The Open University of Sri Lanka
Bachelor of Technology
ECX 5238 - Electrical Machines & High Voltage Engineering
Final Examination 2008/2009

057

Duration Three hours

Date: 5^{th} April 2009 Time: 0930-1230

Answer five questions only. Select at least one question from section B.

Section A

Q1. (a) From first principles obtain expressions for
- (i) the velocity of propagation
- (ii) the surge impedance
- (iii) the energy stored in a surge, in transmission lines in terms of the inductance and the capacitance per unit length.

(b) A long overhead line **L1** (surge impedance = 550 Ω) is connected to another overhead line **L2** (surge impedance = 400 Ω, length = 3 km) through a cable **C** (surge impedance = 50 Ω, length = 1 km). The line **L2** is terminated in a 2000 Ω resistive load. If a step surge of vertical front 200 kV is initiated in line **L1** and travels towards the cable, determine using the Bewley lattice diagram and sketch the voltage waveform appearing at the load for the first 21 μs after the surge arrives at the load. *(velocity of propagation: overhead line 3×10^8 m/s, cable 2×10^8 m/s)[attenuation negligible]*

Q2. (a) Describe briefly two methods that may be used to distribute the stress more equally in high voltage cable insulation.

(b) A single phase cable for a 3-phase 76 kV system, is to be designed using 3 insulating materials A, B and C with peak critical breakdown stresses of 200 kV/cm, 190 kV/cm and 240 kV/cm and corresponding relative permittivities of 4.0, 3.2 and 2.9 respectively. If the conductor radius is 10 mm, determine the order and thickness of the insulation for optimum dimensions of the cable. Take a safety factor as 2 in the design.

(c) The insulation of a single phase, 66 kV high voltage cable has a critical breakdown stress of 160 kV/cm (peak) and a relative permittivity of 4.0. The supply transformer is centre tapped so that both 66 kV and 33 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.

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

Q3. (a) (i) Describe the use of resonance in the generation of high alternating voltage for testing purposes. Why is this method not suitable for power transmission?

(ii) A 100 kVA, 50 Hz, 230/50 kV testing transformer has an 8% leakage reactance and a 2% winding resistance. A cable of capacitance 15 nF is to be tested at 250 kV using this transformer as part of the resonance circuit. Determine the value of the inductance (Q-factor= 20) required to obtain resonance and the value of the input voltage required.

(b) A step surge of magnitude 100 kV reaches the terminal of a transformer which has a uniformly distributed capacitance to earth of the complete winding of 4 nF and a capacitance of the winding from end to end of 160 pF also uniformly distributed. If the neutral of the transformer can be considered solidly grounded, derive an expression and sketch the initial voltage distribution in the winding. The effective length of the winding is 1 m. Sketch also the probable envelope of the subsequent oscillations.

Q4. The simplified equivalent circuit of an impulse generator is shown in figure Q4, with the capacitor C1 being initially charged.

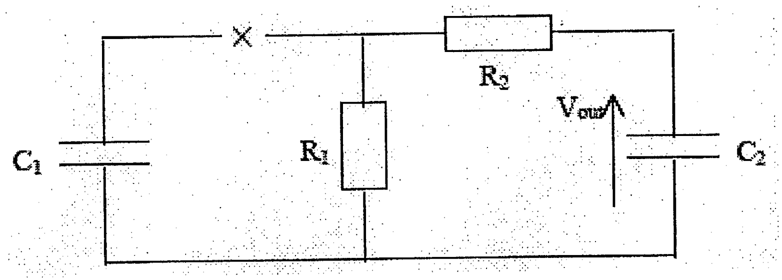

Figure Q4

(a) Derive **approximate expressions** for the voltage efficiency η of the impulse generator, and the charging time constant τ_c and the discharging time constant τ_d.

(b) Obtain also expressions for the wave front time (based on 30% to 90%) and the wavetail time in terms of τ_c, τ_d and η.

(c) It is desired to design a 6-stage impulse generator to have an output voltage of 1000 kV of standard IEC waveform (1.2/50 μs with 90% voltage efficiency), and to have an output energy of 50 kJ. Making reasonable judgments, determine the main components of the multistage impulse generator.

(d) Draw the complete circuit indicating values for each component.

Q5.

(a) Briefly explain the statistical method of insulation co-ordination with the aid of suitable diagrams.

(b) With the aid of suitable diagrams, show that wave tail distortion due to corona in an overhead line can be expressed in the form $\frac{\Delta t}{x} = K\left[1 - \frac{e_0}{e}\right]$

(c) A 500 kV steep fronted wave (rate of rise 1000 kV/μs) reaches a transformer of surge impedance 1600 Ω through a line of surge impedance 400 Ω and protected by a lightning arrestor with a protective spark-over level of 650 kV, 90 m from the transformer.

(i) Sketch the voltage waveforms at the arrestor location

(ii) Sketch the voltage at the transformer location.

(iii) Determine the time at which the arrestor operates.

(iv) Determine the maximum voltage to which the terminal equipment will rise.

Q6.

(a) For a hexa-phase bridge converter with ignition angle α, sketch the typical waveforms of

(i) voltage across a thyristor

(ii) the output dc voltage

(iii) input line current on the ac system

(Assume no commutation)

(b) Sketch the typical waveforms of the dc voltage (before smoothing), when operating as an inverter with commutation angle γ and extinction angle δ.

(c) An HVDC link AB operates from 220 kV/110 kV transformers operating on 220 kV, 50 Hz alternating supplies. The converter at end B operates as an inverter on constant extinction angle control ($\delta_0 = 8°$ with 5° margin on δ_0 for de-ionisation). The reactance of each converter transformer is 14 Ω. If the converter delivers 80 MW, determine the followings

(i) direct current

(ii) direct voltage

(iii) commutation angle

(iv) power factor

(v) The reactive power requirement of the converter B.

(A brief derivation of equations used is required.)

Section B

Q7.

(a) (i) Give sketches to show the construction of a 12/8 pole, three phase variable reluctance stepper motor. What is the basic step angle of this motor?

(ii) Indicate the switching pattern for normal stepping and half stepping operations?

(iii) Explain briefly why the speed response of a stepper motor is always oscillatory.

(b) Give a block diagram structures of a closed loop 3-phase induction motor drive that use current limit control and slip regulation control. Describe briefly the operation of each.

(i) A 50 Hz, 4 pole, 3 phase induction motor runs at 1460 rpm at rated condition. Its pull out speed is 1350 rpm. Determine the range of speed of constant horse power mode of closed loop control?

Q8.

(a) Explain briefly why the synchronous generators tend to produce very large initial fault current following a sudden 3-phase short circuit fault at the terminals.

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

$$i = \left(5 + 20e^{-2t} + 15e^{-50t}\right) Sin(\omega t + \theta_0) - 40e^{-20t} Sin\,\theta_0 \quad kA$$

(i) What is θ_0 in this expression?

(ii) What are the values of sub transient time constant, transient time constant and armature time constant under short circuit condition?

(iii) Determine the values of reactance's x_d, x_d', x_d'' and x_q'' for the generator?

(iv) Calculate approximate initial rms fault current.

(c) A 3-phase, 100 MVA, 11 kV, salient pole synchronous generator has direct axis synchronous reactance 1.7 pu and quadrature axis synchronous reactance 1.0 pu. The generator delivers 75 MVA at 0.95 p.f over excited at rated voltage to an infinite bus. Calculate the internal voltage and the load angle.