UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 8 Examination in Engineering: November 2016

Module Number: EE8301 **Module Name: High Voltage Engineering**

[Three Hours]

[Answer all questions, each question carries 12 marks]

Q1. a) Explain what is meant by coronal mass ejection and its effects on high voltage power system.

b) Describe the advantage of connecting an overhead line to substation equipment through a short cable.

c) Explain the needs of developing an alternative to SF_6 which is abundantly used in high voltage switchgear as an insulation gas. Build your arguments based on environmental issues.

d) Compare high voltage oil filled transformers with dry transformers.

e) Explain the circumstances under which FACTS have gained importance.

[5 × 2.4 Marks]

Q2. a) Two electrode plates which are separated by a distance d are introduced in to a gas sample and connected to a variable voltage source. Show that current growth at the anode can be expressed as

$$I_d = I_0 e^{\alpha d}$$

where I_0 is the current at cathode and I_d is the current at anode. Define the first coefficient of ionization of gases α. Explain the main assumption you make.

[4.2 Marks]

b) Show that the current growth equation can be modified to

$$I_d = \frac{I_0 e^{\alpha d}}{[1 - \gamma(e^{\alpha d} - 1)]}$$

when the assumption made in part (a) is taken in to account in the analysis. Define γ and state the Townsend's criterion for spark breakdown.

[4.2 Marks]

c) The measurements taken in a certain Townsend type discharge is given in Table Q2 where x is the distance from one plate and I is the current measured at x distance. Determine the Townsend's first and second ionization coefficients.

Table Q2

x (mm)	4	6	8	10	12	14	16	18	20	22
I (pA)	25	35	45	60	80	120	180	300	550	2000

[3.6 Marks]

Q3. a) A transient waveform travelling along a high voltage transmission line with line inductance L and line capacitance C has $i^{+}(s)$ forward current and $i^{-}(s)$ reverse current. Assume that line resistance is negligible. Using the first principles in s-domain, prove that the forward voltage wave is given by,

$$e^{+}(s) = Z_0 i^{+}(s)$$

and the revere voltage wave is given by,

$$e^{-}(s) = -Z_0 i^{-}(s)$$

where $Z_0 = \sqrt{\frac{L}{C}}$

[6.0 Marks]

b) The AB transmission line is 20 km long. It has a capacitance of 0.025 μF/km and inductance of 1 mH/km. This line ends up with a resistor at end B. A transient surge of steep wave front and very long wave tail with magnitude of 10 p.u. enters into the line from end A. Assume that the power system beyond the end A has very low surge impedance. It is observed that the voltage at end B just after 0.1 ms, and 0.3 ms are 14.4 p.u. and 7.4016 p.u. respectively. Calculate the value of resistance connected at end B and attenuation factor of the transmission line.

[6.0 Marks]

Q4. a) Discuss how the electrical analogy of thermal circuits can be useful in solving a cable heat dissipation problem.

[3.0 Marks]

b) Show that the power loss in a cable, when it is a part of group of cable can be expressed as

$$P_{Loss} = I^2\left(R_c + 7.7\times10^{-3}\frac{1}{R_{sh}}\left[\frac{r_m}{d}\right]^2 + \frac{\omega^2 {M_{sh}}^2}{R_{sh}}\right)$$

Where, I - current in the conductor, R_c - the resistance of the core, r_m - mean radius of sheath, d – Distance between cables (centre to centre), R_{sh} – resistance of full length of cable, ω - angular power frequency and M_{sh} - mutual inductance between a core of one cable and the sheath of an adjacent cable. Ignore the dielectric loss.

[3.6 Marks]

c) The cross section of the buried cable mentioned in part (b) is shown in Figure Q4. Temperatures (θ) at various points and thermal resistances (R) of various layers are as marked in the figure. Just a short while after the circuit breaker has been closed insulator temperature θ_2 is measured at the midpoint of the insulator. Take the insulator as T network in your electrical model. W_d, W_c, W_s are dielectric, core and sheath losses respectively. Cable has been kept denergised for a long period of time before energisation. Derive the following expression and explain how this expression can be used for determining cable ampacity.

$$W_c + W_d + W_s + \frac{\theta_1 - \theta_2}{R_1} = \frac{\theta_4 - \theta_5}{R_5} + C_1\frac{d\theta_1}{dt} + C_2\frac{d\theta_2}{dt} + C_3\frac{d\theta_3}{dt} + C_4\frac{d\theta_4}{dt}$$

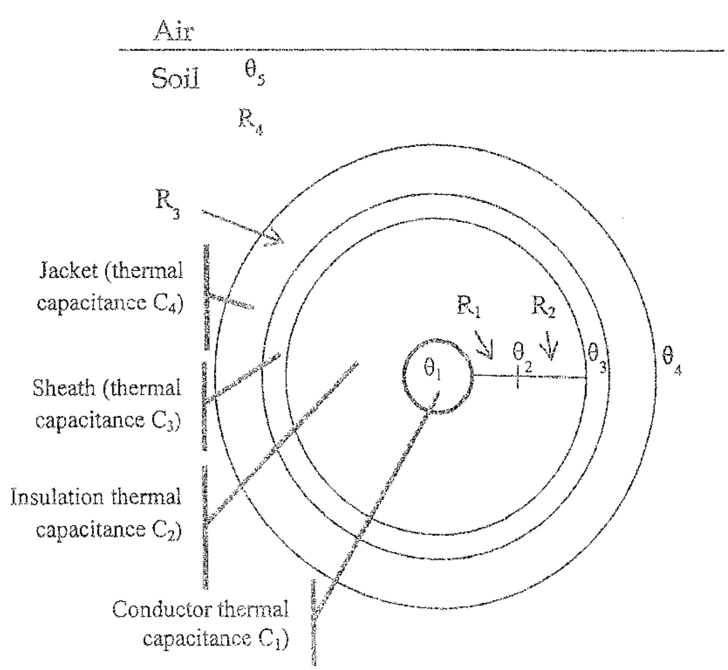

Figure Q4

[5.4 Marks]

Q5. a) Explain the practical existence of chopped surge waveforms and how we can generate them for high voltage testing purposes.

[3.0 Marks]

b) The circuit shown in Figure Q5 is commonly used in high voltage laboratories to generate surge voltage. Derive an expression for $e(t)$.

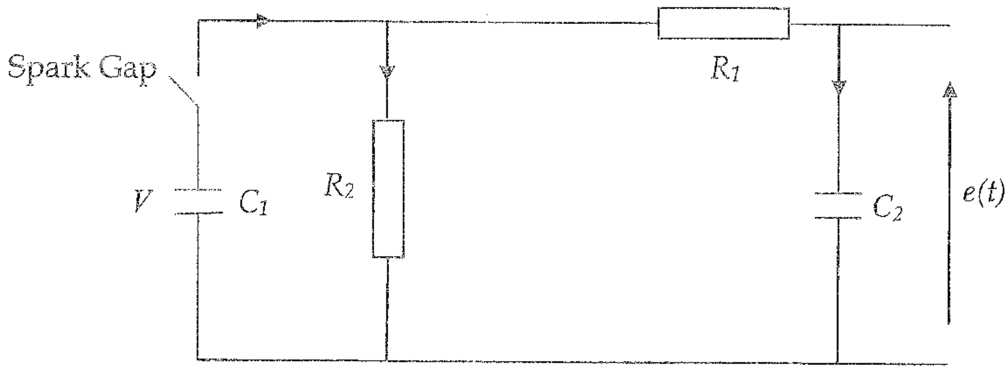

Figure Q5

[6.0 Marks]

c) Explain the philosophy behind the selecting C_1, C_2, R_1, R_2 and show that with general notations under certain assumptions one can reach

$$\alpha = \frac{1}{R_2(C_1 + C_2)} \quad \text{and} \quad \beta = \frac{(C_1 + C_2)}{R_1 C_1 C_2}$$

State your assumptions.

[3.0 Marks]