THE OPEN UNIVERSITY OF SRI LANKA
BACHELOR OF TECHNOLOGY
ECX-5238 – High Voltage Engineering and Electrical Machines
Final Examination 2012/2013
Duration: Three Hours

Date: 19th August 2013 Time: 0930-1230

Instructions to candidates: Answer any ***five (05)*** questions. Select at least ***one*** question from section **B**. Graph papers will be available on your request.

Section A: High Voltage Engineering

1. a) Describe very briefly with the aid of suitable sketches, the mechanism of generating lightning stroke. **[2 marks]**

b) Describe with respect to surges originating in an overhead line, the effect of connecting the overhead line to the terminal equipment via a short length of cable. **[2 marks]**

c) In an experiment for determining the breakdown strength of transformer oil, the following observations were made:

Gap Spacing (mm)	4	6	10	12
Voltage at Breakdown (kV)	90	140	210	255

Find the relationship between the breakdown voltage and gap in the form of $V = K d^n$ **[8 marks]**

d) A solid dielectric specimen with dielectric constant of 4.0 as shown in the Figure Q1.d has an internal void of thickness 1 mm. The specimen is 1 cm in thickness and is subjected to a voltage of 80 kV (rms). If the void is filled with air and if the breakdown strength of air can be taken as 30 kV (peak)/cm, find the voltage at which an internal discharge can occur. **[8 marks]**

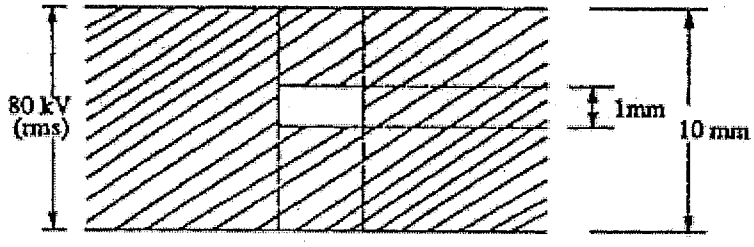


Figure Q1.d

2. a) Explain with diagrams, two types of rectifier circuits for producing high d.c. voltages.

b) Why is a Cockcroft-Walton circuit preferred for voltage multiplier circuits? Explain its working with a schematic diagram.

c) Describe with a neat sketch, the working of a Van de Graaff generator. What are the factors that limit the maximum voltage obtained?

d) Explain the different schemes for cascade connection of transformers for producing very high a.c. voltages.

e) Why is it preferable to use isolating transformers for excitation with cascade transformer units, if the power requirement is large?

f) Describe the use of sphere gaps in high voltage measurements.

g) Derive an expression for the deflecting torque of an electrostatic voltmeter used to measure high voltages.

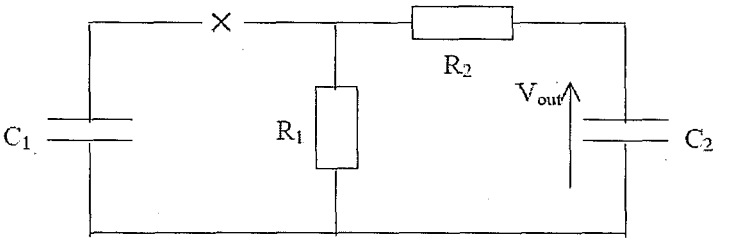
h) Derive an expression for spark breakdown in the Townsend breakdown process, stating any assumptions made. **[8*2.5= 20 marks]**

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

b) A single phase cable for a 3-phase 66 kV system, is to be designed using 3 insulating materials A, B, and C with peak critical breakdown stresses of 180 kV/cm, 200 kV/cm and 250 kV/cm and corresponding relative permittivities of 4.4, 3.2 and 2.8 respectively. If the conductor radius is 10 mm, determine the order and thickness of the insulation for optimum dimensions of the cable. Take safety factor as 2 in the design. **[8 marks]**

c) A surge with a magnitude of 160 kV has a linear rate of rise of 800 kV/μs. It originates in a transmission line with a surge impedance of 450 Ω and travels towards a terminal device ($Z_0 = 2550\Omega$). It is protected by a lightning arrestor at a distance of 20 m from the device. If the arrestor flashover voltage is 210 kV, determine the time at which the arrestor operates and the maximum voltage to which the terminal equipment will rise. [velocity of propagation: overhead line 3 x 10^8 m/s, cable 2 x 10^8 m/s, Permittivity of free space $\varepsilon_o = 8.854 \times 10^{-12}$ F/m] **[10 marks]**

4. a) The simplified equivalent circuit of an impulse generator is shown in Figure Q4a.



$C_1 = 15\ nF,\ C_2 = 1.5\ nF,\ R_1 = 5\ k\Omega,\ R_2 = 150 k\Omega$

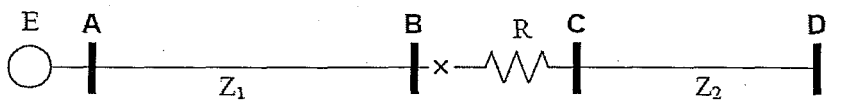
Figure Q4.a

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

(i) The approximate voltage efficiency of the impulse generator **[2 marks]**
(ii) The output voltage waveform across C_2 **[5 marks]**
(iii) The wave-front time (based on 30% to 90%) and wave-tail time **[6 marks]**
(iv) The nominal energy capacity of the impulse generator **[3 marks]**
State any assumptions made in your derivations

b) Sketch the complete circuit diagram of the above impulse generator if it has six stages, indicating the values of all the components on it. **[4 marks]**

5. a) A constant voltage source of magnitude E has energized the line AB initially with the switch at B open. If the switch is closed at time t = 0, determine expressions for the first surges that would set off on BA and CD.



[10 marks]

b) If E = 240 kV, Z_1= 500 Ω, Z_2= 400 Ω, and R = 300 Ω, travel time of CD is 100 μs, D is on open circuit and A is too far from B for reflections to be considered during the period of interest, determine and sketch the voltages at B and C for the first 250 μs after the switch is closed at time t = 0. **[10 marks]**

Section B: Electrical Machines

1. a) A three phase synchronous generator is delivering a power of *0.9 p.u* to an infinite bus at rated voltage and at 0.80 power factor lagging. The generator has $x_d = 1.0$ *p.u.* and $x_q = 0.6$ *p.u.* Calculate the internal EMF and the load angle. **[8 marks]**

b) A certain generator subjected to a sudden 3 phase short circuit at its terminal while on no-load with 11 kV between lines produces short circuit fault current given by the following expression:

$$i = \left(6 + 50\,e^{-2t} + 15\,e^{-50t}\right)Sin\left(\omega t + \theta_0\right) - 40\,e^{-20t}Sin\theta_0 \text{ kA}$$

(i) What is θ_0 in this expression? **[3 marks]**

(ii) What are the values of sub-transient time constant, transient time constant and armature time constant, under short circuit condition? **[3 marks]**

(iii) Determine the values of reactances x_d, x'_d, x''_d and x''_q for the generator **[3 marks]**

(iv) Calculate approximate initial rms fault current **[3 marks]**

2. a) Calculate the basic step angle for the following stepper motors:

(i) 12/8 pole, 3-phase, single stack VR motor **[1 mark]**

(ii) 4/6 pole, 2-phase, PM stepper motor **[1 mark]**

(iii) 4/36 pole, 3-phase, multi stack VR motor **[1 mark]**

(iv) 4/9 pole, 2-phase, PM hybrid motor **[1 mark]**

b) Sketch typical pullout-torque versus stepping-rate characteristics for a stepper motor and give step responses in the modes of multi-step and slewing **[4 marks]**

c) What do you mean by terms start rate and stop rate **[2 marks]**

d) From the phasor diagram of a synchronous machine with constant synchronous reactance X_s operating a constant terminal voltage V_t and constant excitation voltage E_f, show that the locus of the tip of the armature current phasor is a circle. On a phasor diagram with terminal voltage chosen as the reference phasor indicate the position of the center of this circle and its radius. Express the coordinates of the center and the radius of the circle in terms of V_t, E_f, and X_s **[10 marks]**

3. a) The line current of 11 kV, three phase, star connected synchronous motor is 60 A at a power factor of 0.8 leading. The effective resistance and synchronous reactance per phase are respectively 1 Ω and 30 Ω. Find the phase and the line value of the induced emf and also the power input of the motor. **[10 marks]**

b) The load in a factory is 800 kVA at 0.85 power factor lagging and in addition there is a synchronous motor having an input of 200 kW. Determine the input to the synchronous motor in kVA and the power factor at which it must operate, if the power factor of the combined load should be 0.95 lagging. **[10 marks]**