EXPERIMENT Transmission Line

Transmission Lines

OBJECTIVE

This experiment demonstrates the steady-state performance characteristics of power transmission lines and some of the effects of control measures on transmission line performance.

REFERENCE

1. "Elements of Power System Analysis", Fourth Edition, William D. Stevenson, Jr., McGraw-Hill Book Company, 1982, Chapter 5.

INTRODUCTION

Figure 1 shows the internal connects of the model transmission line. The jacks and switches on the hardware correspond to the jacks and switches on the figure. Switch S_1 is used to change the line configuration from three-phase to single-phase. Switch S_2 totally disconnects the excited transmission line from the load; this feature permits testing for line regulation. The 1Ω resistors in phase A permit current measurements with the oscilloscope.

The model transmission line is made from pi-sections and is approximately equivalent to a $15kV_{L\text{-}L}$ line of 19 miles length. 19 miles is a long run for a 15*kV* line, but it is very appropriate for the laboratory since it demonstrates all the principles well.

The laboratory set-up is made as shown in Figure 2. All meters are marked to indicate their function in the system. The Data Acquisition and Control Interface, DACI, is connected to read the **input voltage** on E1 and **input current** on I1 (40A), the **output voltage** on E2 and **output current** on I2 (40A). This permits measurement of input and output power factor angles and the angle between input and output voltages by merely using the metering instruments in the software LVDAC-EMS.

The analog wattmeters on the output side is labeled Q_o. This meter is used to measure the A-phase current and the voltage difference between phases C to B. The reading from the meter is $\sqrt{3}\ Q_{phase}$.

The induction motor connected to the dynamometer provides the load for the transmission line. The other machine connected to the line output is a synchronous condenser that is used to the effects of power factor correction.

The set-up being used permits measurement of the following signals: input line-to-neutral voltage, input line current, input phase power, input power factor angle, output line-to-neutral voltage, output line current, output phase power, output power factor angle, output reactive power, and efficiency, angle between input and output voltage, and voltage drop. Transmission line regulation is found by using switch S_2.

All measurements during this laboratory experiment are made for a 70*V* line-to-neutral output voltage. This is because the power grid is based on a known constant output voltage to the customer. The measurements made during Parts 5, and 6 will indicate the problem of voltage control in a transmission system from the generating end.

SUGGESTED PROCEDURE

1. Connect the system shown in Figure 2. Connect the system exactly as shown. Failure to do so may preclude measurement of some quantities. Use Figure 3 to connect the analog watt-meter (device Q_o in Figure 2). Set all fluke ammeters (A0, A1) to **manual 10A range** using the up and down buttons.

2. Remove the dynamometer lock. Make sure that the torque meter is set to 0 Newton-meters before energizing the transmission line and that it only reads positive torques as the motors start running. Start by smoothly increasing the output voltage from the 3ϕ AC Source until the transmission line output voltage is $70V_{LN}$ The input voltage Vin (E1) should be about $120V_{LN}$ this will change as we maintain Vout (E2) at $70V_{LN}$. Apply 0.5Adc to the field of the **synchronous condenser** (the unloaded motor). These actions energize the transmission line and start both machines. This action has established the “base case”. Open the metering instruments in the software LVDAC-EMS. Check the current ranges for Iin (I1) and Iout (I2) are set to 40A on the right-hand menu. Set up the 9 meter displays to measure the input line-to-neutral voltage, input line current (40A), input phase power (E1, I1), phase shift between the input voltage E1 and current I1, output line-to-neutral voltage (E2), output line current (I2), output phase power, phase shift between the output voltage (E2) and current (I2), and phase shift between input and output voltage. Record all the data for the base case, including the power factor angles based on the phase shifts

f = line frequency

ΔTimeVI = Time delay between V, and I

Pf angle = TimeVI * f * 360°   power factor angle

ΔTimeVinVout = Time delay between Vin, and Vout

Vin-Vout angle = TimeVinVout * f * 360°   angle between Vin and Vout

<u>Iexc</u>	**Vin L-N**	**Iin**	**Pin**	**Pfin angle**	**Vout L-N**	**Iout**	**Pout**	**Pfout angle**	**Qout**	**Vin-Vout angle**
0.5A					**70V**					

Base Case

3. To find the voltage regulation turn switch S_2 to the off position and measure the output voltage. This one measurement is sufficient to demonstrate regulation. Turn switch S_2 back to the on position.

Voltage Regulation: $VR = \frac{Vnl - Vfl}{Vfl} \times 100\%$

	V_{IN}	V_{OUT}
Switch S2 on loaded		**70V**
Switch S2 off unloaded		

4. Place 5 load bank switches up and apply field excitation to the dynamometer until the induction motor is **loaded to 0.8** Newton-meters of torque. Adjust the 3-ϕ AC Source for 70*V* **line to neutral** transmission line output voltage. Repeat the measurements made in Part 2. Note particularly the changes in the power factors, voltage angle, and voltage drop.

<u>Iexc</u>	**Vin L-N**	**Iin**	**Pin**	**Pfin angle**	**Vout L-N**	**Iout**	**Pout**	**Pfout angle**	**Qout**	**Vin-Vout angle**
0.5A					**70V**					

Loaded 0.8 Newton-meters

5. Return the system to the base case. Fill out Table 1 by increasing the field excitation of the synchronous condenser from 0.5 ADC to 2.5 ADC. Keep output voltage constant (70 *V*) during the measurements.

Iexc	**Vin L-N**	**Iin**	**Pin**	**Pfin angle**	**Vout L-N**	**Iout**	**Pout**	**Pfout angle**	**Qout**	**Vin-Vout angle**
0.5A					**70V**					
1.0 A					**70V**					
1.5 A					**70V**					
2.0 A					**70V**					
2.5 A					**70V**					

Table 1 Base Case

6. Repeat Part 5, this time applying field excitation to the dynamometer until the induction motor is loaded to 0.8 Newton-meters and record your data in Table 2.

Iexc	**Vin L-N**	**Iin**	**Pin**	**Pfin angle**	**Vout L-N**	**Iout**	**Pout**	**Pfout angle**	**Qout**	**Vin-Vout angle**
0.5A					**70V**					
1.0 A					**70V**					
1.5 A					**70V**					
2.0 A					**70V**					
2.5 A					**70V**					

Table 2 0.8N-M Load

7. Fill out Tables 3 and 4. The quantity ***X_L*** is the per-phase reactance, *L* is the per-phase inductance, and *R* is the per-phase resistance.

Base Case Calculations (part 2.)

S_{IN}		Q_{IN}		Q_{loss}	
S_{OUT}		Q_{OUT}		P_{loss}	
X_L		L		R	

Table 3 Base case per-phase Calculations

Loaded Line Calculations (part 4.)

S_{IN}		Q_{IN}		Q_{loss}	
S_{OUT}		Q_{OUT}		P_{loss}	
X_L		L		R	

Table 4 Loaded line per-phase Calculations

Have instructor sign off the calculations before you leave the lab.

Use these calculations to study for the quiz.

Review for quiz

1. Explain the differences between the measurements of Part 2 base case and Part 4 loaded case. Discuss the differences in:
- Voltage Drop across TL
- Current flow through TL
- Real power drop in the transmission line Pin-Pout (losses in the TL)
- Input and output power factor angles
- Input and output Q's
- Imaginary power drop in the transmission line Qin-Qout

Remember voltages, currents, and impedances are complex.

2. Using data from Part 3, find voltage regulation of the transmission line. **Note**: use the base case value as the full load value.

Voltage Regulation: $VR = \frac{Vnl - Vfl}{Vfl} \times 100\%$

3. Describe the impact of load-side power factor correction on the operation of the transmission line. Relate your description to the measurements from Parts 5, and 6.

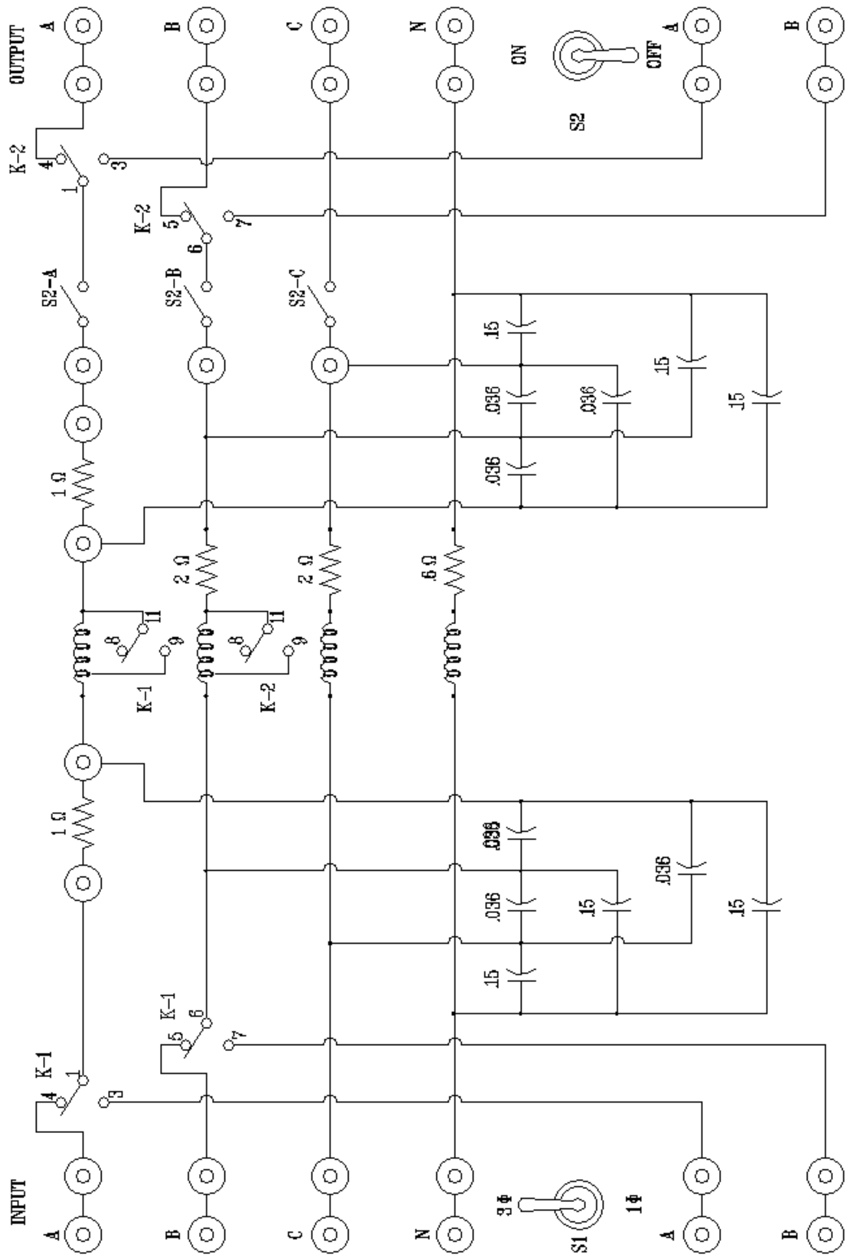
Describe impact of Load-side power factor correction on these quantities:

- Voltage drop across TL
- Current flow through TL
- Real power Pin, and Pout
- Real power drop in the transmission line Pin-Pout (losses in the TL)
- Input and output power factor angles
- Input and output Q's
- Imaginary power drop in the transmission line Qin-Qout

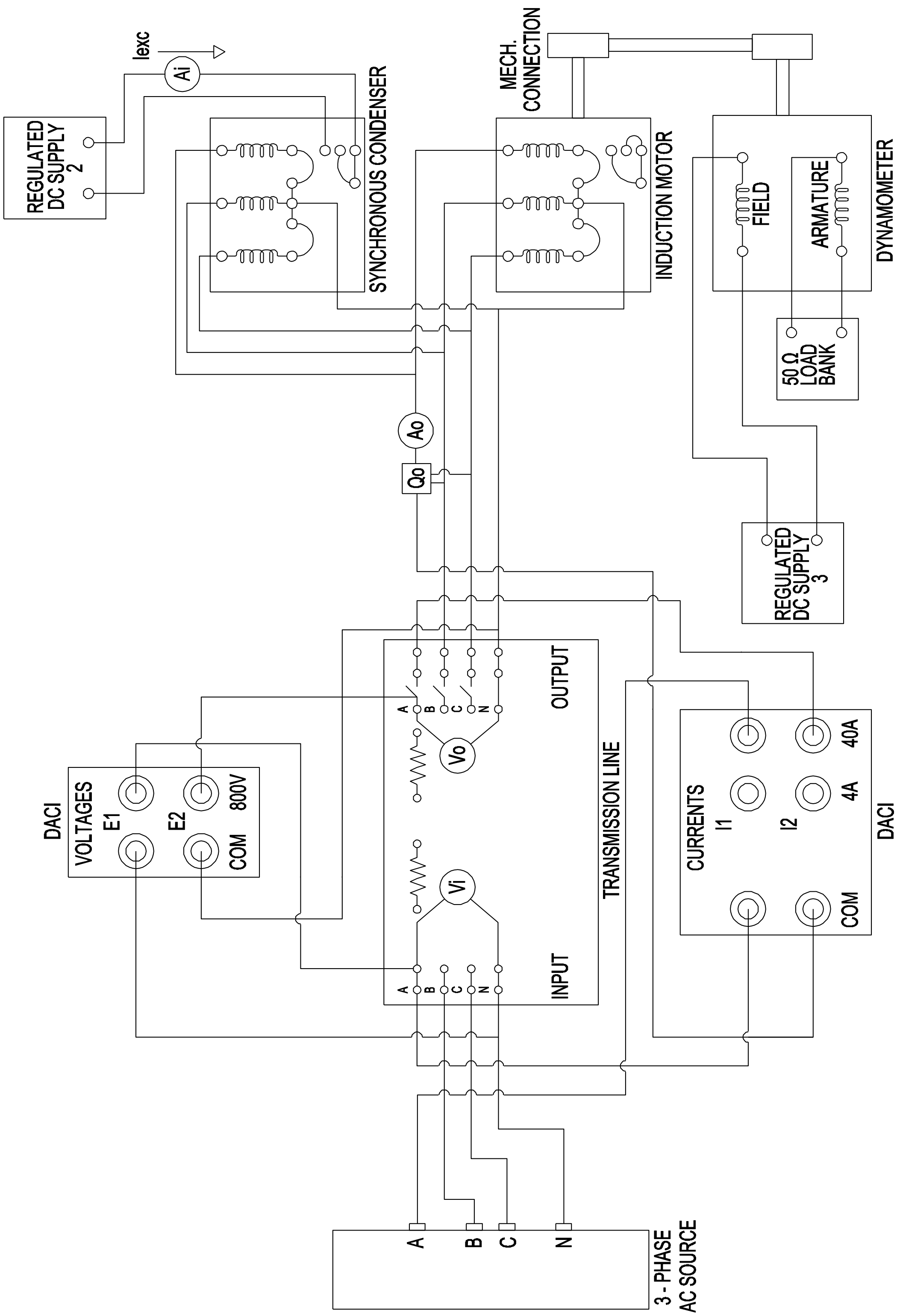
Remember voltages, currents, and impedances are **complex**

4. Explain how a wattmeter can be used to measure reactive power, as done in this experiment. Must show proof such as **vector drawing** of V, I remember that a wattmeter measures **real power**.

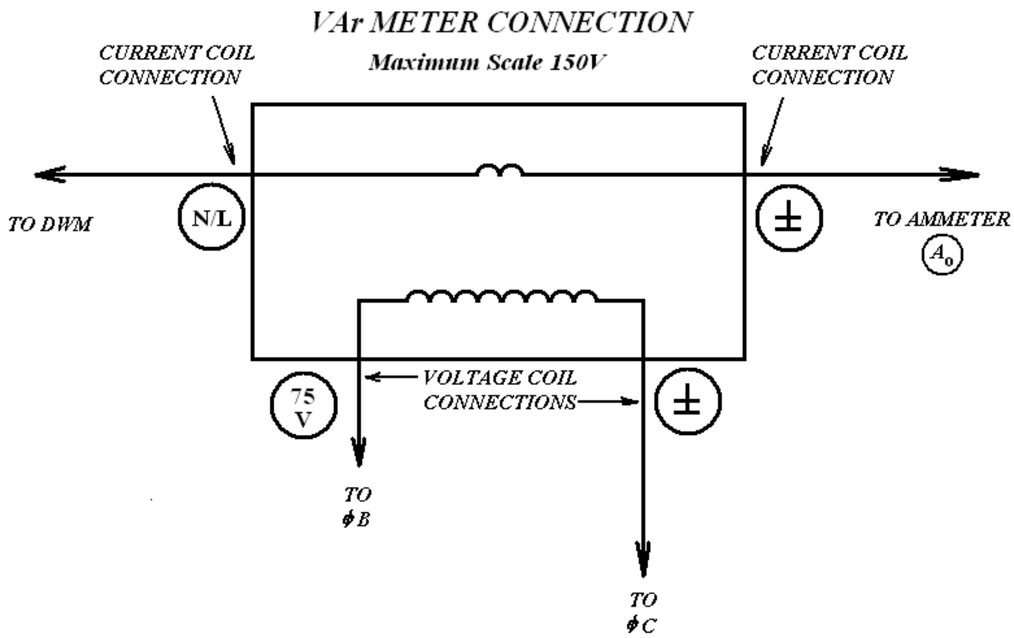
5. Determine the per-phase **inductance** and **resistance** of the model transmission line and explain how you found it. Show all work.

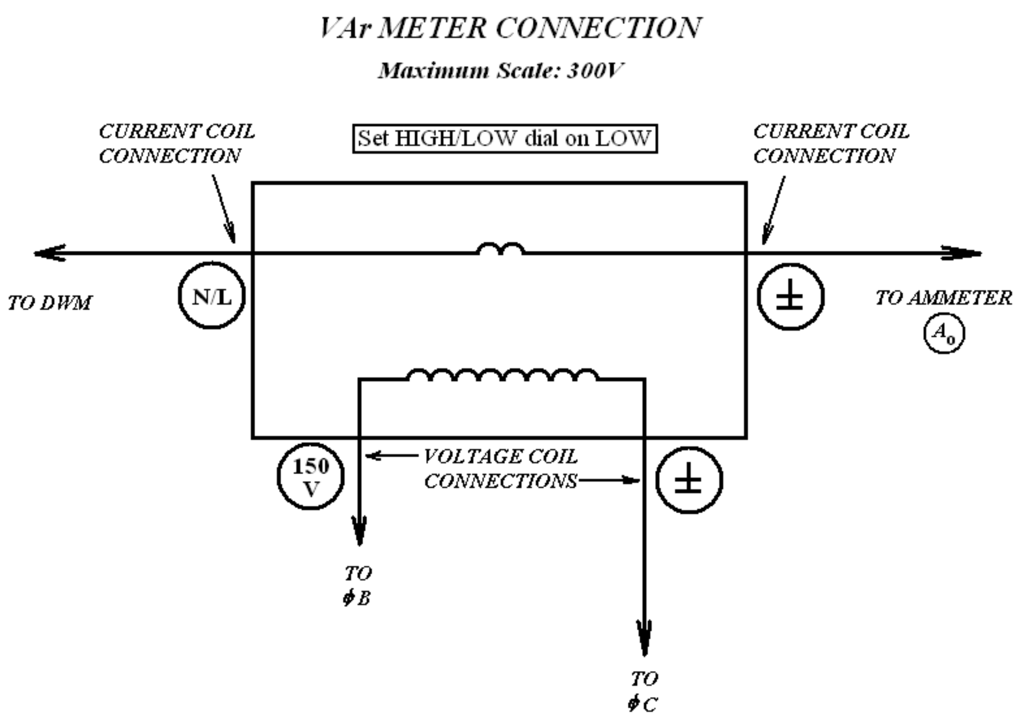


<u>Figure 1</u>: MODEL TRANSMISSION LINE



<u>Figure 2</u>: TEST CONNECTIONS





<u>Figure 3</u>: ANALOG WATT-METER CONNECTIONS