			EXAMS OFFICE USE ONLY

University of the Witwatersrand, Johannesburg

Course or topic No(s)	ELEN4003 and ELEN5002A
Course or topic name(s) Paper Number & Title	HIGH VOLTAGE ENGINEERING
Examination to be held during month(s) of	JUNE 2017
Year of Study (Art & Science leave blank)	FOURTH for ELEN4003
Degrees/Diplomas for which this course is prescribed (Bsc (Eng.) should indicate which branch)	BSc (Eng) (Electrical)/PGDip (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, e.t.c)	Paschen's curve for air (kV vs bar.mm)

Time allowance

Course no.	ELEN4003 and ELEN5002A	**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

a) It is desired to determine the Townsend first ionisation coefficient α of a certain gas. Using a uniform field electrode setup in a controlled pressure chamber, at a voltage of 10 kV, a steady state charge transfer rate of 600 μC per second is measured when the gap is set at 3 mm. If the gap is reduced to 1 mm and the voltage adjusted to maintain the same electric field strength as in the initial gap, a charge flow rate of 100 μC per second is measured.

i) Assuming negligible attachment coefficient in the gap, calculate the Townsend first ionisation coefficient, α for the gas.

(10 marks)

ii) If for the gap of 1 mm the air gap pressure is changed from 1 bar to 3 bar and the voltage increased to cause spark-over, determine the spark-over voltage in each case and explain the difference.

(4 marks)

b) In order to protect the terminal equipment connected to an 11 kV distribution line against conducted lightning surges, it is decided to use arcing horns (which may be considered to be a rod-rod gap) positioned across the bushing connected to the terminal equipment as illustrated in Figure 1.1. Using a sketch, and assuming a probable V-t curve, show on the same axes the relative location of the V-t curves for the protective arcing horns (rod-rod gap) and the bushing. Explain your answer and how V-t curves are used in insulation coordination in general.

(6 marks)

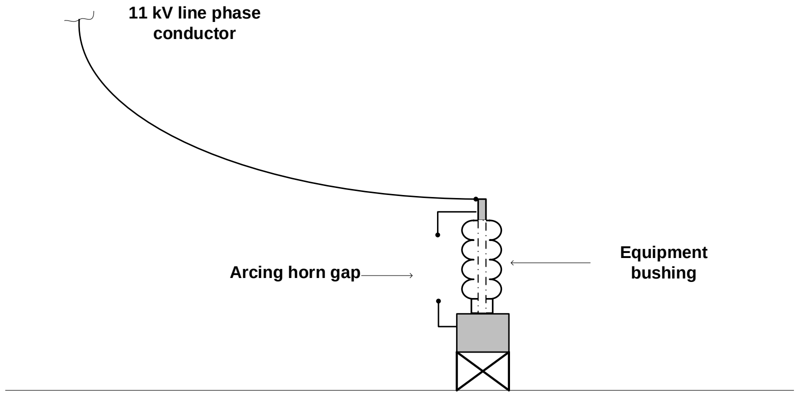

Figure 1.1: 11 kV distribution line terminal equipment surge protection

(Total 20 marks)

Question 2

A 500 kV DC co-axial busbar system has an inner conductor radius of 15 mm and an outer conductor inner radius of 115 mm. The space between the electrodes is filled up with SF_6 (relative permittivity 1). A 5 mm thick solid particle of relative permittivity 800, levitates at a height of 5 mm above the surface of the inner electrode as illustrated in Figure 2.1.

a) Calculate the maximum and minimum electric fields strength in the insulation gap without the particle.

(4 marks)

b) In the presence of the floating particle, calculate the maximum electric field strengths in the resultant three insulation gaps i.e. between the particle and inner electrode, in the particle and in the gap between the particle and inner surface of the outer electrode.

(12 marks)

c) On the same axes, sketch well labelled electric field profiles in the insulation gap with and without the floating particle.

(4 marks)

The formula for the electric field (E) inside a coaxial electrode setup; $E = \frac{V}{x ln\left(\frac{R}{r}\right)}$

The electric field E_k at a radial distance x_k in layer k of a multi-layered dielectric in a coaxial electrode setup can be expressed as below:

$$E_k = \frac{V}{x_k \left\{\frac{\varepsilon_k}{\varepsilon_1} ln\left(\frac{r_2}{r_1}\right) + \frac{\varepsilon_k}{\varepsilon_2} ln\left(\frac{r_3}{r_2}\right) + \cdots\right\}}$$

All symbols have the usual meaning.

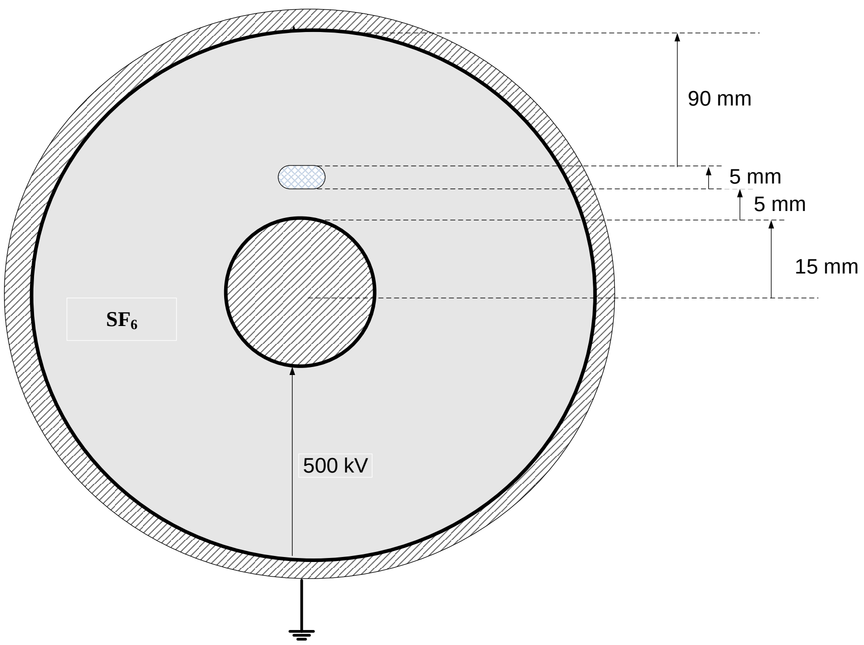

Figure 2.1: Cross-section of the GIS duct.

(Total: 20 marks)

Question 3

(a) The breakdown voltage of an air gap under an impulse voltage is a statistical phenomenon, explain why?

(5 marks)

(b) An up-down U_{50} test procedure was conducted on a restorative insulation gap. The data in Figure 3.1 was obtained.

i) Calculate the first estimate U_{50}^{*} for the data.

(3 marks)

ii) Calculate the more accurate U_{50} for the data.

(12 marks)

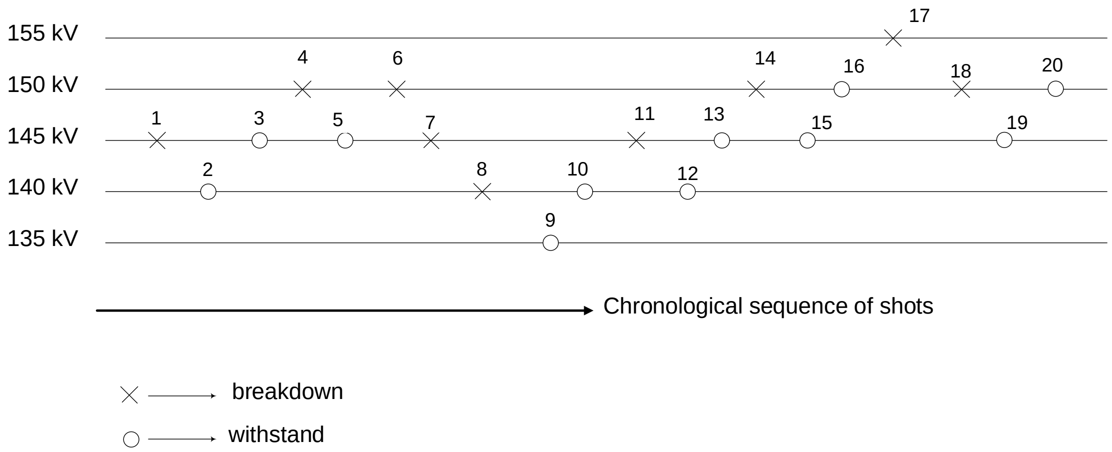

Figure 3.1: U_{50} up-down test data

(Total: 20 marks)

Question 4

a) An air insulated co-axial duct has a core radius of 50 mm and outer conductor inner radius of 150 mm.
Assuming standard atmospheric pressure of 1 bar, use the iterative method (the equations below can be used) or any other suitable method, to determine whether or not a voltage of 225 kV will likely cause a breakdown through the streamer mechanisms.

(14 marks)

b) Discuss why SF_6 is a popular insulation medium for compact GIS and also why currently there are efforts to develop alternative insulation gases.

(6 marks)

The electric field (E) inside a coaxial electrode setup is given by,

$$E_x = \frac{V}{x \ln\left(\frac{R}{r}\right)}$$

The streamer criterion may be taken as:

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

For air,

$$K_i = 1.6X[E_i - 2.2P]^2 - 0.3PX$$

All symbols in the equations have the usual meanings.

(Total: 20 marks)

Question 5

(a) In oil-insulated high voltage equipment, air bubbles are observed drifting away from the regions of enhanced electric field while water droplets behave in the opposite.

i) Using the equation below, explain the phenomenon and how the contaminants may lead to complete insulation breakdown.

ii) Explain why the phenomenon is independent of voltage polarity.

(8 marks)

$$F = \varepsilon_{oil} r^3 \left(\frac{\varepsilon - \varepsilon_{oil}}{\varepsilon + 2\varepsilon_{oil}}\right) E \frac{dE}{dx}$$

All symbols have the usual meaning.

(b) A 10 kA, 8/20 µs lightning current impulse terminates directly onto a phase conductor of an overhead transmission line about 200 m away from the terminal tower just outside a substation. The line is open circuited as illustrated in Figure 5.1. The line surge impedance is 100 Ω. Assuming negligible attenuation, determine the minimum clearance (d) between the phase conductor and the terminal tower structure that would ensure no flashover to the tower under the impulse overvoltage travelling wave conditions.

You may assume that the breakdown voltage of an air gap under impulse voltage is given by $V_b = 500d$ kV where the symbols have the usual meaning.

(12 marks)

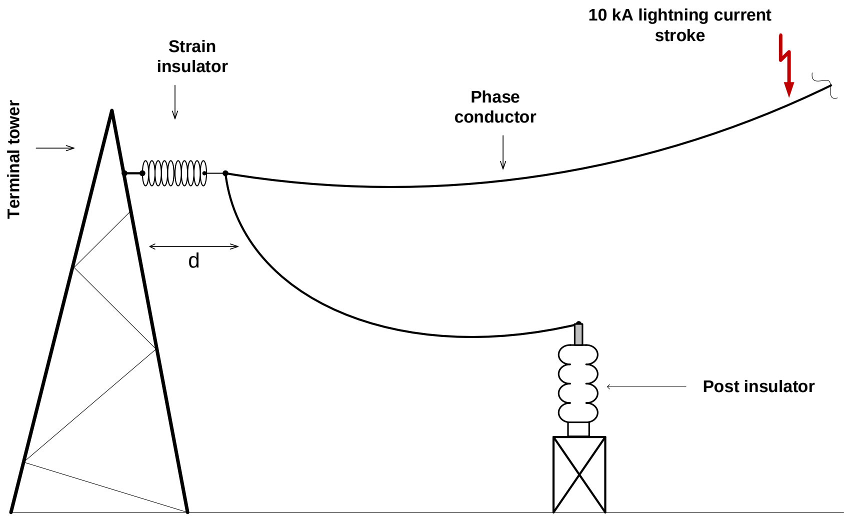

Figure 5.1: Lightning voltage surge on a transmission line

(Total: 20 marks)

Question 6

a) For on-site tests of power cable systems, a test frequency range of 20-300 Hz is accepted. A 160 kV AC series resonant test system is available. The cables to be tested have capacitance of 200 nF/km;

i) If the longest cable that the series resonant system can test is 10 km, calculate the shortest cable that can be tested.

(8 marks)

ii) What are the advantages of the series resonant test system over alternative HV test methods for power cables?

(4 marks)

b) Explain the meaning and importance of each of the following partial discharge (PD) parameters in the interpretation of PD signals;

- PD apparent charge magnitude
- PD inception voltage (PDIV)
- PD pulse repetition rate
- PD phase-resolved-pattern (PDPRP)

(8 marks)

(Total: 20 marks)

Question 7

Consider a two stage Cockroft-Walton generator with each capacitor being 0.10 μF. If this multiplier supplies a mean current of 50 mA to a test object and the RMS value of the input voltage is 100 kV at 50 Hz,

(a) Discuss with the aid of an equivalent circuit how voltage escalation is achieved in the two stage voltage generator.

(6 marks)

(b) Determine the generator output voltage with and without the test object connected.

(6 marks)

(c) Calculate the percent ripple and discuss how to reduce the value to below the 3% as required by standards.

(8 marks)

Voltage drop and ripple voltage are expressed as follows:

$$\Delta V = \frac{I}{fC}\left[\frac{2n^3}{3} - \frac{n}{6}\right]$$

$$\partial V = \frac{I}{2fC}\left[\frac{n(n+1)}{2}\right]$$

All symbols have the usual definition.

(Total: 20 marks)

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