

Power Systems Analysis

Midterm Exam

Part II (1h15m)

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Questions:
3 points for this section

Remember to write down the calculations and eventual considerations that allowed you to derive the result. For part II, you can get a maximum of $\Rightarrow +3$ points and a minimum of $\Rightarrow 0$ point.

← Insert your SCIPER number on the left and write your full name below. ↓

Surname and Name:

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Exercise

You're sitting in the control room of a power station, monitoring a generator (G) that supplies power to a load (U) through a network of transformers (T_1 and T_2) and a line which is 1 km long (L). The equivalent circuit of the system is shown in Figure 1.

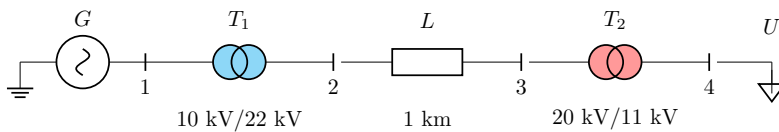


Figure 1: Single phase equivalent circuit of the considered power system.

It's a calm day until you receive a call from the load side informing you that they plan to change their power factor to 0.9 while keeping their active power absorption constant. This news catches your attention because it means you'll need to adjust the generator's excitation current. You

glance at the control panel, where the generator's current internal e.m.f. ($\bar{E}_i$) and terminal voltage ($\bar{V}_1$) values are displayed (see Figure 2). In particular, you can see that $\bar{V}_1 = 10.7 \text{ kV} \angle 0^\circ$ and $\bar{E}_i = 15 \text{ kV} \angle 25^\circ$, i.e., $\delta = 25^\circ$. Unfortunately, the exact data for the current load consumption slips your mind, leaving you with only your engineering knowledge to determine the adjustments needed. **Your task is to determine whether the excitation current of the generator should be increased or decreased to go from the actual (unknown) power factor to the new one (0.9).**

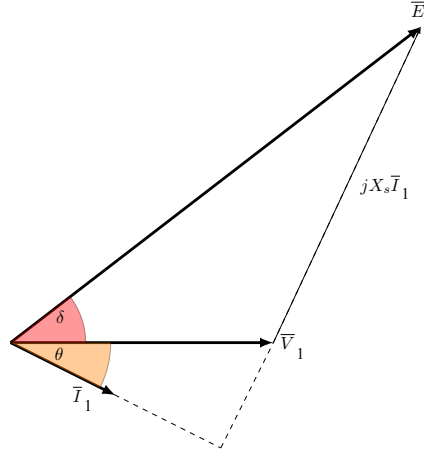


Figure 2: Control panel of the power station, displaying the generator's current internal e.m.f. ($\bar{E}_i$) and terminal voltage ($\bar{V}_1$).

By making use of the p.u. models of the devices in the system, it is asked to reply to the following questions:

1 Check the Generator's Initial Condition:

- (i) Calculate P_1 , Q_1 , and $\bar{I}_1$ at the generator terminals. Determine whether your generator is over-excited or under-excited. **(0.5 pt)**

2 Choose the Right Line Model:

- (ii) Given the parameters of the line, choose the appropriate approximation for computing the ABCD parameters. Justify your choice, and compute the ABCD for line L . **(0.5 pt)**

3 Circuit Analysis in Per Unit:

- (iii) Find the active and reactive power P_4 , Q_4 initially supplied to the load. **(1 pt)**
- (iv) Calculate the power factor of the load PF_4 under the initial conditions. **(0.5 pt)**

4 Make the Final Call on Excitation:

- (v) Based on your analysis, conclude whether you need to increase or decrease the magnitude of the generator's excitation current to adapt to the load's new power factor of 0.9. Justify your answer **qualitatively**. Consider that given the operational constraints of your system, the generator terminal voltage and active power output should stay the same. **(0.5 pt)**

Data:

The characteristics of L , G , T_1 and T_2 are contained in Table 1, 2, 3 and 4, respectively.

Parameter	Value
Resistance (r)	$0.128 \cdot 10^{-3}$ [Ohm/m]
Reactance (x)	$0.345 \cdot 10^{-3}$ [Ohm/m]
Susceptance (b)	$4.300 \cdot 10^{-9}$ [S/m]
Conductance (g)	$0.007 \cdot 10^{-9}$ [S/m]
Length (l)	$1.000 \cdot 10^3$ [m]

Table 1: Nominal Parameters of Transmission Line L

Parameter	Value
Nominal Voltage Primary	10 kV
Nominal Voltage Secondary	22 kV
Nominal Power (S_n)	200 MVA
Short Circuit Voltage (v_{cc})	10%
Short Circuit Resistance (r_{cc})	0

Table 3: Nominal Parameters of Transformer T_1

Parameter	Value
Nominal Power (S_n)	300 MVA
Nominal Voltage (V_n)	10 kV
Synchronous Reactance (x_d)	1.463 pu

Table 2: Nominal Parameters of Generator G

Parameter	Value
Nominal Voltage Primary	20 kV
Nominal Voltage Secondary	11 kV
Nominal Power (S_n)	250 MVA
Short Circuit Voltage (v_{cc})	10%
Short Circuit Resistance (r_{cc})	0

Table 4: Nominal Parameters of Transformer T_2

Solution

Q1: Calculate P_1 , Q_1 , and $\bar{I}_1$ at the generator terminals. Determine whether your generator is over-excited or under-excited.

The system consists of a generator, transformers T_1 and T_2 , and a transmission line L with specific base values for each section.

1. **System Base Values:** With the following base values:

$$V_{1b} = 10 \text{ kV}, \quad V_{2,3b} = 22 \text{ kV}, \quad V_{4b} = 12.1 \text{ kV}, \quad S_b = 300 \text{ MW},$$

the corresponding base impedances are:

$$Z_{1b} = \frac{v_{1b}^2}{s_b} = 0.333 \Omega,$$

$$Z_{23b} = \frac{v_{2b}^2}{s_b} = 1.61 \Omega,$$

$$Z_{4b} = \frac{v_{3b}^2}{s_b} = 0.488 \Omega.$$

Given the chosen bases we calculate:

$$\bar{v}_1 = 1.07 \angle 0^\circ \text{ pu},$$

$$\bar{e}_i = 1.5 \angle 25^\circ \text{ pu},$$

2. **Generator Active and Reactive Power at Initial Conditions:** Given $\bar{v}_1 = 1.07 \angle 0^\circ$ and $\bar{e}_i = 1.5 \angle 25^\circ$, with $x_d = 1.463 \text{ pu}$, we calculate:

$$p_1 = \frac{|\bar{v}_1| |\bar{e}_i|}{x_d} \sin \delta = 0.464 \text{ pu},$$

$$q_1 = \frac{|\bar{v}_1|}{x_d} (|\bar{e}_i| \cos \delta - |\bar{v}_1|) = 0.212 \text{ pu}.$$

The active and reactive powers delivered at BUS 1 are therefore:

$$P_1 = 139.1 \text{ MW},$$

$$Q_1 = 63.5 \text{ MVar}.$$

Thus, the generator supplies active power $p_1 = 0.464 \text{ pu}$ and reactive power $q_1 = 0.212 \text{ pu}$. The generator is over-excited, as it is supplying reactive power. The complex power s_1 at the generator is then given by:

$$\bar{s}_1 = p_1 + jq_1 = 0.464 + j0.212 \text{ pu}.$$

Finally, the current $\bar{i}_1$ at the generator terminals can be calculated as:

$$\bar{i}_1 = \frac{\bar{s}_1^*}{\bar{v}_1} = 0.433 - j0.198 \text{ pu}.$$

Q2: Given the parameters of the line, choose the appropriate approximation for computing the ABCD parameters. Justify your choice, and compute the ABCD for line L .

1. **Transmission Line Impedance (ABCD Model):** For the transmission line parameters:

$$\bar{z}_L = \frac{rl + jxl}{Z_{23b}} = \frac{0.128 + j0.345}{1.61} = 0.079 + j0.214 \text{ pu.}$$

since the line is 1 km long and supplied at around 20 kV, we can model it using a short-line approximation the ABCD parameters in per-unit for the line are:

$$\bar{a} = 1, \quad \bar{b} = \bar{z}_L = 0.0793 + j0.2138, \quad \bar{c} = 0, \quad \bar{d} = \bar{a}.$$

Q3: Find the active and reactive power P_4 , Q_4 initially supplied to the load and calculate the power factor of the load PF_4 under the initial conditions.

1. **Voltage and Current at Transformer T_1 (BUS 2):** The per-unit impedance of transformer T_1 is:

$$\bar{z}_{T_1} = jx_{T_1} = j \cdot v_{cc,T_1} \cdot \left(\frac{S_b}{S_{n,T_1}} \right) = j0.150 \text{ pu.}$$

Therefore,

$$\bar{v}_2 = \bar{v}_1 - \bar{z}_{T_1} \bar{i}_1 = 1.040 - j0.065 \text{ pu.}$$

The active and reactive power at the secondary side of T_1 (BUS 2) are:

$$p_2 = \Re(\bar{v}_2 \bar{i}_2^*) = 0.464 \text{ pu}, \quad q_2 = \Im(\bar{v}_2 \bar{i}_2^*) = 0.178 \text{ pu.}$$

The active and reactive powers delivered at BUS 2 are therefore:

$$P_2 = 139.1 \text{ MW},$$

$$Q_2 = 53.3 \text{ MVar.}$$

2. **Voltage and Current at the End of the Line (BUS 3):**

$$\bar{v}_3 = \bar{a}\bar{v}_2 - \bar{b}\bar{i}_2 = 0.964 - j0.142 \text{ pu,}$$

the current at BUS 3 is the same as BUS 2 because we are neglecting the shunt elements ($\bar{c} = 0$).

$$\bar{i}_3 = \bar{i}_2 = \bar{i}_1 = 0.433 - j0.198 \text{ pu.}$$

The active and reactive power at BUS 3 are:

$$p_3 = \Re(\bar{v}_3 \bar{i}_3^*) = 0.446 \text{ pu}, \quad q_3 = \Im(\bar{v}_3 \bar{i}_3^*) = 0.129 \text{ pu.}$$

The active and reactive powers delivered at BUS 3 are therefore:

$$P_3 = 133.7 \text{ MW},$$

$$Q_3 = 38.7 \text{ MVar.}$$

3. **Transformer T_2 (End of Line to Load BUS 4):** The per-unit impedance for transformer T_2 is:

$$\bar{z}_{T_2} = jx_{T_2} = j \cdot v_{cc,T_2} \cdot \left(\frac{S_b}{S_{n,T_2}} \right) = j0.12 \text{ pu.}$$

Therefore, the voltage and current at the load are:

$$\bar{v}_4 = \bar{v}_3 - \bar{z}_{T_2} \bar{i}_3 = 0.940 - j0.194 \text{ pu,}$$

$$\bar{i}_4 = \bar{i}_3 = \bar{i}_2 = \bar{i}_1 = 0.433 - j0.198 \text{ pu.}$$

The active and reactive power at BUS 4 are:

$$p_4 = \Re(\bar{v}_4 \bar{i}_4^*) = 0.446 \text{ pu,} \quad q_4 = \Im(\bar{v}_4 \bar{i}_4^*) = 0.102 \text{ pu.}$$

The active and reactive powers delivered at BUS 4 are therefore:

$$P_4 = 133.7 \text{ MW,}$$

$$Q_4 = 30.6 \text{ MVar.}$$

The initial power factor at load BUS u is:

$$\text{PF}_4 = \cos \left(\arctan \left(\frac{q_4}{p_4} \right) \right) = 0.975.$$

Q4: Based on your analysis, conclude whether you need to increase or decrease the magnitude of the generator's excitation current to adapt to the load's new power factor of 0.9. Justify your answer. Consider that given the operational constraints of your system, the generator terminal voltage and active power output should stay the same.

Since the current power factor is 0.975 and the new target power factor is 0.9, the generator excitation current must be increased to compensate for the load's higher consumption of reactive power.

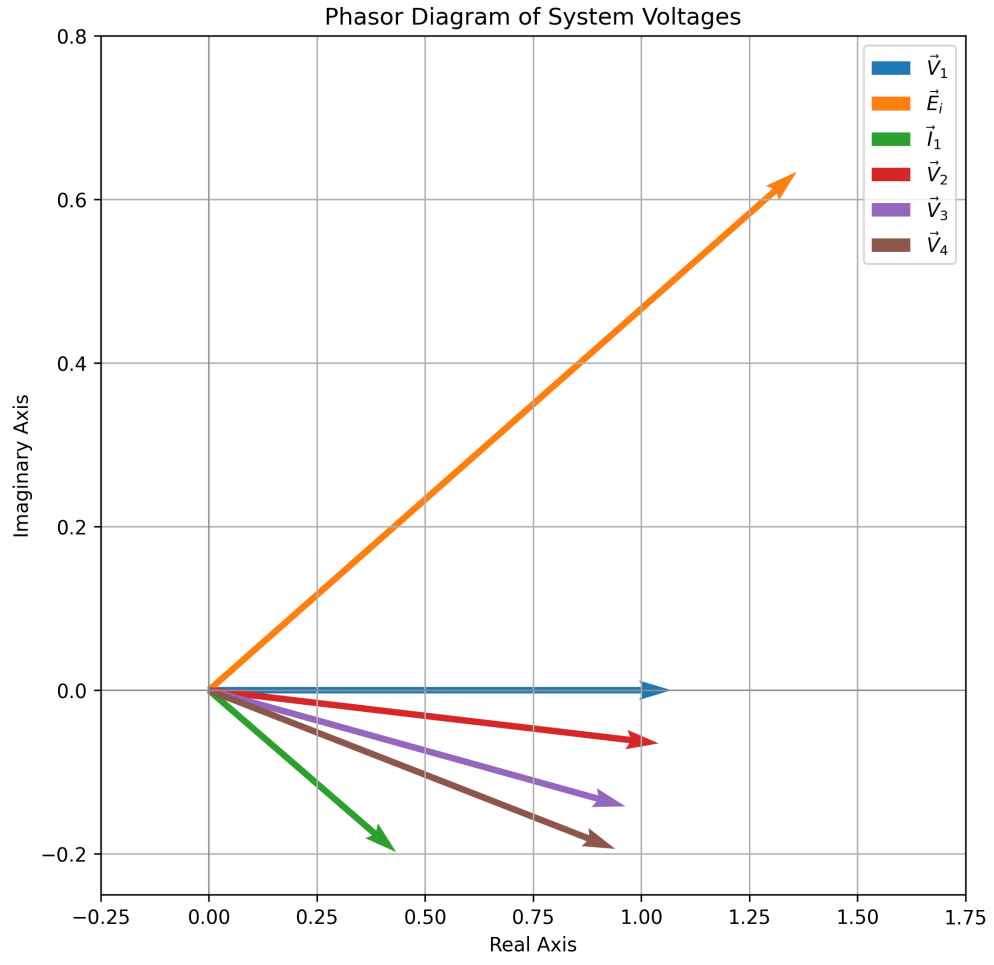


Figure 3: Phasor plot of the p.u. voltage phasors in the initial loading conditions.