			EXAMS OFFICE USE ONLY

University of the Witwatersrand, Johannesburg

Course or topic No(s)	ELEN4003
Course or topic name(s) Paper Number & Title	HIGH VOLTAGE ENGINEERING
Examination to be held during month(s) of	JUNE 2016
Year of Study (Art & Science leave blank)	FOURTH
Degrees/Diplomas for which this course is prescribed (Bsc (Eng.) should indicate which branch)	BSc(Eng)(Electrical)
Faculty/ies presenting candidates	ENGINEERING & THE BUILT ENVIRONMENT
Internal examiner(s) and telephone extension number(s)	Prof. CUTHBERT NYAMUPANGEDENGU Ext. 77213
External examiner(s)	MR. THAVENESEN GOVENDER
Special materials required (graph/ music/ drawing paper/ maps/ diagrams/ tables/ computer cards, etc)	Paschen's curve for air (kV vs bar.mm)

Time allowance

Course no.	ELEN4003	**Hours**	THREE

Instructions to candidates

Answer only FIVE (5) out of a total of seven (7)
All symbols and equations as defined in the course
Show all working
Crib sheet and calculator allowed

Question 1

In a stator slot of a rotating machine, a 1 mm thick air cavity exists between the interface of the epoxy and mica insulation layers as shown in Figure 1. Assuming atmospheric air pressure of 1 bar and uniform electric field in the cavity;

i) Calculate the RMS voltage across the slot that would cause PD inception in the air-filled cavity.

(10 marks)

ii) Calculate the electric fields in the epoxy and mica insulation layers adjacent to the cavity and then sketch the electric field profile across the slot.

(**10 marks**)

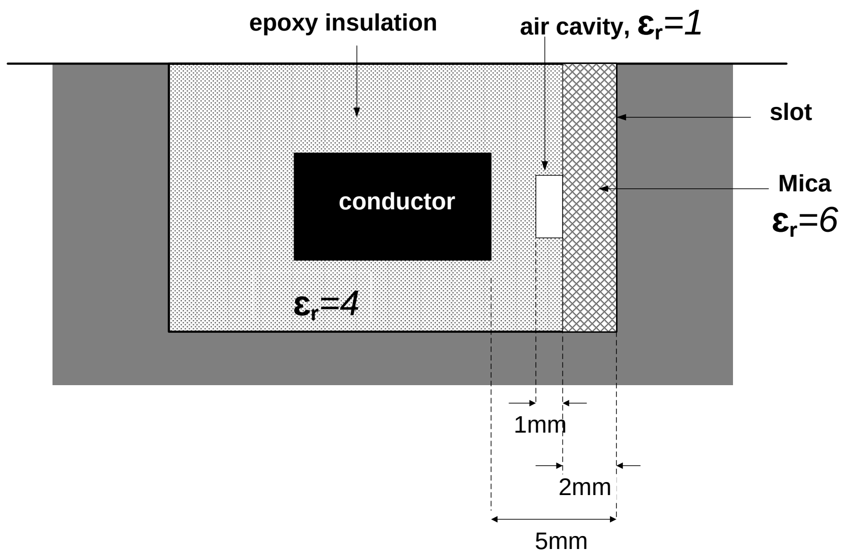


Figure 1: A single turn coil in a stator slot

Hint: In a multi-layered dielectric system the electric field in layer k is given by:

$E_k = \frac{V}{\frac{\varepsilon_k}{\varepsilon_1}d_1 + \frac{\varepsilon_k}{\varepsilon_2}d_2 + \cdots}$. All symbols have their usual meanings.

(Total 20 marks)

Question 2

(a) It is desired to determine the Townsend's first ionisation coefficient, α, of a certain gas. Using a uniform field electrode setup in a controlled pressure chamber, at voltage of 10 kV a steady state current of 20 μA is measured when the gap is set at 1.5 mm. If the gap is reduced to 1 mm and the voltage adjusted to maintain the same electric field strength in the gap, a current of 10 μA is measured;

i) Calculate the Townsend's first ionisation coefficient, α.

(8 marks)

ii) If at the gap of 1 mm the voltage is further increased until breakdown, give the condition for breakdown and calculate Townsend's secondary ionisation coefficient, ϒ.

(4 marks)

(b) In designing a 765 kV_{rms} SF_6 GIS duct, and due to space limitations, the radius R in Figure 2 is limited to 200 mm. Determine the corresponding optimal value of the busbar radius r and corresponding maximum electric field in the duct.

The formula for the electric field (E) inside a coaxial electrode setup; $E = \frac{V}{x.ln\left(\frac{R}{r}\right)}$ may be used without proof where all symbols have the usual meaning.

(8 marks)

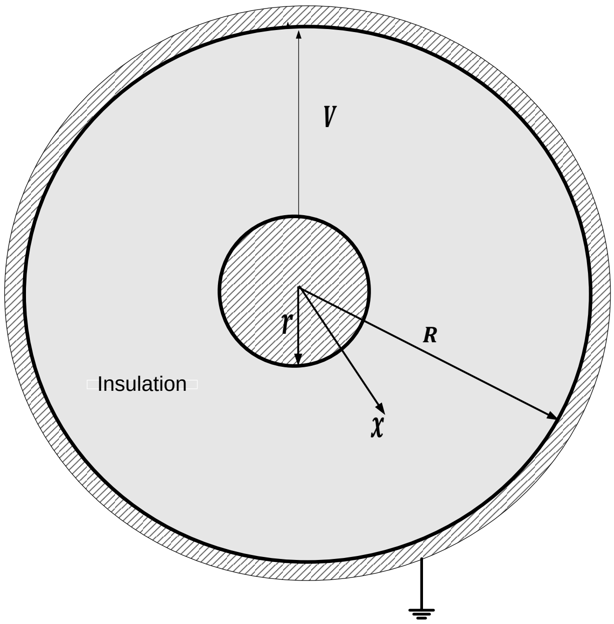


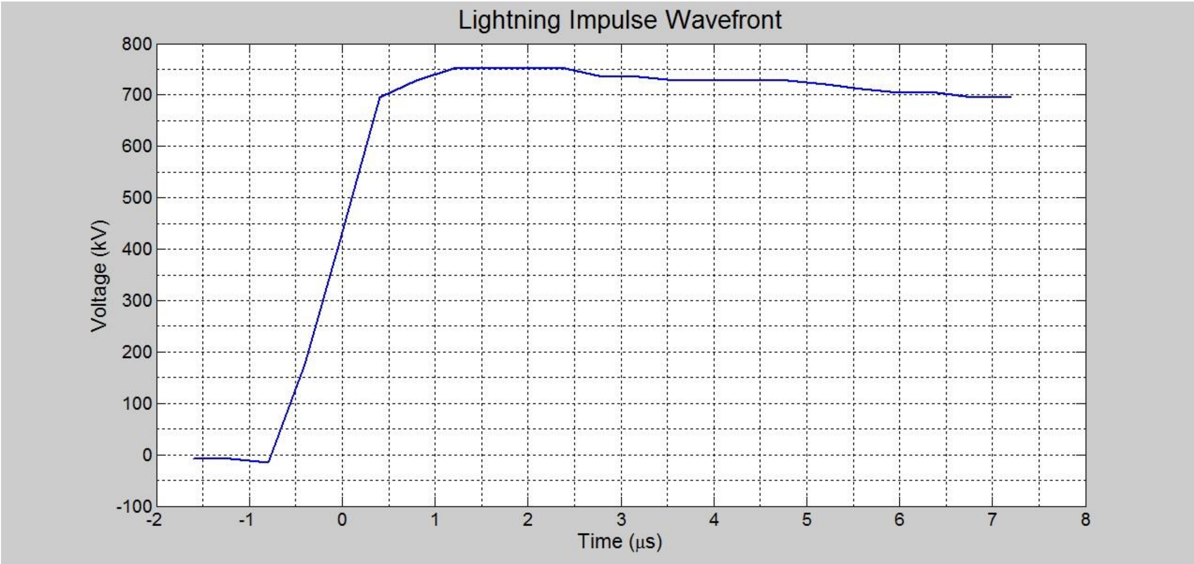
Figure 2: Cross-section of the GIS duct.

(Total: 20 marks)

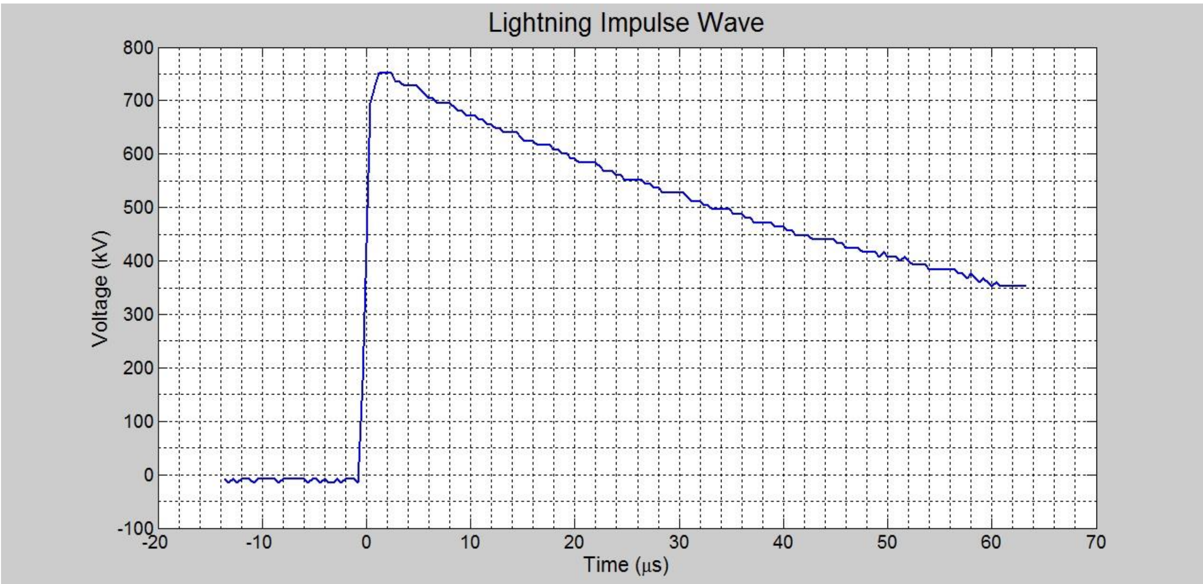
Question 3

(a) A test engineer is setting up a Marx impulse generator for lightning voltage withstand tests on line insulators in accordance with the IEC 60060-1 standard. The insulators are designed to withstand 765 kV peak lightning impulse voltage. The impulse generator gives an impulse wave as shown in Figure 3. Determine whether this impulse is a standard lightning impulse voltage.

(7 marks)



(a)



(b)

Figure 3: The measured impulse voltage; (a) is the front and (b) is the full wave.

(b) A 50 kA, 5/50 µs lightning impulse current terminates directly onto the tip of a metallic tower on a 400 kV overhead power transmission line. The tower equivalent inductance, resistance, and tower footing resistance are respectively; 100 µH, 5 Ω and 20 Ω. Using suitable sketches and equivalent circuit, calculate the maximum voltage that may build up on the tower and explain possible consequences. Also discuss possible techniques to avoid problems.

(13 marks)

(Total: 20 marks)

Question 4

A sphere-sphere electrode setup is shown in Figure 4 with d=200 mm and R=100 mm. If the insulation is air at standard atmospheric pressure;

(i) Using an iterative or any other suitable method, determine whether a positive DC voltage of 450 kV will cause breakdown between the two electrodes.

(14 marks)

(ii) If the actual tests are conducted to verify the predicted breakdown voltage, what factors may contribute to differences that may occur between the predicted and the actual breakdown voltage?

(6 marks)

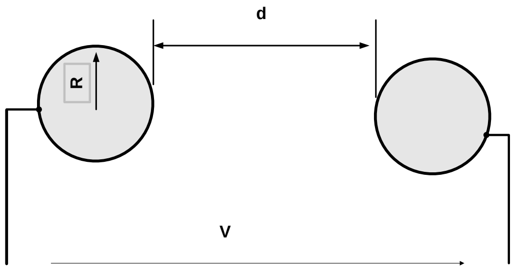


Figure 4: The sphere-sphere electrode setup.

Note: If necessary the following equation for the electric field between sphere-sphere electrodes may be used without proof where all symbols have the usual meaning.

$$E_x = \frac{VR(R+d)}{2d}\left[\frac{1}{(R+x)^2} + \frac{1}{(R+d-x)^2}\right]$$

The streamer criterion may be taken as:

$$\int(\alpha)dx = K = 18 \text{ or } K = \sum_{i=0}^{i=n} K_i$$

For air, $K = 1.6x_i[E_i - 2.2P]^2 - 0.3Px_i$; where the symbols have their usual meanings.

(Total: 20 marks)

Question 5

(a) Explain with the aid of a clearly labelled diagram how in the conventional partial detection setup (IEC60270), a discharge occurring in an air-filled cavity in the test object results in a PD current following in the detection impedance which becomes the measured PD signal.

(10 marks)

(b) Explain the electrothermal failure mechanism in solid insulation.

(5 marks)

(c) Using the equation of the force on a floating particle in liquid insulation as given below, explain how suspended particles in insulation would behave if the applied voltage were changed from DC to AC.

$F = \varepsilon_{oil} r^3 \left(\frac{\varepsilon - \varepsilon_{oil}}{\varepsilon + 2\varepsilon_{oil}}\right) E \frac{dE}{dx}$. All symbols have the usual meaning.

(5 marks)

(Total: 20 marks)

Question 6

a) Explain the advantages and disadvantages of a power frequency cascaded transformer set used as a HVAC voltage source.

(5 marks)

b) You are required to specify a test source for the testing of a 2 km length of buried power cable which operates at 66 kV_{rms}. The cable has a total capacitance of approximately 5 μF. What test source do you recommend? Determine the main parameters of the source and state what advantages it has over competing systems. If necessary it can be assumed that a reactor can be wound with a ratio of inductive reactance to resistance (i.e. quality factor) of 40 at 50 Hz.

(15 marks)

(Total: 20 marks)

Question 7

(a) You are tasked with designing a single stage impulse voltage generator in the high voltage laboratory. You are supplied with 3 x 12,5 nF, 50 kV capacitors. You decide to connect in series the two identical capacitors and use the remaining as the load capacitance. If you know that for a 1.2/50 μs wave, the rise time is 2.96 of the front time constant and the fall time is 0.73 of the fall time constant.

(i) Sketch the single stage voltage impulse generator and explain how the impulse voltage is generated.

(4 marks)

(ii) Calculate the values of the required front resistor (R_f) and the tail resistor (R_t).

(6 marks)

(b) Show with an equivalent circuit how voltage escalation is achieved in a 3-stage impulse voltage generator. Explain the function of each component.

(10 marks)

(Total: 20 marks)

Paschen’s curve for air (kV vs bar.mm)