University of Moratuwa, Sri Lanka

B. Sc. Engineering Degree Course

Level 4 – Semester 1 Examination 2003/04

EE402 - INSULATION CO-ORDINATION

Time Allowed: Two Hours — February 2005.

Answer **All** Questions. — Total marks for the paper is 70 marks.

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

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1. (a) Describe very briefly with the aid of suitable diagrams the provision of shielding of overhead lines against direct lightning strokes. [3 marks]

(b) Show from first principles that surges can be represented by a combination of forward and reverse travelling waves. [3 marks]

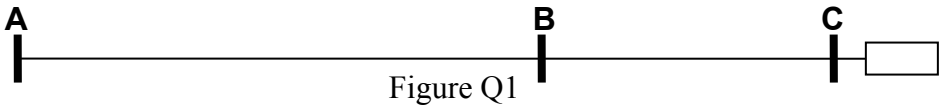

Figure Q1

(c) Figure Q1 shows an overhead line AB (l = 120 km, Z_o = 350 Ω, attenuation factor = 0.9) energised from an alternating source (surge impedance = 50 Ω, rms value 100 kV) at end A when the voltage is at its peak value. Another line BC (length 90 km, Z_o = 450 Ω, attenuation factor = 0.95) connected at end B feeds the terminal equipment (Z_o = 1550 Ω) at C. Sketch the Bewley lattice diagram indicating significant values on it. State any assumptions made in your calculations.[8 marks]

(d) Sketch, indicating significant values, the voltage at B for the first 1.4 ms after the surge is initiated at A. [4 marks]

2. (a) Derive expressions for the (i) surge impedance, (ii) velocity of propagation of a surge, and (iii) energy stored in a surge. You may assume standard expressions for the inductance per unit length and capacitance per unit length of a transmission line. [3 marks]

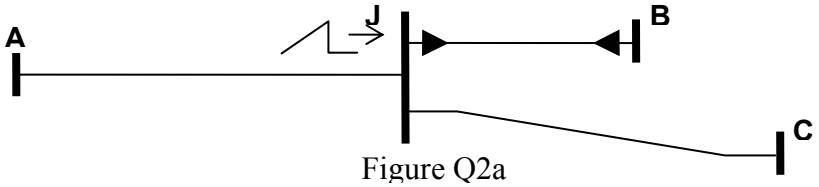

Figure Q2a

(b) Figure Q2a shows lines AJ (Z_o = 400 Ω, 200 km), cable BJ (Z_o = 50 Ω, 40 km) and line CJ (Z_o = 400 Ω, 90 km) meeting at a junction J. For a triangular surge (peak value 200 kV, vertical front, linear tail of duration 500 μs) originating on AJ, determine from first principles the reflection coefficient and the transmission coefficients at junction J. [6 marks]

(c) If terminals B and C in figure Q2a are on open circuit, determine and sketch the voltage waveforms at J, B and C for the first 500 μs after the triangular wave first arrives at J. Neglect Attenuation. [4 marks]

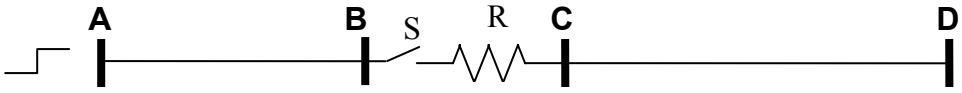

Figure Q2b

(d) Figure Q2b shows a line CD (Z_o = 600 Ω) energised through a switching resistor (R = 400 Ω) from an already energised line AB (Z_o = 400 Ω, E = 100 kV). Determine the magnitudes of the first surges transmitted on to lines BA and CD. Derive any expressions used. [4 marks]

3. A 6-stage impulse generator may be represented by the simplified equivalent circuit shown in figure Q3.

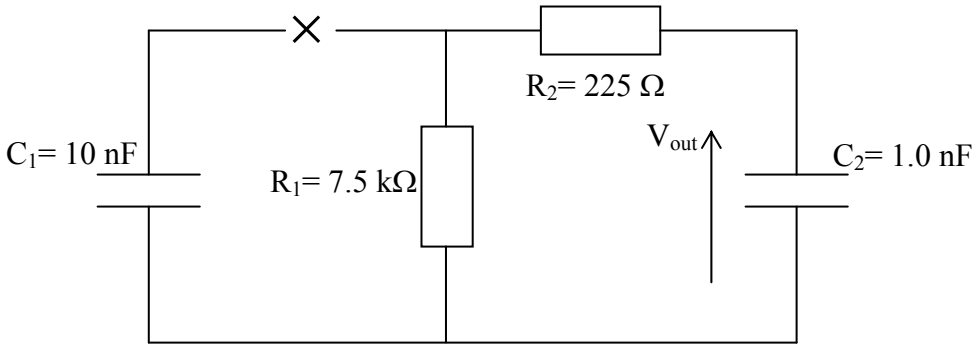

Figure Q3

(a) Sketch the complete circuit diagram of the impulse generator showing all 6 stages, and labelling all the components on it. [4 marks]

If the input transformer of the impulse generator has a peak secondary voltage of 50 kV, determine

(b) the approximate voltage efficiency of the impulse generator [2 marks]

(c) the nominal energy capacity of the impulse generator [1 marks]

(d) the wavefront time (based on 30% to 90%) and wavetail time [6 marks]

(e) the output voltage waveform across C_2 [2 marks]

State any assumptions made in your derivations.

Explain very briefly, with suitable diagrams, why a trigatron gap is normally used in the first stage of a multi-stage impulse generator. [2 marks]

4. (a) Derive from first principles an expression for the corona distortion as a surge travels along a transmission line. [12 marks]

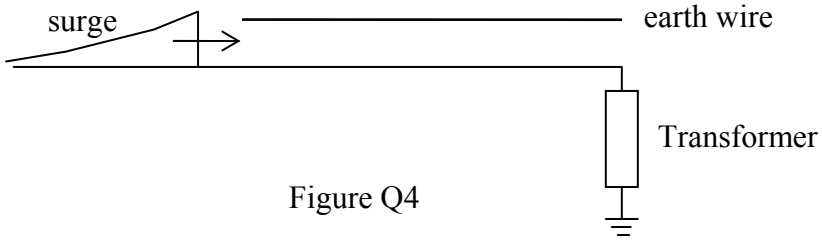

Figure Q4

(b) Figure Q4 shows a transformer which has an impulse insulation level of 1050 kV. It is to be operated with an insulation margin of 15% under lightning impulse conditions. The transformer has a surge impedance of 2250 Ω and is connected to a transmission line having a surge impedance of 450 Ω. A short length of overhead earth wire is to be used for shielding the line near the transformer from direct strikes. Beyond the shielded length, direct strokes on the phase conductor can give rise to voltage waves of the form $960\ e^{-0.04\,t}$ kV (with t expressed in μs).

If the corona distortion in the line is represented by the expression $\frac{\Delta t}{x} = k\left[1 - \frac{e_0}{e}\right]\ \mu s/m$, where k = 0.01 μs/m and e_0 = 240 kV, determine the minimum length of shielding wire necessary in order that the transformer insulation will not fail due to lightning surges. [6 marks]