08:30	20/06/2013	SHB1A	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 JUNE 2013
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	DR JM VAN COLLER 717 7211
External Examiner(s)	MR A EDWARDS
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)

Question 1

(a) The geometry of an existing transposed transmission line is shown in Figure 1. The conductors in each phase can be assumed to be cylinders of aluminium with a diameter of 30 mm. Determine the inductance, capacitance and resistance per phase for the line. The line length is 100 km. Skin effect corrections must be made for an operating frequency of 50 Hz. (8)

$$\rho_{al} = 2{,}83 \times 10^{-8}\ \Omega m$$

$$\mu_0 = 4\pi \times 10^{-7}\ H/m$$

$$\varepsilon_0 = \frac{10^{-9}}{36\pi}\ F/m$$

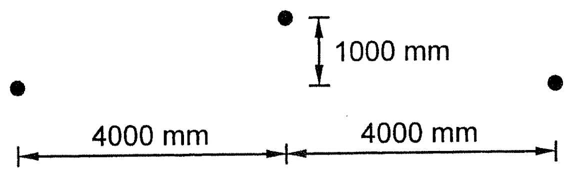


Figure 1: Single conductor geometry

(b) The line in (a) above is to be uprated by adding an additional conductor, identical to the existing ones, to each phase, as shown in Figure 2. For this geometry, determine the inductance, capacitance and resistance per phase for the line. (8)

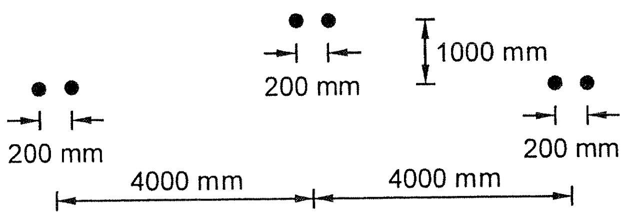


Figure 2: Two conductor bundle geometry

(c) Using the data arrived at in (a) and (b) above, determine the power limits of both the new and uprated lines, when operated at a line voltage of 132 kV. Why do your calculations show that the power limit is only marginally increased and not doubled when adding the second phase conductor? However, the reduction in resistance is significantly reduced. What advantage does this have? (4)

Question 2

(a) A 500 km, three-phase transmission line, operating at 50 Hz and line voltage of 400 kV has the following parameter values:

Resistance per phase: 8.00 Ω
Inductance per phase: 475 mH
Capacitance per phase: 5.50 μF

The line feeds a load of 600 MW at a power factor of 0.85 lagging. Determine the type and magnitude of shunt compensation that is required at the load if the voltage at both ends of the line is to be 400 kV. Justify all assumptions. (10)

(b) Series compensation is to be applied to this line to increase its power limit by 20%. Explain the principles behind series compensation and then calculate the value of the capacitance that needs to be placed in series with each phase. (6)

(c) Explain a situation where inductance is placed in series with a transmission line. (4)

Question 3

(a) In order to achieve acceptable security of supply, transmission systems are built to achieve at least an N-1 criterion. Explain what is meant by this statement. Assume two transmission lines link areas that include generation. Explain under what conditions stability can be lost when one of the lines is suddenly disconnected. (10)

(b) A 1500 MW, balanced, three-phase load is fed via two 275 kV power lines, one having a series impedance of 35 Ω and the other a series impedance of 25 Ω. In bad weather, a three-phase short-circuit occurs on the 35 Ω line. If the torque angle of the system increases at a rate of 0.5° per millisecond, what is the maximum duration of the short circuit, before the opening of the faulty line, so that stability of the system will be maintained. (10)

Question 4

Figure 3 shows two generators feeding a common load over two parallel 400 kV lines. The lines are identical and are each 300 km long. The relevant details of each item of equipment are given in Table 1.

Table 1: Equipment ratings and impedances

	Rating	Z_o	Z_1	Z_2
G_1 & G_2	400 MW @ 0,8 pf	10%	12%	12%
T_1 & T_2	500 MVA	8%	10%	10%
T_3 & T_4	300 MVA	8%	10%	10%
L_1 & L_2		0,5 Ω/km	0,25 Ω/km	0,25 Ω/km

(a) Using a common base of 500 MVA, determine the zero, positive and negative sequence impedances for each item of equipment in per unit values. (5)

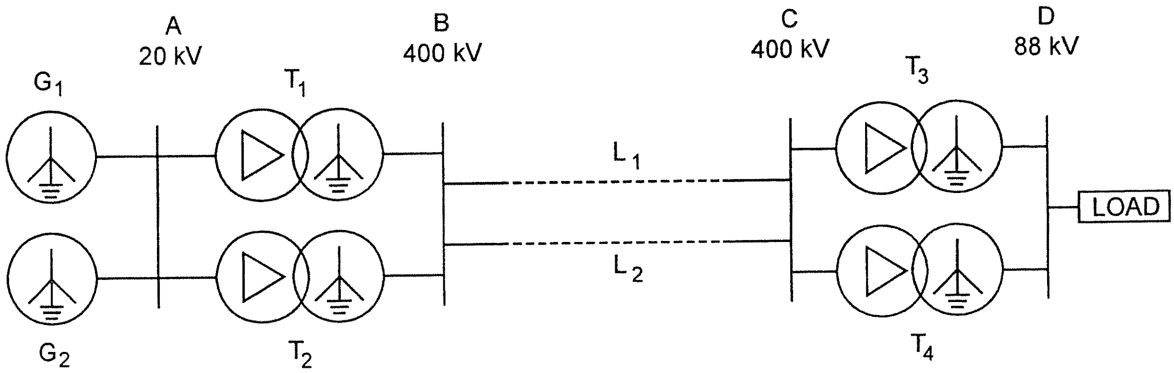


Figure 3: Radial feeder

(b) Draw the sequence networks for each sequence and determine the Thevenin equivalent for each network for a fault on busbar D. Using these networks determine the actual fault current at busbar D in the event of a symmetrical three-phase fault and a single-phase-to-ground fault at busbar D. (10)

(c) In the event of a single-phase-to-ground fault at busbar D, determine the currents in each of the three phases of each of the transmission lines. (5)

Question 5

(a) Explain why sometimes the secondary windings of VTs are connected in series and the secondary windings of CTs are sometimes connected in parallel. (5)

(b) Suggest the problems that may occur if the secondary circuit of the VT is used to also supply other (non-protection relay) loads. (5)

(c) Explain what is meant by a CT nameplate rating of 1000/1A, 5VA-10P10. (5)

(d) 132000/110 V VTs and 1000/1 A CTs are used to measure impedance. For a VT secondary voltage equal to the rated value and the CT secondary current equal to ten times the rated value, give a typical calculation showing the effect of a phase angle error of ±5° on the impedance seen by an impedance relay. What would be the implications for the impedance relay protecting a transmission line? (5)

Question 6

IDMT relays (standard inverse) are used to protect the network in Figure 4 below

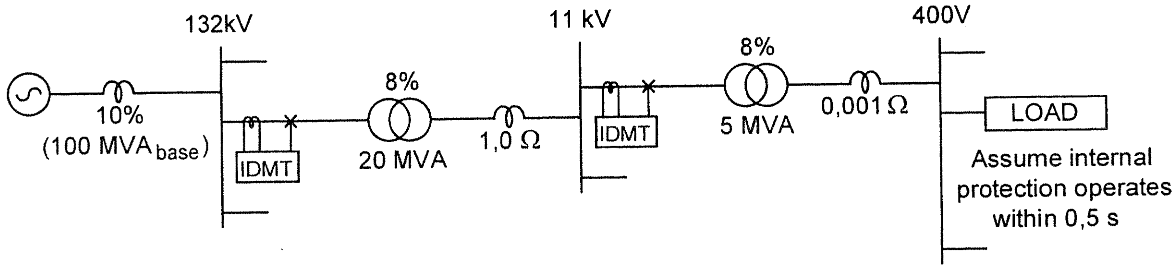


Figure 4: Radial network

(a) Choose suitable CT ratios and calculate suitable settings for the IDMT relays (15)

(b) What other functionality could be added to the IDMT relays for better protection of the upstream equipment? (5)

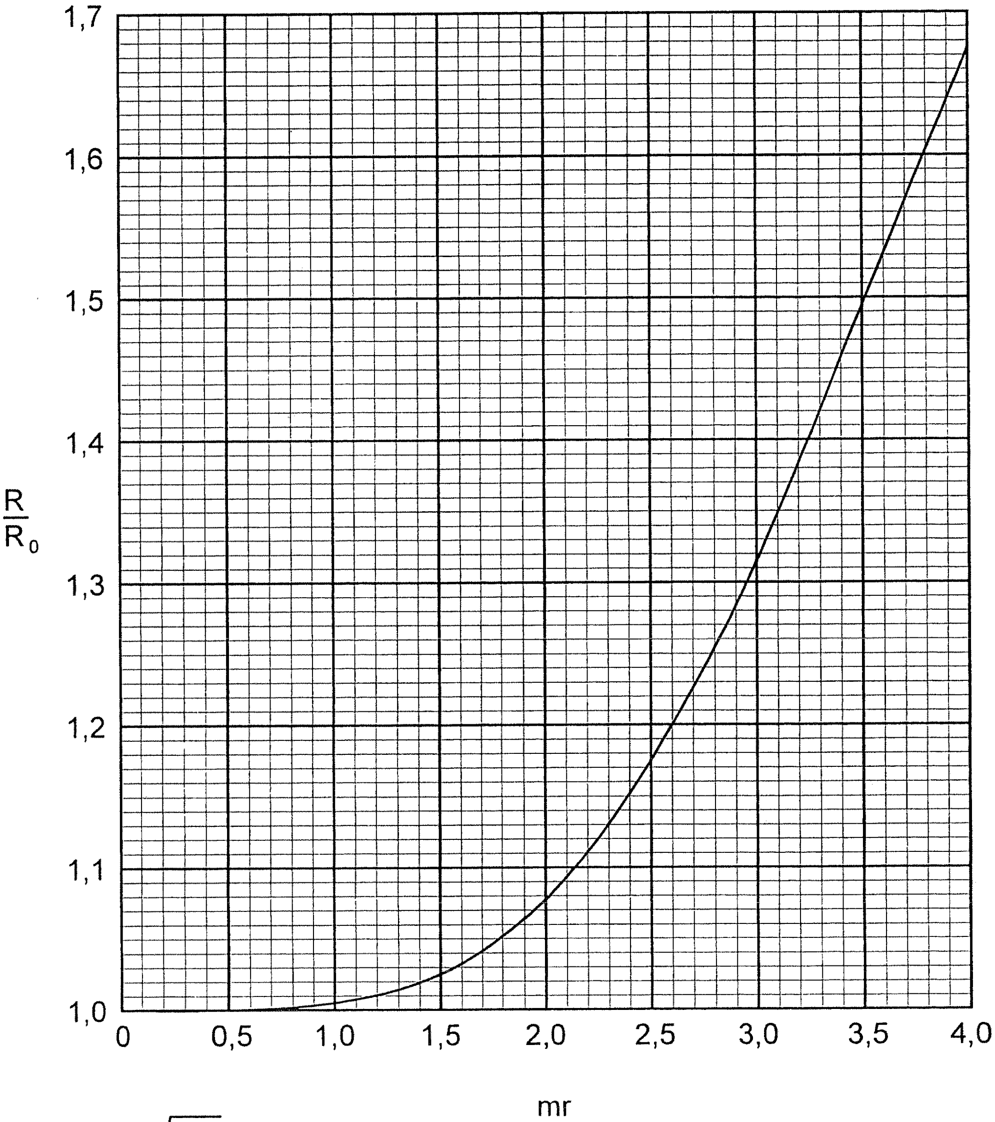
Question 7

(a) Explain the difference in operation of a high-impedance differential protection relay compared with a biased differential protection relay when used for transformer protection. (8)

(b) Spurious operation of a restricted earth fault protection relay is sometimes experienced. Suggest possible reasons and possible remedies. (6)

(c) Explain what happens when an out-of-step (OOS) condition occurs in a power system. Why is it of special importance when using impedance protection? (6)

Appendix 1 Skin Effect: Resistance Ratio:



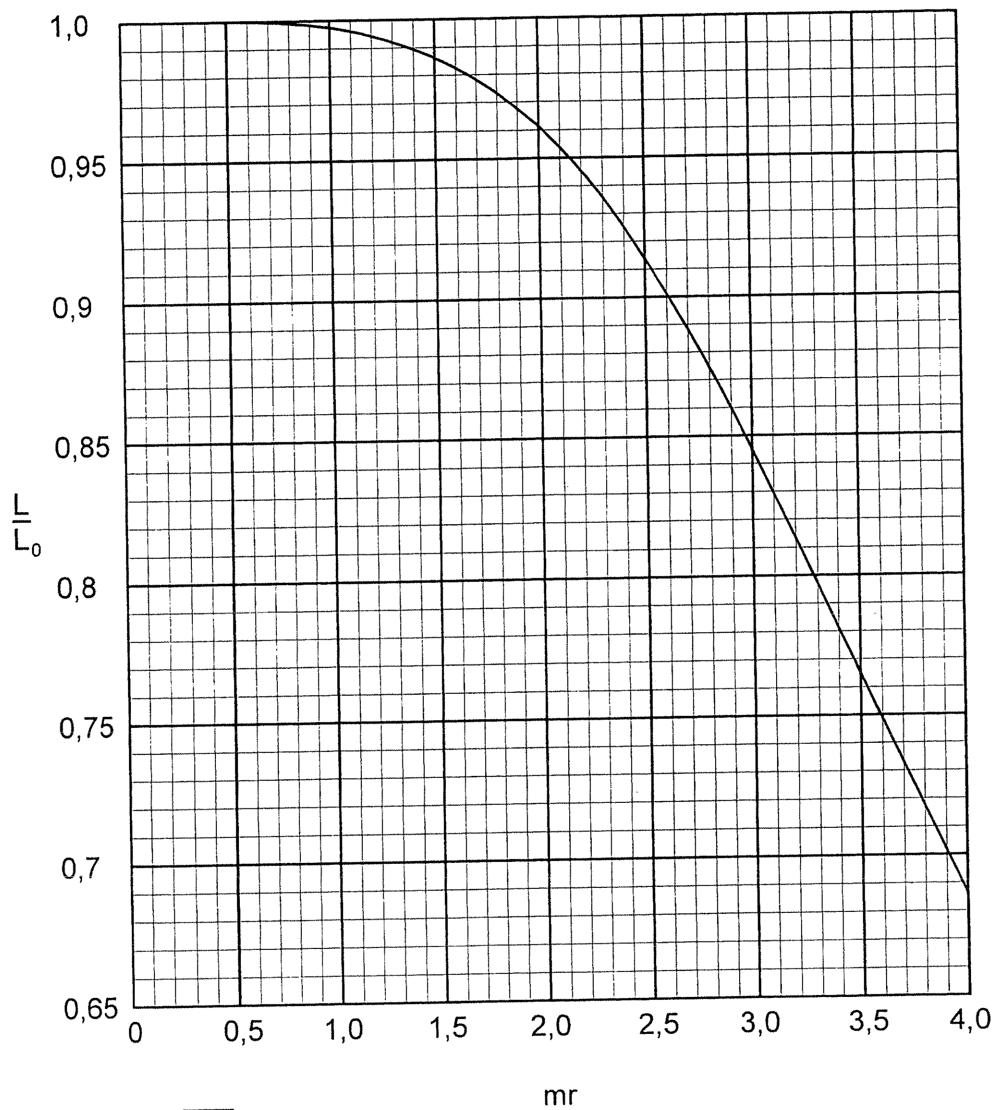
Skin Effect: Resistance Ratio

$m = \sqrt{\dfrac{\omega\mu}{\rho}}$

$\mu = \mu_r \mu_o$

r = radius, in m

Appendix 2: Skin effect: Internal Inductance Ratio



$$m = \sqrt{\frac{\omega\mu}{\rho}}$$

Skin Effect: Internal inductance Ratio

$\mu = \mu_r \mu_o$

r = radius, in m