UNIVERSITY OF SWAZILAND
MAIN EXAMINATION, MAY 2016

FACULTY OF SCIENCE AND ENGINEERING

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

TITLE OF PAPER:	**POWER SYSTEMS**
COURSE NUMBER:	**EE452**
TIME ALLOWED:	**THREE HOURS**

INSTRUCTIONS:

1. There are five questions in this paper. **Answer ALL questions.**
2. Questions do not carry equal marks, but are as indicated at the beginning of each question.
3. Marks for different sections of a question are shown on the right hand margin.
4. If you think not enough data has been given in any question you may assume any reasonable values.
5. A sheet with selected formulae some of which you may need is attached at the end of the question paper.

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THIS PAPER HAS SEVEN (7) PAGES INCLUDING THIS PAGE

QUESTION 1 ***(15 marks)***

The cross-sectional diagram of a three-phase transmission line with each conductor consisting of two bundled sub-conductors is shown in Fig. Q1. The sub-conductors are similar and solid, each with radius r of 0.9 cm. The spacing of the sub-conductors within the bundle d is 10 cm and the line is fully transposed. To simplify the analysis you may assume that the spacing between the conductors D is much greater than the sub-conductor spacing, i.e. $D \gg r$.

(a) Determine the inductance per phase per kilometer of the transmission line. *(6 marks)*

(b) Determine the capacitance to neutral per phase per kilometer of the line. *(5 marks)*

(c) If the line is 50 km long and is maintained at 66 kV, 50 Hz, calculate the charging current per phase of the line. Neglect the effects of ground proximity. *(4 marks)*

$$\mu_o = 4\pi \times 10^{-7} \text{ H/m}$$
$$\varepsilon_o = 8.854 \times 10^{-12} \text{ F/m}$$

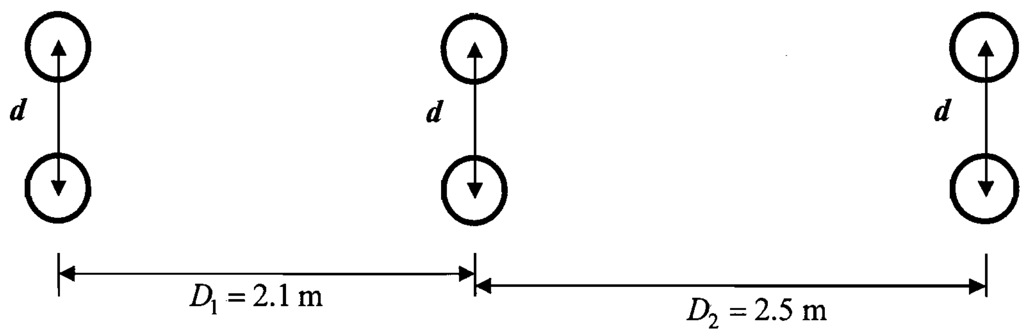

Fig. Q.1

QUESTION 2 *(20 marks)*

(a) Briefly explain, giving advantages and disadvantages, each of the following power distribution networks structures:

(i) Radial structures *(3 marks)*

(ii) Loop (Ring) structures *(4 marks)*

(iii) Interconnected structures *(3 marks)*

(b) A single-phase distributor is 3 km long and supplies a load of 100 A at 0.9 p.f. lagging at the far end, and a load of 80 A at 0.8 p.f. lagging at its midpoint. The loop resistance and reactance per kilometre (to and fro) of the line is $0.06 + j0.15\ \Omega$. If the voltage at the far end is maintained at 230 V, calculate:

(i) The sending end voltage. *(8 marks)*

(ii) The phase angle between the voltages at the two ends of the line. *(2 marks)*

QUESTION 3 *(25 marks)*

(a) Define each of the following terms and explain how each one influences the cost of generating electrical power:

(i) Load Factor *(4 marks)*

(ii) Diversity Factor *(5 marks)*

(b) A power station is to supply four regions of loads whose peak values are 10,000 kW, 5000 kW, 8000 kW and 7000 kW. The diversity factor of the load at the station is 1.5 and the average annual load factor is 60%. Calculate the maximum demand on the station and annual energy supplied from the station *(6 marks)*

(c) State and briefly discuss main functions of a substation in a power network. *(10 marks)*

QUESTION 4 ***(25 marks)***

(a) Show that the *ABCD* line constants of a transmission line represented by its π-model are given by

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1+\dfrac{YZ}{2} & Z \\ Y\left(1+\dfrac{YZ}{4}\right) & 1+\dfrac{YZ}{2} \end{bmatrix}$$

where Z is its series impedance and Y is its shunt admittance. *(7 marks)*

(b) A 220 kV, three-phase transmission line has a per phase series impedance of $Z = 0.04 + j0.5\ \Omega$ per km and a per phase shunt admittance $Y = j4\times10^{-4}$ S per km. The line is 100 km long (medium) and delivers 250 MVA at lagging p.f. of 0.8 at 210 kV. Use the π-model to determine the following:

(i) *ABCD* constants of the line *(5 marks)*

(ii) The sending end voltage and current *(8marks)*

(iii) The percentage voltage regulation *(3 marks)*

(iv) The percentage transmission efficiency *(2 marks)*

QUESTION 5 *(15 marks)*

A three-phase 400-kV, 50-Hz transmission line is 420 km long and may be assumed **lossless**. The line is energized with 400 kV at the sending end. When the load at the receiving end is removed, the voltage at the receiving end rises to 600 kV, and the sending end current is $636.6\angle 90°$ A per phase.

(a) Determine:

(i) The phase constant β in radians per km, *(4 marks)*

(ii) The surge impedance Z_C in Ω. *(2 marks)*

(b) Ideal shunt reactors are to be installed at the receiving end to keep $|V_S| = |V_R| = 400$ kV when the load is removed. Determine

(i) The reactance per phase, *(5 marks)*

(ii) The required three-phase MVAR. *(2 marks)*

(c) What is the Surge Impedance Loading (SIL) of the line? *(2 marks)*

SUMMARY OF TRANSMISSION LINE *ABCD* CONSTANTS

Parameter	$A = D$	B	C
Units	p.u.	Ω	S
Short Line $G = C = 0$	1	Z	0
Medium Line $G = 0$ (π-model)	$1+\frac{YZ}{2}$	Z	$Y\left(1+\frac{YZ}{4}\right)$
Long Line (length l, equivalent π-model)	$\cosh(\gamma l) = 1+\frac{Y'Z'}{2}$	$Z_c \sinh(\gamma l) = Z'$	$\frac{1}{Z_c}\sinh(\gamma l) = Y'\left(1+\frac{Y'Z'}{4}\right)$
Lossless Line (length l, $R=G=0$)	$\cos(\beta l)$	$jZ_c \sin(\beta l) = jX'$	$\frac{j\sin(\beta l)}{Z_c}$

Equivalent π-model of long line:

$$Z' = Z_C \sinh\gamma\ell = Z\frac{\sinh\gamma\ell}{\gamma\ell}, \qquad \frac{Y'}{2} = \frac{1}{Z_C}\tanh\frac{\gamma\ell}{2} = \frac{Y}{2}\frac{\tanh\gamma\ell/2}{\gamma\ell/2}$$

Equivalent π-model of lossless line: $Z' = jX' = jZ_C \sin\beta\ell, \qquad \frac{Y'}{2} = j\frac{\sin\beta\ell}{Z_C}$

For lossless line:

$Z_C = \sqrt{L/C}$ Ω, $\beta=\omega\sqrt{LC}$ rad/m, $v = 1/\sqrt{LC}$, Note here L is inductance/unit length

$SIL = 3V_R I_R^* = 3|V_R|^2/Z_C = (V_{LLrated})^2/Z_C$ W

Overhead Transmission lines:

$$L = \frac{\mu_o}{2\pi}\ln\frac{GMD}{GMR_L}, \qquad C = \frac{2\pi\varepsilon_o}{\ln\frac{GMD}{GMR_C}}$$

Injection of VARs into a Short Transmission Line results in:

$$V_S^2 = \left[V_R + I_pR - (I_m - I_q)X\right]^2 + \left[I_pX + (I_m - I_q)R\right]^2$$

where $I_R = I_p - jI_q$