The Open University of Sri Lanka
Bachelor of Technology
ECX 5238 - High Voltage Engineering & Electrical Machines
Final Examination 2011/2012
Duration Three hours

Date: 19/03/2012 **Time: 1400-1700 hrs**

Answer five questions only. Select at least one question from section B. All questions carry equal marks.

Section A

Q1.

The simplified equivalent circuit of an impulse generator is shown in figure Q1, with the capacitor C_1 being initially charged.

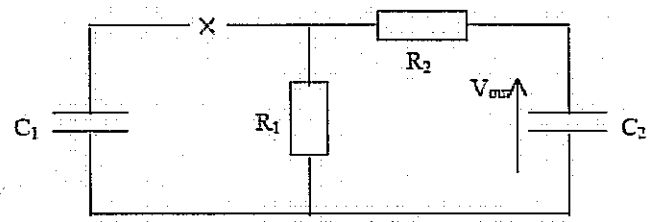

Figure Q1

(a) Derive expressions for the voltage efficiency η, charging time constant τ_c and the discharging time constant τ_d. **[5 Marks]**

(b) Obtain expressions for the wave-front time (based on 30% to 90%) and the wave-tail time in terms of τ_c, τ_d and η. **[5 Marks]**

(c) It is desired to design a 6-stage impulse generator to have an output voltage of 900 kV standard IEC waveform (1.2/50 μs with 90% voltage efficiency), and to have an output energy of 60 kJ. Making reasonable judgments, determine the main components of the multistage impulse generator. **[10 Marks]**

Q2.

(a) i. Describe briefly a resonance method used to control the output of high voltage test transformer. **[4 Marks]**

ii. A 100 kVA, 250 V/200 kV feed transformer has resistance and reactance of 1 % and 5 % respectively. This transformer is used to test a cable at 400 kV at 50 Hz. The cable takes a charging current of 0.5 A at 400 kV. Determine the series inductance required. Assume 1 % resistance of the inductor. Also determine input voltage to the transformer. Neglect dielectric loss of the cable. **[8 Marks]**

(b) Outline with the use of an example, the significance of type tests, sample tests & routine tests on high voltage equipment. **[8 Marks]**

Q3.

(a) Explain clearly how the lightning arrestor is selected for protecting a power transformer. **[5 Marks]**

(b) Show that separation limit of lightning arrestor from protected equipment can be expressed in the form **[5 Marks]**

$$E_t = E_a + \beta\left(\frac{de}{dt}\right) \times \frac{2l}{300} \qquad \textit{Symbols carry their usual meanings}$$

(c) A Lightning arrester with a spark over level of 621 kV is used to protect a transformer (surge impedance 9600Ω) from surges originating in an overhead transmission line (surge impedance 400Ω). If the BIL of the transformer is 825 kV, and the maximum anticipated surge has a peak value of 500 kV with a rate of rise of 600 kV/μs, determine the maximum distance away from the transformer that the arrester could be located, if the protective margin required is 20%. Sketch also the voltage variation at the arrester and at the transformer locations **[10 Marks]**

Q4.

(a) Starting from the travelling wave solution, show how analysis of surges can be done using the Bergeron method of graphical solution. **[3 Marks]**

(b) A transmission line **AB** (surge impedance 400 Ω) is fed at end **A** from a constant voltage supply (100 kV, internal surge impedance 100 Ω) and is connected at end **B** to a non-linear resistor who's V-I characteristic have the expression

$$v = 7000\, i\ kV \qquad \textit{for } v < 140\ kV$$
$$v = 140\ kV \qquad \textit{for } i \geq 20\ A$$

If the line is energized at end **A** at time zero, Calculate & sketch the waveforms of voltage at A & B for the first 5 transits of the line using the graphical Bergeron method. Also sketch the waveforms of current at A & B. **[7 Marks]**

(c) An overhead line AB (length 60 km, surge impedance 500 Ω, attenuation factor for a single transit 0.95) is fed from a source of negligible internal impedance. A cable BC (length 20 km, surge impedance 50 Ω, attenuation factor for a single transit 0.9) connects the line to a 950 Ω resistive load. Determine using the Bewley lattice diagram, the voltage waveforms appearing at B & C for the 700 μs after a triangular voltage surge (vertical front, 200 kV peak decaying to zero in 400 μs) originates at the source. **[10 Marks]**

Q5.

(a) Describe briefly two methods that are used to distribute the electric stress more equally in a single core cable. **[8 Marks]**

(b) A high voltage cable is to be made with a conductor of radius 20 mm with the outermost diameter being 120 mm. Three materials A, B and C are available for insulation.

Material	ξ max (kV/cm)	ε_r
A	110	2.4
B	95	3.8
C	130	1.6

Determine the optimum thickness of the materials and the order in which they should be laid, to obtain the maximum operating voltage for the cable. If a safety factor of 1.5 is to be used, what is the value of this maximum voltage? **[12 Marks]**

Q6.

(a) Draw a schematic diagram of an HVDC control system. Sketch the full voltage current characteristic of the same. **[8 Marks]**

(b) An HVDC link AB, operates from 220 kV/120 kV transformers operating on 220 kV, 50 Hz alternating supplies. The converter at end B operates as an inverter on constant extinction angle control ($\delta^o = 10^0$, and 5^0 margin on δ^o for deionization). The reactance of each converter transformer can be taken as 15 Ω. If the converter is delivering 80 MW,

Determine:

(1) The direct current, **[2 Marks]**

(2) The direct voltage, **[2 Marks]**

(3) The commutation angle, **[3 Marks]**

(4) Power factor, **[3 Marks]**

(5) A.C. current on secondary, **[2 Marks]**

Section B

Q7.

(a). Sketch phasor diagram for a 3-phase, salient pole rotor, synchronous generator. Show that real power output is given by

$$P = \frac{3EV_t}{x_d}\sin\delta + 3V_t^2\left[\frac{x_d - x_q}{2x_d x_q}\right]\sin 2\delta$$

The symbols carry usual meanings. Derive a similar expression for the reactive power output. **[10 Marks]**

(b) A salient pole synchronous generator is having direct-axis and quadrature-axis synchronous reactances of 1.5 p.u. and 1.0 p.u. respectively. The generator delivers 0.85 p.u. of real power at 0.85 power factor lagging at rated voltage. Calculate the load angle and internal emf. **[10 Marks]**

Q8

(a) Using sketches, describe the construction of the following types of stepper motors.

(1) 6/4 pole, 3-phase single stack VR motor **[4 Marks]**
(2) 36 teeth/phase, 2-phase multi stack VR motor **[4 Marks]**
(3) 4/9 pole, 2-phase PM hybrid motor **[4 Marks]**

Give the basic step angle for each motor.

(b) A 3-phase single stack VR stepper motor has approximately sinusoidal static-torque angle characteristic of peak value 1.8 per Ampere.

(i) Sketch anti-torque angle curves for the three phases in the same diagram showing appropriate numerical values. **[4 Marks]**

(ii) What is the pullout torque in slewing mode for basic stepping operation with 1 A phase current? **[4 Marks]**