University of Moratuwa, Sri Lanka

B. Sc. Engineering Degree Course

Final Part III Examination 2002/03

UEE 403 - High Voltage Engineering

Time Allowed: 0930 – 1230 hrs 3 February 2004.

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

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1 (a) A certain dielectric can be considered to be represented by the equivalent circuit shown in figure Q1(a). What is the maximum voltage that can be applied across the dielectric if partial discharges in air is to be avoided. State any assumptions made. [4 marks]

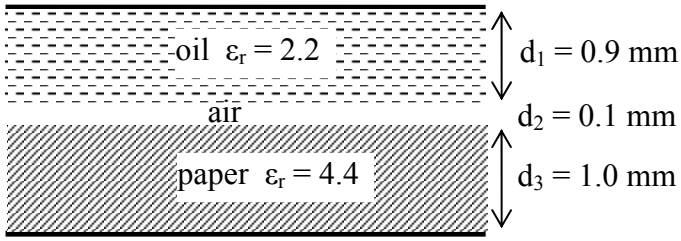

Figure Q1(a)

(b) A 132 kV, three-phase, 50Hz transmission line uses 15 mm diameter equally spaced ACSR conductors. What should be the spacing between these conductors, if it is to be designed such that the corona inception voltage is 5% higher than the normal operating voltage of the line at normal temperature and pressure conditions. [4 marks]

(c) Describe with the aid of suitable diagrams, the Bergeron's method of graphical solution of transmission line surges. [4 marks]

(d) Briefly describe a method of recording the occurrence of lightning in an overhead transmission line. [3 marks]

(e) Explain why a steep fronted surge waveform is more likely to cause damage to the line-end turn insulation of a transformer winding rather than elsewhere. [3 marks]

(f) Describe the use of resonance in the generation of high alternating voltages for testing purposes. Why is this method not suitable for power transmission ? [3 marks]

(g) Describe, with the use of suitable diagrams, the use of sphere gaps in high voltage measurements. [3 marks]

(h) Figure Q1(h) shows a substation S to which are connected 4 transmission lines AS, BS, CS and DS. If a surge of magnitude 100 kV arrives along BS, determine the surge transmitted to SD and the surge reflected back on SB. [4 marks]

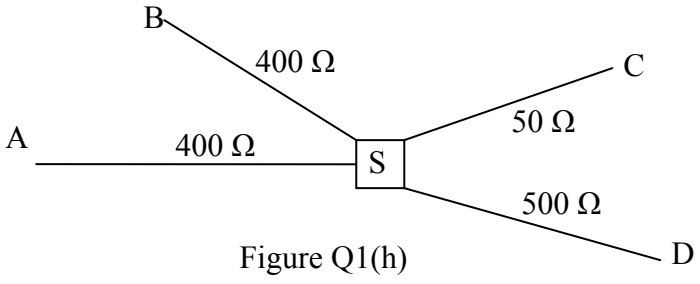

Figure Q1(h)

2 (a) A long transmission line AB (Z_o= 450 Ω) is connected to a terminal device at C (Z_o= 1950 Ω) through a short length of cable BC (Z_o= 50 Ω, 400 m, attenuation factor in single transit =0.9). A triangular surge (100 kV vertical front, 6 μs duration to zero) originates in the overhead line AB and travels towards the cable. Sketch the voltage waveform at C for the first 11 μs from the arrival of the surge at B. A may be assumed to be too far from junction B to consider reflections at A coming back to B. [12 marks]

(b) Sketch also the waveform that would have appeared, if the overhead line was directly terminated in the device instead of through the cable. [2 marks]

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

(c) Briefly explain, with appropriate calculations, the use of switching resistors in circuit breakers to reduce switching surges. [4 marks]

3 A six-stage impulse generator designed to generate the standard waveform (1.2/50 μs) has a per stage capacitance of 0.06 μF to be used to test transformers with an equivalent winding to earth capacitance of 1 nF. A peak output voltage of 550 kV is required for testing the transformer. The wavefront time is to be defined based on 30% and 90% values.

(a) With the aid of appropriate calculations select the values of the resistive elements in the circuit to produce the required waveform. State any assumptions made. [14 marks]

(b) Draw the basic circuit diagram of the multi-stage impulse generator indicating all relevant values on it. Indicate also on the diagram the wavefront and wavetail control resistors and the charging resistors. [3 marks]

(c) Determine the nominal energy of the impulse generator designed. [1 mark]

Equations used, if any, must be derived from first principles.

4 (a) Outline, with the use of an example, the significance of type tests, sample tests and routine tests on high voltage equipment. [3 mark]

(b) Describe with the aid of suitable diagrams and appropriate calculations, the use of the Schering Bridge in high voltage testing. [5 mark]

(c) Three insulating materials A, B and C are available (with properties given in the table) for use in a high voltage a.c. cable. If the conductor radius is 12 mm, and the radius of the sheath is 25 mm, determine the order and thickness of the various layers of insulation for an optimum working voltage. [8 mark]

Material	A	B	C
Breakdown voltage (kV/cm)	150	130	110
Relative Permittivity	3.5	2.5	4.4

Determine also the maximum operating voltage of the cable, if a safety factor of 1.5 is used in the design. [2 mark]

5 (a) Briefly explain, with the aid of suitable diagrams, the statistical method of insulation co-ordination. [4 marks]

(b) With the aid of suitable diagrams, show that wavetail distortion due to corona in an overhead line can be expressed in the form $\frac{\Delta t}{x} = K.\left[1 - \frac{e_o}{e}\right]$ [6 marks]

(c) A surge arrester is required to protect a 20 MVA, 132/33 kV, 3 phase transformer (effectively earthed, BIL = 550 kV, Z_o = 1600 Ω). With appropriate calculations, select the required discharge current rating for the arrester to protect it from 930 kV surges arriving on a transmission line with a surge impedance of 400 Ω. [8 marks]

Discharge current (kA)	5	10	20
Discharge Voltage (kV)	316	350	418

6 (a) A 100 kVA, 50 Hz, 230/50 kV testing transformer has an 8% leakage reactance and a 2% winding resistance. A cable of capacitance 15 nF is to be tested at 250 kV using this transformer as part of the resonance circuit. Determine the value of the inductance (Q-factor = 20) required to obtain resonance and the value of the input voltage required. [10 marks]

(b) Describe briefly how the measurement of dielectric constant and dissipation factor of a liquid dielectric are calculated using a brass test cell at high frequencies. Derive expressions for the quantities in terms of the measurements. [8 marks]

7 An hvdc link AB operates from 220 kV/300 kV transformers on 220 kV, 3phase, 50 Hz alternating supplies at either end. The converter at end B operates as an inverter on a constant extinction angle of 12^0. If the link is operating at a direct current of 1.2 kA and the reactance of each converter transformer is 20 Ω, determine

(a) the nominal voltage of the direct current link, [3 marks]

(b) the operating direct voltage, [3 marks]

(c) the active power delivered by the link, [1 marks]

(d) the ignition angle of inversion, [3 marks]

(e) power factor at the inverter end, [3 marks]

(f) fundamental component of current on the a.c. side, [3 marks]

(g) sketch the compounded operating characteristics of the converters on a d.c. voltage vs d.c. current diagram, if the current margin between the rectifier and the inverter settings is 100 A.. [2 marks]

A brief derivation of equations used is required.