			EXAMS OFFICE

University of the Witwatersrand, Johannesburg

Course or topic No(s)	ELEN4005
Course or topic name(s) Paper Number & Title	POWER TRANSMISSION AND PROTECTION
Examination/Test* to be held during month(s) of (*delete as applicable)	EXAMINATION MAY 2009
Year of Study (Art & Science leave blank)	FOURTH
Degrees/Diplomas for which this course is prescribed (B.Sc.(Eng.) should indicate which branch)	B.Sc.(Eng.) ELECTRICAL
Faculty/ies presenting candidates	ENGINEERING
Internal examiner(s) and telephone extension	PROF JP REYNDERS DR JM VAN COLLER 717 7211
External Examiner(s)	MR A BARTYLAK
Special materials required (graph/ music/ drawing paper maps, diagrams, tables, computer cards, etc.)	Single A4 handwritten formula sheet prepared by student is allowed Skin effect curves (attached)
Time allowance	Course ELEN4005 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 ANY 5 QUESTIONS OUT OF 7 b) ENGINEERING CALCULATORS MAY BE USED c) HANDWRITTEN FORMULA SHEET TO BE HANDED IN (INSERT INTO 1st ANSWER BOOK)

(THIS PAGE TO FOLLOW EXAMINATION COVER SHEET SUBMITTED)

Internal Examiners or Heads of Departments are requested to sign the following declaration:

- As Internal Examiner/Head of Department, I certify that this question paper is in final form, as approved by the External Examiner, and is for reproduction.

  (application to formal examinations as approved by an external examiner)

- As Internal Examiner/Head of Department, I certify that this question paper is in final form and is ready for reproduction.

  (application to formal tests not requiring approval by external examiner)

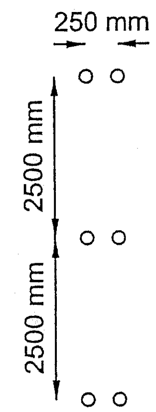
(Delete whichever not applicable)

Name: JOHN VAN COLLER ....

Signature: ....JMCo

(THIS PAGE NOT FOR REPRODUCTION)

Question 1



The phases are vertically displaced by 2500 mm

Each phase comprises two horizontal subconductors spaced 250 mm apart

Each subconductor is made from aluminium and is 30 mm in diameter

$$\rho_{al} = 2{,}83 \times 10^{-8} \ \Omega\,\mathrm{m}$$
$$\mu_0 = 4\pi \times 10^{-7} \ \mathrm{H/m}$$
$$\varepsilon_0 = \frac{10^{-9}}{36\pi} \ \mathrm{F/m}$$

Figure 1: Phase geometry of a vertically oriented, 3-phase power line

(a) A vertically-oriented three-phase transmission line is shown in Figure 1. The geometry is unsymmetrical and the top and bottom phases will have a different inductance and capacitance from the center phase. Explain why and when this lack of symmetry is a problem and how it can be corrected.
(4 marks)

(b) Explain two advantages of the use of two or more subconductors instead of a single conductor for each phase.
(2 marks)

(c) Assuming an operating frequency of 50 Hz and that the conductors are smooth, solid cylinders of aluminium, determine the inductance, capacitance and resistance per phase per meter of line-length for the line under three phase operation. Any additional assumptions must be justified.
(10 marks)

(d) A second line, having the same geometry (Figure 1) is to be mounted on the same towers and will be horizontally displaced from the first line by 3 000 mm. With regard to the electric and magnetic fields at ground level, briefly explain the advantages and disadvantages of having the same phase rotation on the second line as on the first line, i.e. phase 1 at the top, phase 2 in the middle and phase 3 at the bottom on both lines, or an alternate arrangement. On average, the lowest phase is 9m above ground.
(4 marks)

Question 2

(a) A large industrial load is fed via two identical 500 km long power lines, operating in parallel. Each line has the parameters tabulated below:

Inductance	0,90 μH/m per phase
Capacitance	10,0 pF/m per phase
Resistance	35,0 μΩ/m per phase

The three-phase load power is 700 MW at a power factor of 0.85, and the required line voltage at the load is 400 kV. The operating frequency is 50 Hz. Determine the nature and magnitude of the shunt compensation, in VAr, required at the load, if the sending-end voltage of the lines is 400 kV.

(11 marks)

(b) Consider the load being supplied by one line only. Series compensation is to be used to give the single line the same power limit as the double circuit. What magnitude of series impedance would you recommend? What type of impedance would it be? Briefly explain where you would place it.

(5 marks)

(c) With reference to long high voltage power lines, briefly explain the advantages and disadvantages of:

(i) Shunt compensation

(ii) Series compensation

(4 marks)

Question 3

(a) Figure 2 shows parallel lines feeding a load from a single generator. The relevant ratings and impedance characteristics for each item of equipment are given in Figure 2.

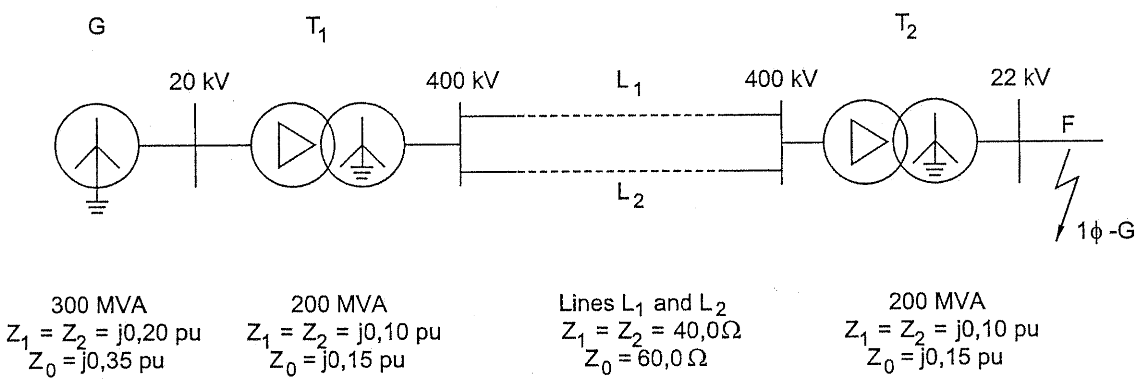


Figure 2: Parallel line feeder

An earth fault occurs at F adjacent to the 22 kV busbar. For this fault determine the fault current:

(i) At the 22 kV busbar (F);

(ii) On each of the transmission lines;

(iii) In the generator.

(14 marks)

(b) It is necessary to reduce the earth fault current without adversely affecting normal, balanced three-phase operation. Explain the influence that the inclusion of impedance in the star-point earth connections of each of the transformers and of the generator would have on the earth fault current at each of the busbars.

(6 marks)

Question 4

(a) In an electrical transmission network, the failure to remove a short-circuit sufficiently rapidly can lead to instability and the collapse of the network. Explain why this is true by referring to a double circuit link between a generator and a load in which one of the two lines experiences a three-phase short-circuit. The explanation must address the acceleration of the generator which occurs during the short-circuit and how the timeous removal of the short introduces adequate decelerating forces to maintain stability. Equations to support the explanation can be used without derivation, provided all the terms are explained. A graphical construction can be used to facilitate the explanation.

(7 marks)

(b) What is "steady-state" stability as applied to an electrical transmission network and under what circumstances can the steady-state stability limit be exceeded?

(3 marks)

(c) A 1 500 MW load is fed via two, parallel, 400 kV, three-phase lines having series impedances of 70 Ω and 90 Ω respectively. For maintenance purposes, the 70 Ω line is switched out and the 90 Ω has to carry the full load. Show that each of the lines should be able to carry the load on their own and then determine whether the switching operation can lead to instability.

(10 marks)

Question 5

(a) List the typical ratings of circuit breakers relevant to protection applications. Describe briefly how circuit breakers are selected.

(5 marks)

(b) Explain what is meant by the statement that the X/R ratio at a particular busbar is 14. When are higher values expected and when are lower values expected? Justify.

(5 marks)

(c) Under what conditions would you expect saturation of a CT?

(5 marks)

(d) Explain what is meant by the residual connection of VTs and explain when it is used.

(5 marks)

Question 6

(a) Explain why IDMT relays are so widely used for protecting both equipment and power networks.

(6 marks)

(b) IDMT relays (standard inverse) are used to protect the radial network in Figure 3

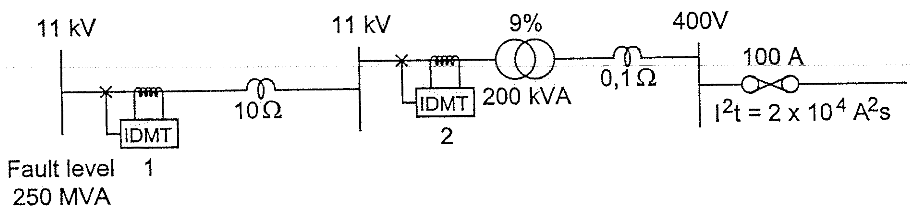


Figure 3: Radial network

Choose suitable CT ratings and calculate suitable settings for the two IDMT relays.

(14 marks)

Question 7

(a) A high-impedance differential relay is used to protect a star-delta 132 kV/22 kV transformer (star point on 132 kV side solidly earthed). Draw the connection of the CTs and explain how the high-impedance relay characteristic is used to prevent spurious operation for large through fault currents.

(10 marks)

(b) A delta-star 22 kV/400 V transformer has restricted earth fault (REF) protection on the 400 V side. If the capacitance per phase is 1 μF, calculate the minimum setting to prevent spurious operation for external earth faults (refer setting to the CT primary side).

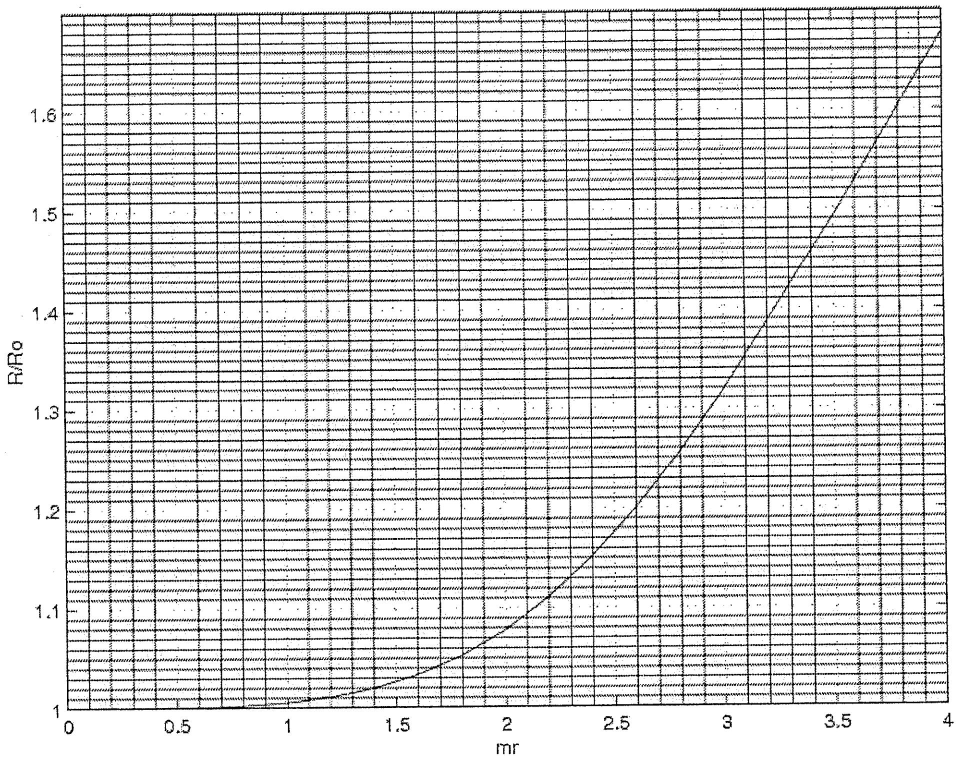
(6 marks)

(c) Explain why carrier acceleration is preferred when using distance protection to protect an HV transmission line.

(4 marks)

Appendix 1: Skin Effect: Resistance Ratio

$$m = \sqrt{\frac{\varpi\mu}{\rho}} \quad \text{where r is the radius in meters}$$



Appendix 2: Skin effect: Internal Inductance Ratio

$$m = \sqrt{\frac{\varpi\mu}{\rho}} \quad \text{where r is the radius in meters}$$