University of Moratuwa, Sri Lanka

B. Sc. Engineering Degree Course

Level 4 – Semester 1 Examination 2004/05

25 January 2006

EE402 - INSULATION CO-ORDINATION

Instructions to candidates:

Time allowed: 2 hours

Answer **All** Questions

Paper contains 4 questions in 4 pages

Total marks for the paper is 70 marks

This examination accounts for 70% of the module assessment

Clearly state any assumptions made, data assumed or interpretations made in the script

Additional Material

Graph paper is available if required

Only authorised Calculators will be permitted

Technical Information

Permeability of free space $\mu_0 = 4\pi \times 10^{-7}$ H/m

Permittivity of free space $\varepsilon_0 = 8.854 \times 10^{-12}$ F/m

Velocity of light in free space = 2.998×10^{8} m/s

Department of Electrical Engineering
Faculty of Engineering

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1. a) Obtain from first principles expressions for (i) the velocity of propagation, (ii) the surge impedance, and (iii) the energy stored in a surge, in transmission lines in terms of the inductance and capacitance per unit length. [4 marks]

b) Starting from the travelling wave solution, show how analysis of surges can be done using the Bergeron method of graphical solution. [2 marks]

c) The transmission line (surge impedance 400 Ω) shown in figure 1.1, is energised from a constant voltage source (100 kV, internal surge impedance 100 Ω) at end A, and is connected to a non-linear load (v = 7000 i for v < 140 kV, and v = 140 kV for i ≥ 20 A). Calculate and sketch the waveforms of voltage at A and B for the first 5 transits of the line. [7 marks]

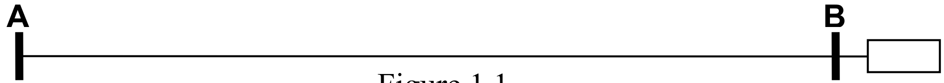

Figure 1.1

d) Figure 1.2 shows an overhead line AB (l = 60 km, Z_o = 400 Ω, attenuation factor = 0.95) energised from a triangular voltage source (vertical front = 100 kV, linear decay to 0 in 0.5 ms, internal impedance = 0 Ω) at end A. Line BC (length 120 km, Z_o = 500 Ω, attenuation factor = 0.9) connected at end B feeds the terminal equipment (Z_o = 2500 Ω) at C. Sketch the Bewley lattice diagram indicating significant values on it for the first 700 μs after the surge is initiated at A State any assumptions made in your calculations. [5 marks]

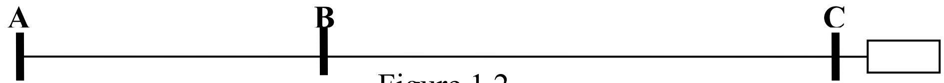

Figure 1.2

e) Sketch, indicating significant values, the voltages at A, B and C for the solution in section 1(d).

[2 marks]

2. a) Explain, with any necessary derivations, one method that may be used to represent lumped inductances and capacitances in travelling wave solutions. [3 marks]

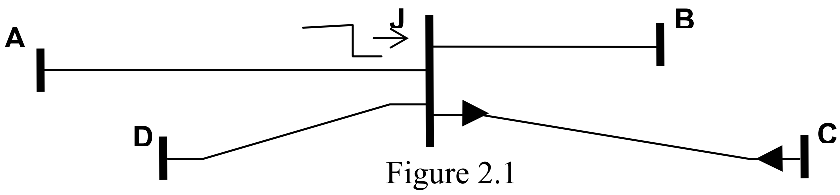

Figure 2.1

b) Figure 2.1 shows lines AJ (Z_o = 300 Ω, 150 km), BJ (Z_o = 400 Ω, 40 km), cable CJ (Z_o = 40 Ω, 60 km) and line DJ (Z_o = 400 Ω, 90 km) meeting at a junction J. For a rectangular surge (100 kV) originating on AJ, determine from first principles the reflected and transmitted first surge voltages and currents into each of the lines at junction J. [4 marks]

c) If terminals B, C and D in figure 2.1 are on open circuit, determine and sketch voltage waveforms at J, and B for the first 300 μs after the step surge first arrives at J. Neglect Attenuation. [5 marks]

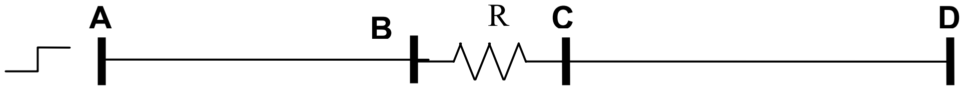

Figure 2.2

d) Figure 2.2 shows a line AB (Z_O = 400 Ω) and CD (Z_O = 600 Ω) connected through a switching resistor (R = 400 Ω). If a surge of magnitude 100 kV originates at A, determine the magnitudes of the first surges reflected back on to line BA and transmitted to line CD. Derive any expressions used. [3 marks]

3. a) Describe briefly the mechanism of lightning stroke initiation. [2 marks]

   b) Sketch the equivalent circuit of an impulse generator to obtain a double exponential waveform, labelling it. [1 marks]

   c) For the circuit drawn in section Q3(b), obtain approximate expressions, stating any assumptions made for

      (i) the voltage efficiency, [1 mark]

      (ii) the nominal energy capacity [1 mark]

      (iii) the wavefront time (based on 30% to 90%), and [3 marks]

      (iv) the wavetail time in terms of the component values. [2 marks]

   d) It is desired to test an equipment with an effective capacitance of 1 nF, using a 4-stage impulse generator with a voltage of 300 kV, standard impulse voltage waveform. If the nominal energy requirement is estimated at 1 kJ, determine the values of the additional components required for the complete impulse generator circuit. [3 marks]

   e) Draw the complete circuit diagram of the impulse generator designed in section Q3(d) labelling all its important components. [3 marks]

   f) Give the equation of the output voltage waveform generated for the circuit designed in section Q3(d). [1 mark]

4. a) Briefly explain, with the aid of suitable diagrams, the statistical method of insulation co-ordination. [2 marks]

   b) Obtain an expression for the voltage distribution in a transformer winding with a uniformly distributed capacitance to earth of the complete winding of C_g and a capacitance of the winding from end to end of C_w also uniformly distributed, for a voltage surge appearing at its terminals. [4 marks]

   c) For the transformer described in section 4(b), if a step surge of magnitude 100 kV reaches the terminal, if C_g = 5 nF and C_w = 200 pF, and the neutral of the transformer can be considered to be solidly grounded, derive an expression and sketch the initial voltage distribution in the winding. Sketch also the envelope of the probable oscillations. The effective length of the winding is 1 m. [4 marks]

   d) A certain surge has a linear rate of rise of 250 kV/μs to 100 kV and constant thereafter. It originates in a transmission line with a surge impedance of 350 Ω and travels towards a terminal device (Z_0 = 3150Ω). It is protected by a surge divertor at a distance of 21 m from the device. If the arrestor operates at 140 kV, determine the time at which the divertor operates and the maximum voltage to which the terminal equipment will rise. Derive any equations used. [7 marks]

[END OF QUESTION PAPER]