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**EXAMS OFFICE**

University of the Witwatersrand, Johannesburg

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| Course or topic No(s) | ELEN4005 |
| Course or topic name(s)<br>Paper Number & Title | POWER TRANSMISSION AND PROTECTION |
| Examination/Test* to be held during month(s) of<br>(*delete as applicable) | EXAMINATION<br>JUNE 2010 |
| Year of Study<br>(Art & Science leave blank) | FOURTH |
| Degrees/Diplomas for which this course is prescribed<br>( B.Sc.(Eng.) should indicate which branch) | B.Sc.(Eng.) ELECTRICAL |
| Faculty/ies presenting candidates | ENGINEERING |
| Internal examiner(s)<br>and telephone extension | PROF JP REYNDERS<br>DR JM VAN COLLER 717 7211 |
| External Examiner(s) | MR A BARTYLAK |
| Special materials required<br>(graph/ music/ drawing paper maps, diagrams, tables, computer cards, etc.) | Single A4 handwritten formula sheet prepared by student is allowed<br>Skin effect curves (attached) |
| Time allowance | Course: ELEN4005 Hours: 3 |
| Instructions to candidates<br>(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<br>b) ENGINEERING CALCULATORS MAY BE USED<br>c) HANDWRITTEN FORMULA SHEET TO BE HANDED IN (INSERT INTO 1st ANSWER BOOK) |

## Question 1

(a) The geometry of an existing three-phase, single conductor per phase, transmission line is shown in Figure 1. The conductors in each phase can be assumed to be cylinders of aluminium, 30 mm in diameter. Determine the inductance, capacitance and series resistance, per phase, for the line. (8)

Notes:

- The operating frequency of the line is 50 Hz.
- The line is 200 km in length and is transposed.
- All dimensions in the figures are in mm.
- Skin effect corrections must be made, as appropriate.
- Any assumptions made must be justified.
- $\rho_{al} = 2{,}83 \times 10^{-8}\ \Omega m$
- $\mu_0 = 4\pi \times 10^{-7}\ H/m$
- $\varepsilon_0 = \dfrac{10^{-9}}{36\pi}\ F/m$

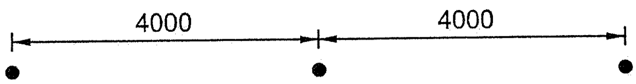



Figure 1: Single conductor in a bundle geometry

(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)

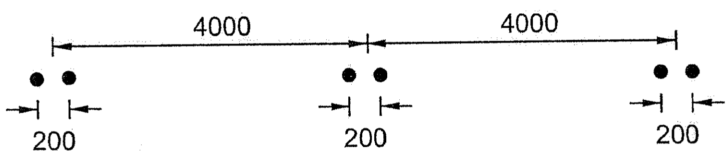



Figure 2: Two conductor in a bundle geometry

(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. Simplistically, it may be thought that doubling the number of conductors leads to a doubling of the capacity of the line. Why do your calculations show that the power limit is only marginally increased and not doubled. However, the reduction in series resistance is significantly reduced. What advantage does this have? (4)

## Question 2

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

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. For the purpose of this calculation, the nominal Π equivalent circuit may be assumed to be accurate. (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 impedance that will be placed in series with each phase. (6)

(c) Mention and explain one advantage and one disadvantage associated with the implementation of series compensation on a transmission line. (4)

## Question 3

(a) In an electrical power system, the removal of a line from the system can lead to instability, despite the fact that the absence of the line does not decrease the power limit of the system to below that of the actual load. Explain why this happens with reference to a simple system in which a generator feeds a load over two parallel lines. Each of the lines is independently capable of carrying the load. Instability occurs when one line is disconnected and the load is thrown onto the remaining line. A diagram and relevant equations should be used to support your argument. (5)

(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)

(c) Explain the influence that changing the phase spacing of a line will have on the Power Limit and hence the stability. (5)

## 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)

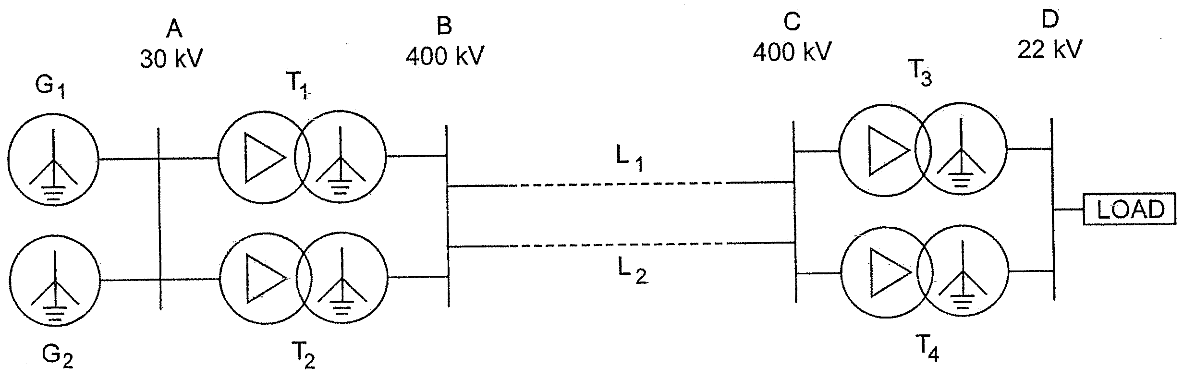



Figure 3: Radial feeder

(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) Discuss the advantages and disadvantages of the capacitor-coupled VT (CVT). (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) A 11000/110 V VT 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

An IDMT relay (standard inverse) is used to protect the network in Figure 4 below

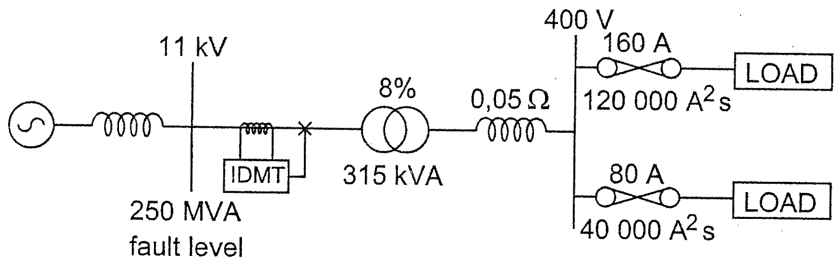



Figure 4: Radial network

(a) Choose a suitable CT ratio and calculate suitable settings for the IDMT relay (15)

(b) What other functionality could be added to the IDMT relay for better protection of the transformer? (5)

## Question 7

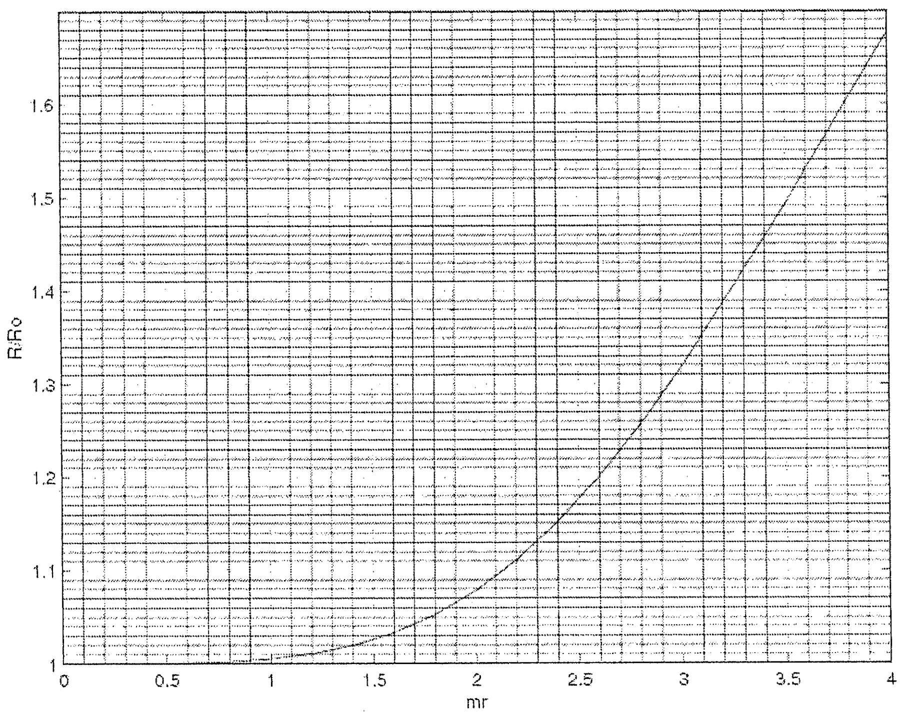
(a) Explain the difference in operation of a high-impedance differential protection relay compared with a biased differential protection relay when used for transformer protection. (8)

(b) Explain where restricted earth fault protection is used to protect transformers and where measuring the neutral current only is used. Your answer would include a list of the advantages and disadvantages of each scheme. (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:

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



**Appendix 2**: Skin effect: Internal Inductance Ratio

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