University of Moratuwa, Sri Lanka
B. Sc. Engineering Degree Course
Final Part III Examination 1999/00

UEE403 - HIGH VOLTAGE ENGINEERING

0900 - 1200 hrs 22 January 2002

Answer **F I V E** Questions Only.

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

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1 (a) Describe very briefly with the aid of suitable diagrams the streamer mechanism for the breakdown of gaseous dielectrics. [2 marks]

(b) Describe very briefly with the aid of suitable diagrams the time lag characteristic of spark breakdown for a standard impulse waveform. [2 marks]

(c) Describe briefly the breakdown of commercial liquids below their intrinsic strength due to the 3 types of impurities which may be present. [3 marks]

(d) State and explain briefly 4 processes by which solid insulation may breakdown below their intrinsic strength. [4 marks]

(e) Either mineral oil (dielectric constant = 2.25, dielectric strength = 25 kV/mm) or coconut oil (dielectric constant = 3.0, dielectric strength = 25 kV/mm), is to be used as a transformer insulation. Assuming a uniform field gap of spacing 8 mm, determine the maximum applicable voltage in each case. A transformer-board barrier (dielectric constant = 4.5, dielectric strength = 50 kV/mm) of thickness 2 mm is to used in part of the space to prevent alignment of particles. What is the overall breakdown voltage in each case, and which oil has the better property in this regard. [4 marks]

(f) Explain briefly, with the aid of suitable diagrams, why a taller tower would require a smaller shielding angle than a shorter tower, with the same configuration of conductors and earth wire., for a similar degree of protection against lightning. [2 marks]

(g) Assuming the expressions for the basic expressions for inductance and capacitance of a transmission line, shown that the surge impedance of the transmission line is given of the form $Z_o = \frac{60}{\sqrt{\varepsilon_r}} \ln\left(\frac{d}{r}\right)$. State also what the symbols in the equation represent. [4 marks]

(h) Explain briefly, with the aid of suitable diagrams, why a capacitive potential divider connected at the output of an impulse generator needs to be matched to the cable connecting it to an oscilloscope, and how the matching may be achieved. [3 marks]

(i) Explain briefly what is meant by type tests, sample tests and routine tests in high voltage equipment. [2 marks]

(j) Explain very briefly the evaluation of the risk factor with regard to the statistical insulation co-ordination. [2 marks]

2 By deriving from first principles, show that the electric stress in a single core cable is not uniform. [3 marks]

Describe briefly two methods that may be used to distribute the stress more equally. [4 marks]

The insulation of a single phase, 76kV high voltage cable has a critical breakdown stress of 180 kV/cm (peak) and a relative permittivity of 4.0. The supply transformer is centre tapped so that both 76 kV and 38 kV are available. If the conductor radius is 9 mm, determine the radii of the sheath and the intersheath required for optimum dimensions of the cable. Take a safety factor as 2 in the design. [8 marks]

What would have been the overall radius of the cable if the intersheath was absent for the same operating voltage. [3 marks]

3 The simplified equivalent circuit of an impulse generator is shown in figure Q3.

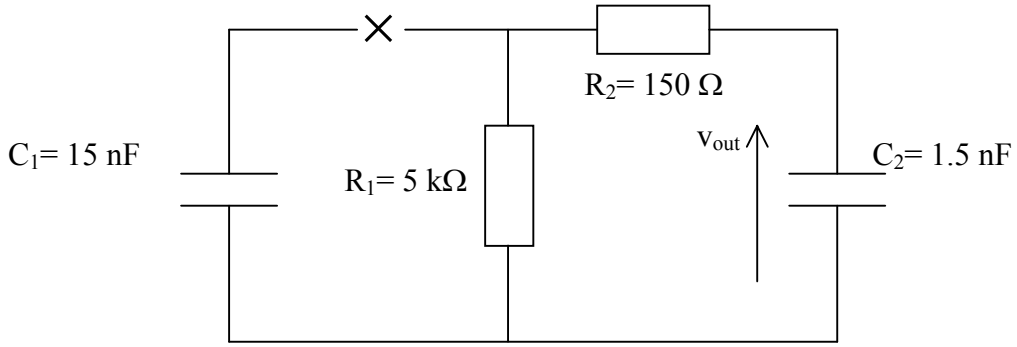

Figure Q3

If the capacitor C_1 is initially charged to 200 kV, determine

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

(b) the output voltage waveform across C_2 [5 marks]

(c) the wavefront time (based on 30% to 90%) and wavetail time [5 marks]

(d) the nominal energy capacity of the impulse generator [2 marks]

State any assumptions made in your derivations.

Sketch the complete circuit diagram of the above impulse generator if it has 6 stages, indicating the values of all the components on it. [3 marks]

Explain very briefly why a trigatron gap is normally used in the first stage of a multi-stage impulse generator. [1 marks]

4 (a) Explain briefly the initiation process in a lightning strike towards the earth [2 marks]

(b) Derive the Townsend's criteria for spark breakdown in a gaseous dielectric. [4 marks]

(c) A transmission line **AB** (surge impedance 450 Ω) is fed at end **A** from a 200 kV constant voltage supply and is connected at end **B** to a non-linear resistor whose V-I characteristic has the expression

$v = i \quad kV \quad \text{for } i \le 240 \text{ A}$

$v = 216 + 0.100\, i \quad kV \text{ for } i \ge 240 \text{ A}$

Determine, using the graphical Bergeron method, the waveform (for 5 transit times of the line) of the voltage at the end **B** when the line is energised at end **A** at time zero. [12 marks]

5 (a) From first principles show that surges in transmission lines can be represented by a combination of forward travelling waves and reverse travelling waves. [4 marks]

(b) A simplified power system consists of three lines AB, BC and BD. The overhead line BC (Z_o = 450 Ω, length =12 km) and cable BD (Z_o = 50 Ω, length = 6 km) are on open circuit at the ends C and D respectively. If a step surge of magnitude 121 kV originates on the overhead line AB (Z_o = 450 Ω) and travels towards B, sketch the voltage waveforms at A & B for the first 100 μs from the inception of the surge at B. 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. [Velocities of propagation in overhead line and cable are 3×10^5 km/s and 2×10^5 km/s respectively. [8 marks]

(c) Two long overhead lines AB and CD (each of surge impedance 350 Ω) are connected through a switching resistor of value 300 Ω. A triangular wave of peak height 100 kV and duration 50 μs originates in the overhead line AB and travels towards the junction B. Determine the magnitudes of the first surges reflected towards A and transmitted towards D. [6 marks]

6 (a) Derive from first principles an expression for the corona distortion as a surge travels alog a transmission line. [6 marks]

(b) A transformer has an impulse insulation level of 1050 kV and is to be operated with an insulation margin of 15% under lightning impulse conditions. The transformer has a surge impedance of 1600 Ω and is connected to a transmission line having a surge impedance of 400 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 $1000\, e^{-0.05\, t}$ kV (where t is expressed in μs).

If the corona distortion in the line is represented by the expression $\frac{\Delta t}{x} = \frac{1}{B}\left[1 - \frac{e_0}{e}\right]$ μs/m, where 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. [12 marks]

7 (a) Draw a schematic diagram of the control of an hvdc system. [2 marks]

(b) Sketch the full voltage current characteristic of the system. [2 marks]

(c) An hvdc link AB operates from 220 kV/120 kV transformers operating on 220 kV, 50 Hz alternating supplies on either side. The converter at end B operates as an inverter on constant extinction angle control ($\delta_o = 12^0$, and 6^0 margin on δ_0 for deionisation). The reactance of each converter transformer can be taken as 15 Ω. If the converter is delivering 80 MW, determine the (i) direct current, (ii) direct voltage, (iii) commutation angle, (iv) power factor, (v) a.c. current on secondary, and (vi) the reactive power requirement of the converter B. [14 marks]