**University of Moratuwa, Sri Lanka**

B. Sc. Engineering Degree Course

Level 4 – Semester 1 Examination 2008

# EE4020 - INSULATION CO-ORDINATION

Time allowed: 2 hours September 2008

**Additional Material**

Graph paper is available if required
Only authorised Calculators will be permitted

**Instructions to candidates**

This is a closed book examination
This examination accounts for 70% of the module assessment
Paper contains 4 questions in 6 pages, including cover page
Answer **All** Questions
Total marks for the paper is 70 marks
Marks allocated to a question, or each part thereof, are indicated in square brackets at the end of the question or corresponding part.
Clearly state any assumptions made, data assumed or interpretations made in the script

**Technical Information**

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 = $2.998 \times 10^{8}$ m/s

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1. a) 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]

b) Show how the result in 1(a) is made use of in the Bergeron's method of graphical solution for surges in a non-linear system. [3 marks]

c) Figure Q1(c) shows a substation J to which are connected 4 transmission lines AJ, BJ, CJ and DJ.

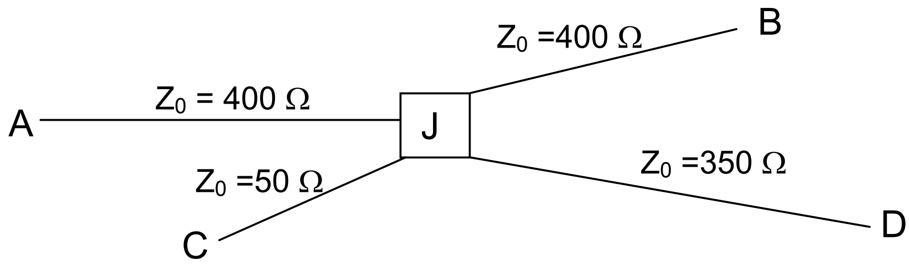


Figure Q1(c)

If a surge of magnitude 200 kV arrives along AJ, determine the surge transmitted to JC and the surge reflected back on JA. [4 marks]

d) Two overhead lines AB ($Z_o$=450 Ω, 120 km) and BC ($Z_o$=550 Ω, 45 km) are connected to a load ($Z_o$=1450 Ω). A triangular wave of vertical front of 100 kV and duration 300 μs originates in the overhead line AB and travels towards the junction B. Draw the Bewley Lattice diagram and obtain the voltage at B for the first 300 μs after the original surge arrives at B. Neglect attenuation. [6 marks]

e) Briefly explain, with appropriate calculations, the use of switching resistors in circuit breakers to reduce switching surges. [2 marks]

f) Derive and show how a lumped inductance may be represented by a short transmission line for transient analysis. [2 marks]

2. a) Describe very briefly with the aid of suitable diagrams the mechanism of the lightning stroke generation. [3 marks]

b) Briefly describe the theory of shielding an overhead transmission line against a direct lightning strike. [4 marks]

c) Briefly describe with the aid of suitable diagrams how the area of attraction of a transmission line can determined. [3 marks]

3. a)

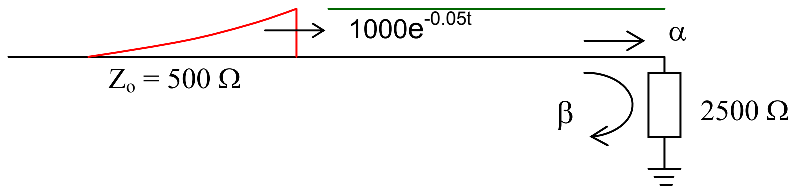


Figure 3(a)

Figure 3(a) shows a transformer ($Z_0$ = 2500 Ω, BIL = 550 kV, insulation margin = 20%) fed from a transmission line ($Z_0$ = 500 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 1000 $e^{-0.05t}$ kV (where t is expressed in μs).

If the corona distortion in the line is represented by the expression $\frac{\Delta t}{x} = \frac{1}{B}\left[1 - \frac{e_0}{e}\right]$ $\mu s/m$

with B = 110 m/μs and $e_0$ = 200 kV, determine the minimum length of shielding wire necessary in order that the transformer insulation will not fail due to lightning surges.

[6 marks]

b) A surge arrester is required to protect a 25 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 950 kV surges arriving on a transmission line ($Z_o$ = 400 Ω). [8 marks]

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

c) Explain very briefly the evaluation of the risk factor with regard to the statistical insulation co-ordination. [4 marks]

d) Describe one form of surge diverter used for protection against lightning. [2 marks]

4. A 200 kV impulse generator is to be designed to generate the IEC standard impulse voltage Waveform (1.2/50 μs). A 25 kV single phase transformer is available. The nominal energy desired for the impulse generator is 1 kJ. With the aid of suitable calculations, determine

   a) Determine the required number of stages for the impulse generator, [1 marks]

   b) Determine the values of the associated elements in the circuit to produce the required waveform. [8 marks]

   c) Draw the basic circuit diagram of the multi-stage impulse generator designed, indicating the values of the wavefront & wavetail control resistors and the charging resistors.

      [3 marks]

   d) Determine the values of the wavefront time, wavetail time and the magnitude of the voltage for the experimental waveforms shown in Figure 4. [5 marks]

   e) Explain the likely reason for the high level of oscillations seen in the wavefront and deduce the probable length of cable connecting the impulse generator with the oscilloscope. [2 marks]

   f) What is the measure that is usually taken to reduce these oscillations. [1 marks]

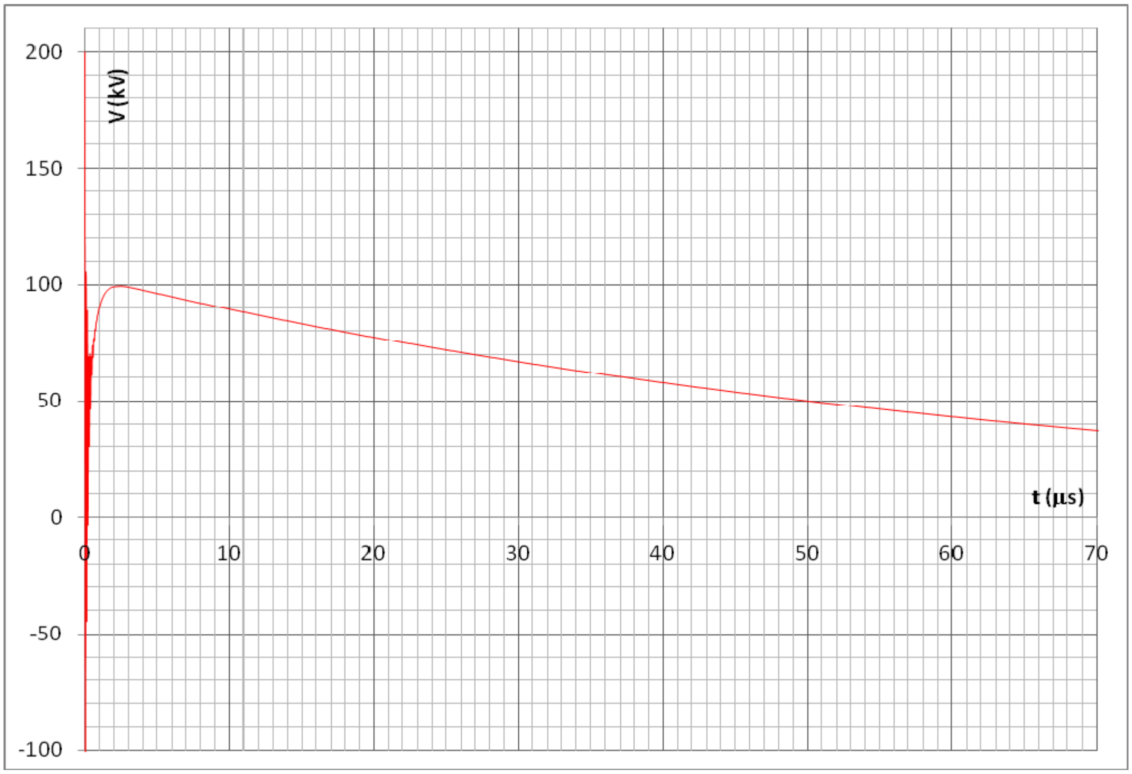


Figure Q4 a – Waveform obtained from the impulse generator

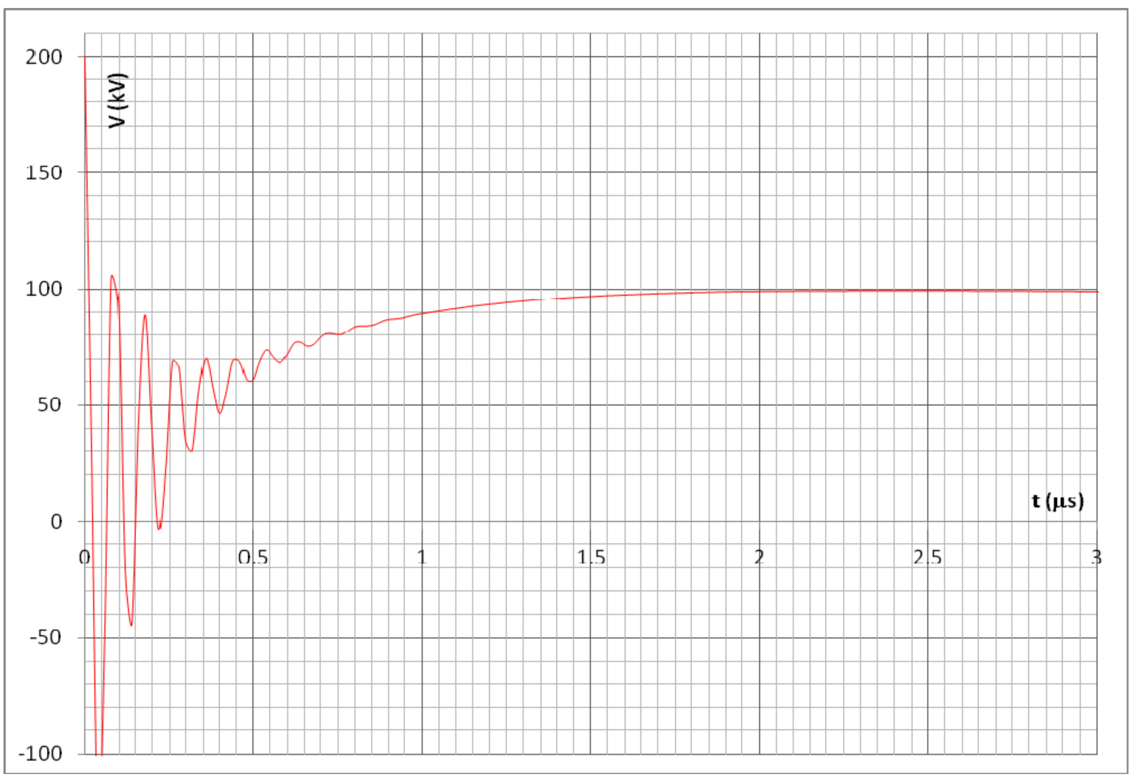


Figure Q4 b – Waveform obtained from the impulse generator for the first 3 μs