UNIVERSITY OF SWAZILAND
MAIN EXAMINATION, MAY 2018

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 any FOUR questions.**
2. Questions carry equal marks.
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, and state these summed values.
5. **A page containing useful formulae, some of which you may need, is attached at the end**

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THIS PAPER HAS SEVEN (7) PAGES INCLUDING THIS PAGE

QUESTION 1 ***(25 marks)***

(a) **(i)** Explain why transmission lines are sometimes bundled. *(3 marks)*

(ii) What is meant by transposition of transmission lines? Under what circumstances should transposition be carried out? *(4 marks)*

(b) A bundled three-phase, **400-kV, 50 Hz, 300-km** long transmission line consists of three bundled same-phase conductors as shown in Fig.Q1b. Each individual conductor in the bundle has a radius of **1.06 cm** and is placed at the corner of an equilateral triangle of side **40 cm**. The bundles of the three phases are horizontally spaced **8 m** apart and the line is properly transposed.

(i) Calculate the **inductance** and **inductive reactance** per phase of the line. *(7 marks)*

(ii) Ignoring the ground effects, calculate the **capacitance** and the **capacitive reactance** of the line between line and neutral *(7 marks)*

(iii) Determine the charging current in the line. *(4 marks)*

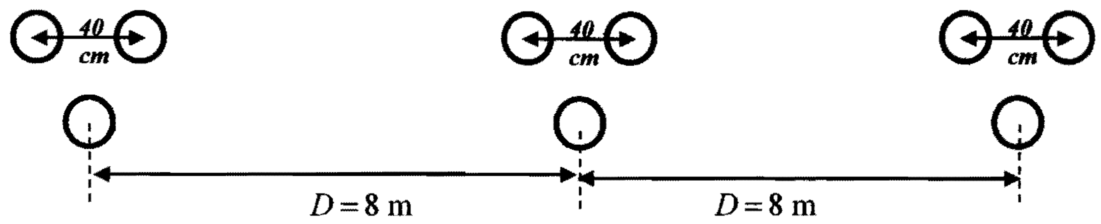

Fig.Q1b

QUESTION 2 ***(25 marks)***

(a) **(i)** Mention 4 techniques that may be employed to control the voltage in a transmission line.

(4marks)

(ii) Why should a high power factor be maintained in industrial power installations?

(3 marks)

(b) A single-phase, **230 –V, 50-Hz** motor consumes **5200 W at 0.7 power factor lagging**. Calculate the value of a component needed to raise its power factor to **0.95 lagging**.

(8 marks)

(c) A **3-phase 50-Hz** overhead short transmission line has an impedance of $\mathbf{3.5 + j12.5}$ Ω per phase. A load of **15 MW** with lagging power factor of **0.8** is connected at the receiving end where the line-to-line voltage is **20 kV**.

Determine the magnitude and phase of the line-to-neutral and line-to-line voltages at the sending end. Use the receiving end voltage as reference phase. *(10 marks)*

QUESTION 3 ***(25 marks)***

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

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

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 $z = \mathbf{0.5\angle 85°}$ **Ω per km** and a per phase shunt admittance $y = \mathbf{4\times 10^{-5}\angle 90°}$ **S per km**. The line is **200 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 sending end power factor. *(2 marks)*

(iv) The percentage transmission efficiency. *(3 marks)*

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

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

- **(i)** Radial systems *(3 marks)*
- **(ii)** Loop (Ring) systems *(4 marks)*
- **(iii)** Interconnected systems *(3 marks)*

(b) State five main functions of a substation in a power network. *(5 marks)*

(c) A single-phase a.c. distributor transmission line is **4 km** long and supplies a load of **120 A at 0.9 p.f. lagging** at the far end, and a load of **85 A at 0.85 p.f. lagging** at its midpoint as illustrated in Fig.Q4c The loop resistance and reactance **per kilometre** of the line is **0.05 +*j*0.18 Ω.** If the voltage at the far end is maintained at **230 V**, calculate, using ordinary network theory:

- **(i)** The sending end current. *(3 marks)*
- (ii) The sending end voltage. *(6 marks)*
- **(iii)** The phase angle between the voltages at the two ends of the line. *(1 marks)*

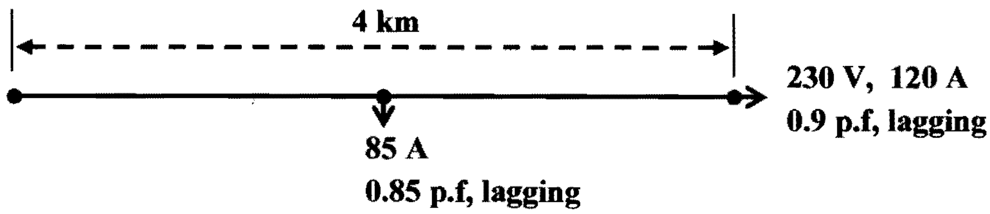

Fig.Q.4c

QUESTION 5 ***(25 marks)***

(a) **(i)** Define **load factor** and briefly discuss how it influences the cost of generating electrical power. *(5 marks)*

(ii) Define the terms: **Demand Factor** and **Diversity Factor** as used in the supply of electrical energy to consumers. *(2 marks)*

(b) A distributor line supplies three transformers, each of which supplies a group of customers. The total connected loads, demand factors and diversity factors of the groups connected to each transformer are as follows:

Transformer	Connected load	Demand Factor	Diversity Factor
TR1	300 kW	0.7	2.3
TR2	180 kW	0.65	1.9
TR3	150 kW	0.8	2.1

(i) Calculate the maximum demand on each transformer. *(6 marks)*

(ii) If, in addition, the diversity factor among the three distribution transformers is **1.4,** calculate the maximum demand on the distributor line. *(2 marks)*

(c) A three-phase **410-kV, 50-Hz** transmission line is **350 km** long and may be assumed **lossless**. The line is energized with **410 kV** at the sending end. When the load at the receiving end is removed, the voltage at the receiving end rises to **550 kV**, and the sending end current is $\mathbf{626.6\angle 90^\circ}$ **A** per phase.

Determine:

(i) The phase constant $\boldsymbol{\beta}$ in radians per km, β *(5 marks)*

(ii) The surge impedance $\boldsymbol{Z_C}$ **in** Ω. *(3 marks)*

(iii) The **Surge Impedance Loading (SIL)** of the line? *(2 marks)*

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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: $Z' = jX' = jZ_C\sin\beta\ell$, $\quad \frac{Y'}{2}=j\frac{\sin\beta\ell}{Z_C}$

Hyperbolic identities: $\cosh(j\beta)=\cos\beta$; $\quad \sin(j\beta)=j\sin\beta$; $\quad \tanh(j\beta)=j\tan\beta$

For lossless line:

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

otherwise, for a lossy line, $Z_C=\sqrt{z/y}$, $\quad \gamma^2 = zy$

Injection of VARs into a Short Transmission Line results in:

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

where $I_R = I_p - jI_q$

$$L=\frac{\mu_o}{2\pi}\ln\left(\frac{GMD}{GMR_L}\right) \text{ H/m per conductor,} \qquad C_{an}=\frac{2\pi\varepsilon_o}{\ln\left(\frac{GMD}{GMR_C}\right)} \text{ F/m to neutral}$$

$\mu_o = 4\pi\times10^{-7}$ H/m $\qquad \varepsilon_o = 8.854\times10^{-12}$ F/m