**University of Moratuwa, Sri Lanka**

B. Sc. Engineering Degree Course

Final Part III Examination 2001/02

# UEE 403 - High Voltage Engineering

Time Allowed: 0930 – 1230 hrs 23 June 2003.

Answer **Five** Questions Only.

Question 1 carries 28 marks and all other Questions carry 18 marks each.

---

Permeability of free space $\mu = 4\pi \times 10^{-7}$ H/m Permittivity of free space $\varepsilon_o = 8.854 \times 10^{-12}$ F/m

---

1 (a) Explain briefly the thermal mechanism of breakdown in an energised dielectric.[2 marks]

(b) For a three core belted type cable, considering the particular instant in the 3 phase cycle when phase "a" voltage is max in the sequence abc, sketch the equipotential lines and the stress lines. [3 marks]

Explain very briefly how you drew these lines. [1 marks]

(c) Show from first principles that a surge on transmission lines can be represented by a forward travelling wave and a reverse travelling wave. [3 marks]

Show how the above result is made use of in the Bergeron's method of graphical solution. [2 marks]

(d) Briefly describe the theory of shielding an overhead transmission line against a direct lightning strike. [3 marks]

(e) Describe the Cockroft-Walton method of generating high direct voltages for testing purposes. [3 marks]

(f) Derive from first principles an expression for the disruptive the critical voltage of air for a two conductor system. State any assumptions made. [3 marks]

(g) Outline the significance of type tests, sample tests and routine tests performed on high voltage equipment. [2 marks]

(h) With the aid of suitable diagrams briefly describe the measurement of dielectric constant and loss tangent of an insulating liquid. [2 marks]

(i) Draw the circuit diagram for a high voltage Schering Bridge where the standard capacitor has a known but very small loss tangent. Derive expressions for the values of the capacitance **C** and the loss tangent of **tan** $\delta$ the unknown, stating any assumptions made in your calculations. [4 marks]

2 By deriving from first principles, show that the thermal resistance of the ground of a buried cable is given by $\frac{k}{3\pi}\ln\frac{2h}{r}$ where the symbols have their usual meanings. [5 marks]

A 220 kV, 50 Hz three phase system has a single phase cable buried in the ground at a depth of 1.7 m below the surface. If the ambient temperature is 27°C and the maximum permissible temperature of the insulation is 85°C, determine the current rating of the cable for the following data. [13 marks]

| | | |
|---|---|---|
| diameter of core | = | 38 mm |
| diameter over insulation | = | 90 mm |
| thickness of lead sheath | = | 2 mm |
| resistance of conductor at 85 °C | = | 0.016 Ω/km |
| relative permittivity insulation | = | 4.2 |
| dielectric loss factor of cable insulation | = | 0.0035 |
| thermal resistivity of cable insulation | = | 5.0°C-m/W |
| thermal resistivity of ground | = | 1.4°C-m/W |

3 (a) A simplified power system consists of three lines AB ($Z_o$= 600 Ω), BC ($Z_o$= 400 Ω, 120 km, overhead line) and BD ($Z_o$= 50 Ω, 20 km, cable). The lines BC and BD are on open circuit at the ends C and D respectively. If a step surge of magnitude 100 kV originates on line AB at A and travels towards B, sketch the voltage waveforms at B, C and D for the first 0.35 ms from the inception of the surge. The lines may be assumed to be lossless and that A is too far from junction B to consider reflections at A coming back to B. [9 marks]

[Velocities of propagation in overhead line and cable are 3 x $10^5$ km/s and 2 x $10^5$ km/s]

(b) Two overhead lines AB ($Z_o$= 500 Ω, length = 300 km, attenuation factor = 0.8) and BC ($Z_o$= 300 Ω, length = 120 km, attenuation factor = 0.9) feed a load of value 1700 Ω. A triangular wave of peak height 100 kV and duration 400 μs originates in the overhead line AB at A and travels towards the junction B. Using Bewley Lattice Diagram, determine and sketch the voltages at A, B and C for the first 1.9 ms.

[9 marks]

4

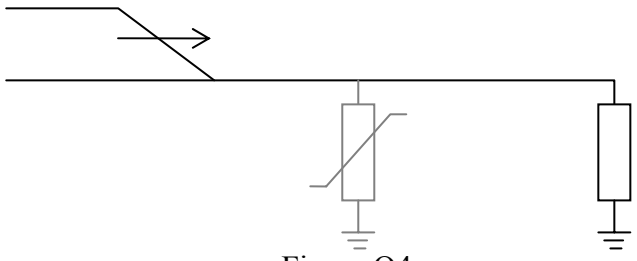

Figure Q4

(a) A 100 kV surge has a linear rate of rise of 500 kV/μs to peak and constant value thereafter (figure Q4). It originates in an overhead transmission line with a surge impedance of 400 Ω and travels towards a terminal device ($Z_0$ = 1600 Ω). It is protected by a lightning arrestor (operating voltage is 145 kV) at a distance of 9 m from the device.

Sketch the voltage waveform at the arrestor location. [10 marks]

(b) Sketch the voltage at the terminal device [4 marks]

(c) Determine the maximum voltage to which the terminal equipment will rise. [2 marks]

(d) Determine the time at which the arrestor operates. [2 marks]

5 Draw the basic circuit diagram of a six stage impulse generator, designed to obtain a double exponential voltage waveform. Indicate on the diagram the wavefront and wavetail control resistors and the charging resistors. [3 marks]

A six stage impulse generator is to be designed to deliver 600 kV at the standard waveform (1.2/50 μs). Nominal energy required for the impulse generator is 2.5 kJ and the voltage efficiency desired is 90%. Indicate, with the aid of suitable calculations, the values of the associated elements in the circuit to produce the required waveform. [15 marks]

6 (a) In a high voltage laboratory, a capacitive potential divider is to be used with a delay cable to observe the surge waveform on an oscilloscope. Explain how the cable may be matched to minimise possible waveform distortion. [5 marks]

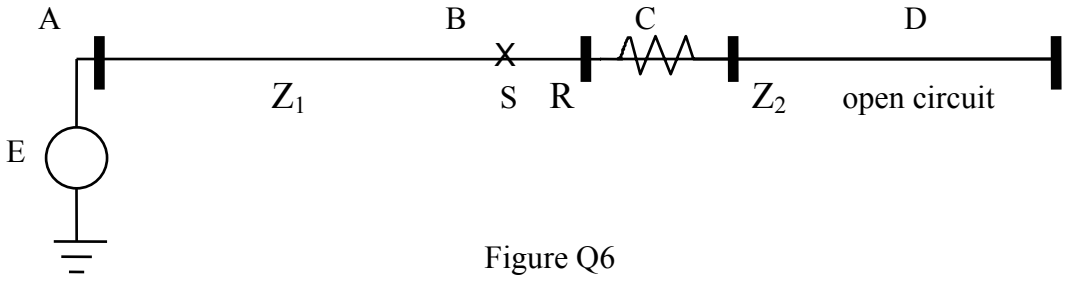


Figure Q6

(b) In the circuit shown in figure Q6, the circuit breaker S (with switching resistor R) energizes the line CD (surge impedance $Z_2$) through an already energized line AB (surge impedance $Z_1$).

Determine (i) the magnitude of the first surges entering BA and CD. [7 marks]

and (ii) the magnitude of the next surge entering BA, due to the first reflection at D. [6 marks]

7 Starting from the three phase waveforms sketch the typical waveforms of the d.c. voltage (before smoothing), when operating as an inverter with commutation angle $\gamma$ and extinction angle $\delta$. [4 marks]

An hvdc link AB operates from 220 kV/110 kV transformers operating on 220 kV, 50 Hz alternating supplies. The converter at end B operates as an inverter on constant extinction angle control ($\delta_o = 8^0$ with $5^0$ margin on $\delta_0$ for deionisation). The reactance of each converter transformer is 14 Ω. If the converter delivers 80 MW, determine (a) the direct current, (b) the direct voltage, (c) the commutation angle, (d) power factor and (e) the reactive power requirement of the converter B. [10 marks]

A brief derivation of equations used is required. [4 marks]