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University of the Witwatersrand, Johannesburg

Course or topic No(s)	ELEN4003
Course or topic name(s) Paper Number & title	HIGH VOLTAGE ENGINEERING
Examination/Test* to be held during month(s) of (*delete as applicable)	JUNE 2018
Year of Study (Art & Sciences leave blank)	SECOND
Degrees/Diplomas for which this course is prescribed (BSc (Eng) should indicate which branch)	BSc(Eng)(Elec)
Faculty/ies presenting candidates	ENGINEERING AND THE BUILT ENVIRONMENT
Internal examiners and telephone number(s)	PROF. K. J. NIXON x77203 DR H. G. P. HUNT x77254
External examiner(s)	MR T. GOVENDER
Special materials required (graph/music/drawing paper) maps, diagrams, tables, computer cards, etc)	NONE

Time allowance

Course Nos	ELEN4003	Hours	3

Instructions to candidates (Examiners may wish to use this space to indicate, inter alia, the contribution made by this examination or test towards the year mark, if appropriate)	(a) Answer all questions. (b) Total Marks: 110 - Full Marks: 100. (c) Closed Book Exam: type 1 calculator; one A4 handwritten notes; All symbols and equations as defined in the course; Show all working

Internal Examiners or Heads of School are requested to sign the declaration overleaf

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Question 1

(a) Explain the terms "ionisation coefficient" and "attachment coefficient" as they apply to a gas and explain the roles which ionisation and attachment play in electrical conduction and breakdown in a gas. (3 marks)

(b) Show that the sparking threshold for a non-attaching gas is given by:

$$\gamma e^{\alpha d} = 1$$

Note: start by considering n_o free electrons at the cathode which give rise to n' secondary electrons as the result of a single electron avalanche. (3 marks)

(c) Two copper spheres each with a radius of 500 mm and separated by 75 mm are positioned in air at a pressure of 1 bar:

(i) *Estimate* the breakdown voltage between the spheres by using a simplifying approximation. You must explain the basis of this estimation. (4 marks)

(ii) Will the estimate you have made be higher or lower than the actual breakdown voltage? *Explain!* (3 marks)

(d) Show how you would go about accurately predicting the breakdown voltage. If an iterative process is being used, it is only necessary to perform one iteration, and then explain how you would continue. (7 marks)

Note:

- The following equation may be used without proof:

$$E = \frac{VR(R+s)}{2s}\left(\frac{1}{(R+x)^2} + \frac{1}{(R+s-x)^2}\right)$$

  where:
  E is the electric field associated with two identical spheres, each of radius R, with their surfaces s apart at the point of closest contact.
  x is the axial distance from the surface of one of the spheres, and V is the voltage between spheres.

- The streamer criterion is:

$$\int (\alpha - \eta)dx \approx 18$$

[Total Marks 20]

Question 2

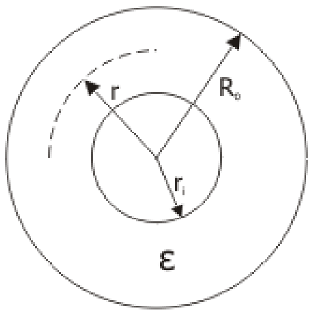
(a) During manufacture, a gas filled void has been formed in a slab of solid insulation. Explain why the partial discharge inception voltage is likely to be considerably lower than the breakdown voltage for the slab of insulation.

(4 marks)

(b) Illustrate the role that the permittivity (ϵ) of the insulation has on the partial discharge inception voltage by comparing the performance of the slab of insulation referred to above if the insulation is epoxy resin (relative permittivity, $\epsilon_r = 2.3$) and if it is mica ($\epsilon_r = 6.0$).

(4 marks)

(c) The section of a co-axial electrode geometry is shown in the figure below. The insulation is made from a dielectric tape 0.2 mm thick which is wound over the centre electrode. Determine the *minimum* partial discharge inception voltage for a cavity of one tape layer in thickness within the dielectric. The radius of the inner conductor, $r_i = 12.5\,\text{mm}$ and the outer radius of the geometry, $R_0 = 25\,\text{mm}$.



Note:

- You may assume that the cavity is filled with air at a pressure of 1.0 bar and that the electric field *within the cavity* is uniform.
- The electric field strength associated with a co-axial arrangement is given by:

$$E = \frac{V}{r \ln \dfrac{R_0}{r_i}}$$

- The relative permittivity of polythene, ϵ_r, is 2.5.

(8 marks)

(d) What measure is used to quantify partial discharge activity? Explain this with the aid of a circuit diagram which models a cavity in a section of insulation.

(4 marks)

[Total Marks 20]

Question 3

An HV equipment manufacturer has recently changed the resin used as an insulating medium in a particular device used on an 11 kV system.

(a) Propose at least two tests that can be conducted on the device in order to investigate the quality of the insulation system as a result of this change. Where applicable, you should include circuit diagrams of the test configuration, and fully explain the role of each component. You should also include typical results of the tests you propose in order to describe the meaning of the measurement. Make sure to indicate the magnitude of the readings you would expect if an item of equipment is to be considered suitable for use.

(12 marks)

(b) One method of generating HVAC is by cascading transformers. A transformer with an excitation coil is required if this is to be done. Explain how three similar transformers can be connected to give three times the input voltage. Use a diagram in your explanation. Explain the advantages and disadvantages of such a setup.

(8 marks)

[Total Marks 20]

Question 4

(a) A DC supply is required for a scientific research application. The supply must be capable of supplying 50 mA continuously at around 500 kV DC to the test object. It is important that the ripple voltage is minimised.

(i) Explain why the choice of a Greinacher or Cockroft-Walton type generator is appropriate to use in this application. (5 marks)

(ii) In order to build the generator you have available a 100 kV AC supply and five 0.1 µF capacitors. Show the circuit you would use in the form of a simple circuit diagram. Justify the position of each of the capacitors in the circuit. (5 marks)

(b) HVDC is fast becoming the solution for the transmission of bulk energy over long distances. Given a distance of between 3000 to 4000 km, discuss the design of a HVDC transmission line that would be able to deliver approximately 3000 MW. Be sure to highlight the advantages of HVDC over AC transmission as well as the key issues surrounding the HVDC line design.

(10 marks)

[Total Marks 20]

Question 5

(a) It is proposed that the terminal plant (e.g. a transformer) at the end of the transmission line is to be protected with a rod-rod gap. Specify the circuit you would use in order to determine the breakdown characteristics of this protective gap, and describe:

(i) The relevance of the numbers used to define the 1.2/50 µs voltage waveform you would use in the test. (4 marks)

(ii) The design of the voltage impulse generator to be used, emphasising the use of a multi-stage Marx-type generator. Briefly describe how you would typically dimension the component values in this generator. (8 marks)

(b) What is the "up-down" method for determining the breakdown voltage of an air gap, and what are its specific advantages? (4 marks)

(c) Using the following equation (where the symbols have their usual meaning):

$$U_{50} = \frac{\sum n_i U_i}{\sum n_i}$$

determine the U_{50} value for the following set of data:

voltage (kV)	number of withstands	number of breakdowns
2200	0	8
2100	2	9
2000	6	8
1900	8	6
1800	10	2
1700	11	0

(4 marks)

(d) Propose a design for a single stage voltage impulse generator to be used in the high voltage laboratory. The generator must produce a standard compliant 1.2/50 µs waveshape with a peak voltage of 45 kV. You are supplied with three 12.5 nF capacitors each rated at 50 kV. You decide to connect two capacitors in series and use the remaining as the load capacitance. Note: 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. (10 marks)

[Total Marks 30]

(Exam Total: Five Questions – 110 : Full Marks – 100 marks)