UNIVERSITY OF SWAZILAND
RESIT/SUPPLEMENTARY EXAMINATION, JULY 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 four questions in this paper. **Answer ALL 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 assumed 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 SIX (6) PAGES INCLUDING THIS PAGE

QUESTION 1 *(25 marks)*

(a) **(i)** Explain the effect of increasing the spacing between the phases of a transmission line on its inductance and its capacitance. *(4 marks)*

(ii) Explain the effect of increasing the conductor radius of a transmission line on its inductance and its capacitance. *(3 marks)*

(b) A single-phase, **11-kV, 50-Hz** transmission line has two conductors each of radius **1.8 cm** and spaced **0.8 m** apart. The line is **20 km** long and the resistivity of its material is $\mathbf{2.83 \times 10^{-8}\ \Omega - m}$

(i) Determine its series resistance per km, ignoring the skin effect. *(4 marks)*

(ii) Determine its shunt capacitance per km. *(4 marks)*

(iii) Determine its series inductance per km. *(4 marks)*

(iv) Determine its total series impedance and its total shunt admittance. *(4 marks)*

(v) Draw and label a lumped π-model of the line. *(2 marks)*

QUESTION 2 *(25 marks)*

(a) A short transmission line is modelled as a series impedance $\boldsymbol{Z} = \boldsymbol{R} + j\boldsymbol{X}$ with no shunt elements. The line has a **sending end voltage** V_S, current I_S and power factor angle ϕ_S, and **receiving end voltage** V_R, current I_R and power factor angle ϕ_R. Using the receiving end voltage as a reference, draw for each of the load conditions below, a **phasor diagram** showing the relationships between receiving and sending end voltages, currents and line voltage drops.

(i) Load with a lagging power factor *(4 marks)*

(ii) Load with a unity power factor *(3 marks)*

(iii) Load with a leading power factor. *(4 marks)*

(iv) State the condition under which the magnitude of the receiving end voltage can be higher than the sending end voltage. *(2 marks)*

(b) A short three phase transmission line has series impedance of $\boldsymbol{Z} = \mathbf{5.6} + j\mathbf{60}\ \Omega$ per phase. The line serves a three-phase load of **1076 MVA** at **345 kV** line-to-line voltage. Calculate the **sending end voltage**, **current** and **power factor** when the load has:

(i) Unity power factor *(4 marks)*

(ii) **0.866 lagging** power factor *(4 marks)*

(iii) **0.866 leading** power factor. *(4 marks)*

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

(a) (i) Why is voltage control important in transmission line networks? *(4 marks)*

(ii) List four distinct methods which can be used to control voltage in a transmission line. *(4 marks)*

(iii) Define the **Daily Load Curve** as used in supply of electricity to consumers and state what information can be derived from it as a guide for the supply of power. *(4 marks)*

(b) An industrial substation serves a total load of **4 MW**. A capacitor of **2 MVAR** is installed to maintain the power factor at **0.97 lagging**. What is the power factor when the installed capacitor goes out of service (i.e. is disconnected)? *(8 marks)*

(c) An **800-kV, 50-Hz lossless** transmission line has a per phase inductance of **1.1 mH/km** and a per phase capacitance of **11.68 nF/km**. What is the ideal power handling capacity of this line? *(5marks)*

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

A three-phase **220 kV, 50 Hz** transmission line is **250 km** long. The line has an inductance of **0.86 mH/km per phase** and capacitance of **0.013 μF/km to neutral per phase**. Assume that the line is **lossless**. A three-phase load rated **160 MW, 220 kV, 0.85 p.f. lagging** is connected at its receiving end.

(a) Determine the **phase constant** and **surge impedance** of the line. *(5 marks)*

(b) Determine the sending end **voltage, current and complex power sent.** *(15 marks)*

(c) Determine the percentage **voltage regulation.** *(5 marks)*

USEFUL FORMULAE SOME OF WHICH YOU MAY NEED

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)	$1+\dfrac{YZ}{2}$	Z	$Y\left(1+\dfrac{YZ}{4}\right)$
Long Line (length l, equivalent π-model)	$\cosh(\gamma l) = 1+\dfrac{Y'Z'}{2}$	$Z_c \sinh(\gamma l) = Z'$	$\dfrac{1}{Z_c}\sinh(\gamma l) = Y'\left(1+\dfrac{Y'Z'}{4}\right)$
Lossless Line (length l, R=G=0)	$\cos(\beta l)$	$jZ_c \sin(\beta l) = jX'$	$\dfrac{j\sin(\beta l)}{Z_c}$

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

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:

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

where $I_R = I_p - jI_q$

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

$\mu_o = 4\pi \times 10^{-7}$ H/m $\qquad \varepsilon_o = 8.854\times10^{-12}$ F/m