/11 kV transformer to protect that from a surge rising at 1000 $e^{-0.05t}$ kV (where t is expressed in μs) on the 33 kV busbar. The transformer surge impedance is 300 S, and the 33 kV line has surge impedance of 240 S. The BIL of the transformer on the 33 kV side is 285 kV, and the transformer is effectively earthed.

1. Select a suitable lightning arrestor. You may use Tables Q1.a) and Q1.b). Mention any assumptions you used.
2. If the corona distortion in the line is represented by the expression $\frac{\Delta t}{x} = \frac{1}{B}\left[1 - \frac{e_o}{e}\right]$, where B = 10 m/μs, e_o = 200 kV and insulation margin is 15%. Determine the minimum length of the shielding wire in order that the transformer insulation provides surge protection.

[5.0 Marks]

Q2 a) i) Elaborate on the term 'Return Stroke'.

ii) State two assumptions in the derivation of shielding angle for overhead ground wires.

iii) Derive the equation for shielding angle with the help of a geometric configuration.

iv) Calculate the tower height H in terms of striking distance if the conductor height h is equal to half of the striking distance. Take the shielding angle as 30 degrees.

[5.0 Marks]

b) A 150 kV DC voltage source, having an internal resistance of 200 Ω is switched on to a 200 km long overhead line with a surge impedance of 400 Ω at time zero. The far end of the line is terminated on a resistance of 1000 Ω as shown in Figure Q2. The velocity of surge propagation in the line is 200 m/μs.

i) Sketch the Bewley Lattice diagram for a period 0 to 4000 μs.

ii) Accordingly, find the voltage and the current at the load at 2500 μs.

[5.0 Marks]

Q3 a) i) Describe the ways that stray capacitance influences the performance of resistance type potential divider.

ii) I. Draw the circuit of a capacitive potential divider in which capacitors are connected in simple capacitor connection.

II. Show that, before charging the cable connecting the potential divider and the measuring instrument, voltage at the measuring instrument is given by

$$E_{4\,initial} = \frac{C_1}{C_1 + C_2} E_1$$

where E_1 is the voltage applied to the high voltage terminal of the potential divider.

III. What will be the value of E_4 when the above said cable is charged?

[5.0 Marks]

b) In a capacitance measurement test of a 3-core belted cable, below measurements were observed:

i) All three cores were bundled by a conductor. When the capacitance is measured between the bundled cores and cable sheath, 18 μF are observed.

ii) Two cores were connected to the sheath. The measured capacitance between sheath and the remaining conductor is 6 μF.

Based on above observations, calculate the core to core and core to sheath capacitance of the cable. Also, calculate the capacitance to neutral of any of cores. Derive all equations you use.

[5.0 Marks]

Q4 a) Discuss the controlled and uncontrolled operational modes of surge generators considering the firing of the spark gap that trigger the circuit.

[5.0 Marks]

b) Given a spark gap, two high voltage resistors R_1, R_2 where $R_2 >> R_1$ and two high voltage capacitors C_1, C_2, draw a circuit that can generate a surge. Calculate the wave front time and wave tail time of the surge generated by this circuit provided that,

$R_1 = 160\ \Omega$

$R_2 = 1200\ \Omega$

$C_1 = 1.5 \times 10^{-8}\ F$

$C_2 = 1.2 \times 10^{-8}\ F$

Prove any formula you use. Measure the time from 0 rather than 0_1.

[5.0 Marks]

Q5 a) Explain the parameters, which are examined by high voltage testing of insulators.

[4.0 Marks]

b) Define below quantities used in high voltage testing.

i) Critical Flash Over voltage (CFO)

ii) Statistical withstand voltage (SWV)

iii) Statistical flashover voltage (SFOV)

[3.0 Marks]

c) Describe up-down method of flash over testing of a sample insulator.

[3.0 Marks]

Table Q1.a): International Maximum System Voltages.

Nominal System Voltage (kV)	11	33	66	132	220
Maximum System Voltage (kV)	12	36	72.5	145	245

Table Q1.b): Arrestor Rating Versus the Impulse Sparkover Voltages.

Arrestor Rating kV rms	Minimum Power frequency withstand	Maximum Impulse Spark-over voltage (1.2/50 μs) kV crest	Maximum Residual Voltage kV crest	Maximum Wavefront Sparkover Voltage kV crest
36	1.5 times rated voltage	130	133	150
50		180	184	207
60		216	221	250
75		270	276	310

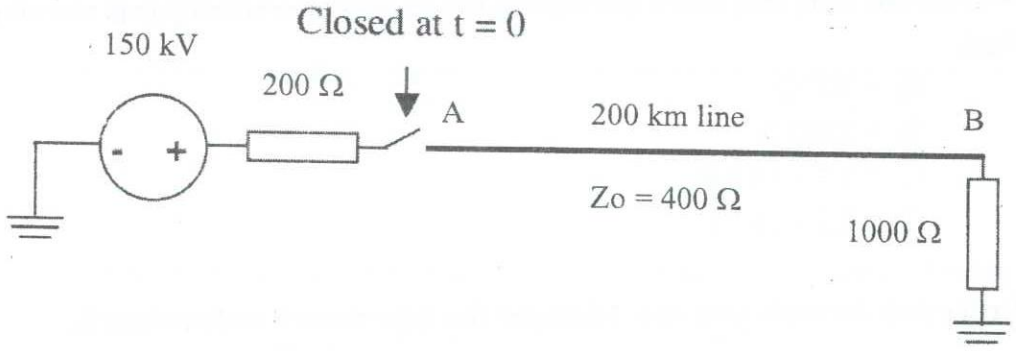

Figure Q2: Transmission Line