

Electric Power / Controls

Courseware Sample

85279-F0



ELECTRIC POWER / CONTROLS

COURSEWARE SAMPLE

by
the Staff
of
Lab-Volt Ltd.

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Introduction

The Lab-Volt 2-kW Electric Power Transmission Training Systems of the 8059 series are designed to learn by hands-on exercises the principles of transmission of electric power – a subject which is usually taught in a strictly theoretical way.

The exercises show how changes in the source, the load, and the transmission line affect the overall performance of the system. In particular, they illustrate the meaning of active and reactive power, how the voltage at the end of a line can be lowered or raised, how power can be forced to flow over one transmission line instead of another, and how a system behaves when subjected to disturbances. The tests relating to switching transients, sudden overloads and momentary short-circuits dramatically demonstrate the mechanical swing of generator poles and the concurrent surges of power over the transmission line. More than any amount of theory could show, these exercises convey the meaning of power stability and the limits to power flow.

Alternator, motor, capacitors, reactors, resistors, meters, regulating autotransformer, series compensator, and transmission lines are employed. Despite their small size, these components are designed to act in exactly the same way under steady-state and transient conditions, as their larger counter parts in industry. This practical, hands-on course is presented in a way that is readily understandable by anyone who has knowledge of electricity at the technical school.

The 2-kW Electric Power Transmission Training Systems are available in four versions. Model 8059-2 is a complete system using analog meters to perform the measurements. Model 8059-4 is also a complete system but it uses a data acquisition interface to perform the measurements. Model 8059-3 is an add-on system to the 2-kW Electromechanical Training System, Model 8013. It provides the equipment to be added to the 8013 to perform the exercises using analog meters. Model 8059-5 is similar to the 8059-3 but it uses a data acquisition interface to perform the measurements.

Courseware Outline

2-kW ELECTRIC POWER TRANSMISSION SYSTEM

- Exercise 1 Power Measurements**
Active and Reactive Power Flow.
- Exercise 2 Voltage Regulation and Power Transmission Capability of a Transmission Line**
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- Exercise 3 Shunt Capacitors and Phase Angle Between Sender and Receiver**
Shunt Capacitors.
- Exercise 4 Parameters Affecting Active and Reactive Power Flow**
Power Flow. Reactive Power. Active Power. Three-Phase Regulating Autotransformer.
- Exercise 5 Power-Handling Capability and Parallel Lines**
Power Handling Capability. Transmission Line Voltage versus Power Handling Capability. Transmission Lines in Parallel versus Power Handling Capability.
- Exercise 6 Effects of Series Compensation on the Power Transfer Capability and System Stability**
Series Compensation. System Stability.
- Exercise 7 Effect of Series Compensation on the Voltage Regulation and Power Factor**
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- Exercise 11 Transmission Line Networks and the Three-Phase Regulating Autotransformer**
Transmission Line Networks. Regulating Autotransformer.

Courseware Outline

2-kW ELECTRIC POWER TRANSMISSION SYSTEM

Exercise 12 The Synchronous Motor Under Load

Synchronous Motor Under Load. Synchronous Motor and Transmission Line.

Exercise 13 Hunting and System Oscillation

Synchronous Motor and Sudden Load Changes. Analogy with an Inertia Wheel Driven by Various Shaft Sizes. Synchronous Motor and Transmission Line.

Exercise 14 Power System Transients

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Appendix A Motor and Generator Coupling

Appendix B Phase Shift Indicator

Appendix C Voltage Increase Using Step Up and Step Down Transformers

Appendix D Equipment Utilization Chart

Appendix E Impedance and Load Table

Appendix F Connection Diagrams for Systems 8059-2 and 8059-3

Appendix G LVDAM Application

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Sample Exercise
Extracted from
2-kW Electric Power
Transmission System

Effects of Series Compensation on the Power Transfer Capability and System Stability

EXERCISE OBJECTIVE When you have completed this exercise, you will be familiar with the effects of series compensation on the power transfer capability and stability of a transmission line.

DISCUSSION OUTLINE The Discussion of this exercise covers the following points:

- Series Compensation
- System Stability

DISCUSSION **Series Compensation**

When the power demand becomes high, there will come a time when an additional transmission line is required. Obtaining a corridor, environmental impact limitations, and line cost can all make provision of a new line difficult. A preferred option is to increase the power transfer capability of an already existing line by means of series compensation.

Series compensation consists in reducing the inductive reactance of a transmission line by connecting a capacitor in series with the line as shown in Figure 39. With this method, the active power transferred through the line becomes:

$$P_T = \frac{E_S \times E_R}{X_L - X_{CS}} \times \sin \theta \quad (25)$$

where P_T is the transferred power (W)
 E_S is the line sender voltage (V)
 E_R is the line receiver voltage (V)
 X_L is the inductive reactance of the line (Ω)
 X_{CS} is the capacitive reactance of the series compensator (Ω)
 θ is the phase shift between the sender and receiver voltages ($^\circ$)

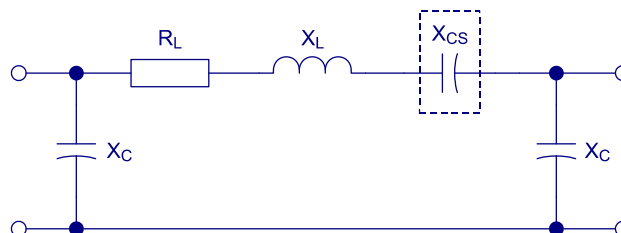


Figure 39. Equivalent circuit of a transmission line with series compensation.

The decrease in line reactance created by series compensation is named compensation factor, k . The value of k is given by:

$$k = \frac{X_{CS}}{X_L} \quad (26)$$

The power transfer capability of a line increases as the compensation factor is increased. The increase in power transfer capability, as a percentage, for a given compensation factor is given by:

$$\text{increase in power transfer capability} = \frac{k}{1-k} \times 100 \quad (27)$$

If, for example, the line is compensated 34%, the increase in power transfer capability will be 51,5%. Compensation factors between 20 and 70% are usual, thereby providing an increase in power transfer capability between 25 and 233%.

System Stability

Because series compensation increases the power transfer capability, it also improves the system stability. In effect, for any given phase shift between the sender and receiver voltages, the amount of transferred power is greater with a compensated line. As an example, Figure 40 shows the power transfer capability of a line with 50% compensation and without series compensation.

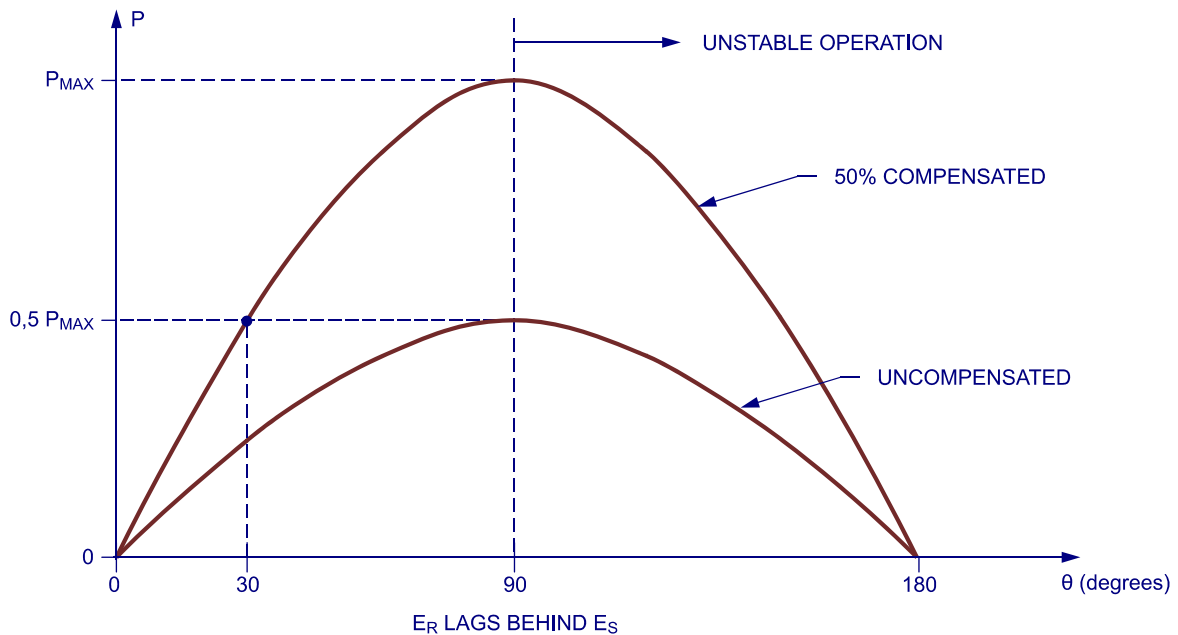


Figure 40. Power transfer capability of a transmission line with and without series compensation.

If the maximum power demand is $0,5 P_{MAX}$, the phase shift between the sender and receiver voltages will be 30° for the compensated line, which corresponds to a stable operating point. However, the phase shift will be 90° for the

uncompensated line, which is just on the edge of instability. In all likelihood, the uncompensated line will be unable to carry the load and its breakers will open.

PROCEDURE OUTLINE The Procedure is divided into the following sections:

- Basic Setup
- Power Measurements

PROCEDURE **Basic Setup**

1. Refer to the Equipment Utilization Chart in Appendix D to obtain the list of equipment required for this exercise.
2. Set up the circuit shown in Figure 41.

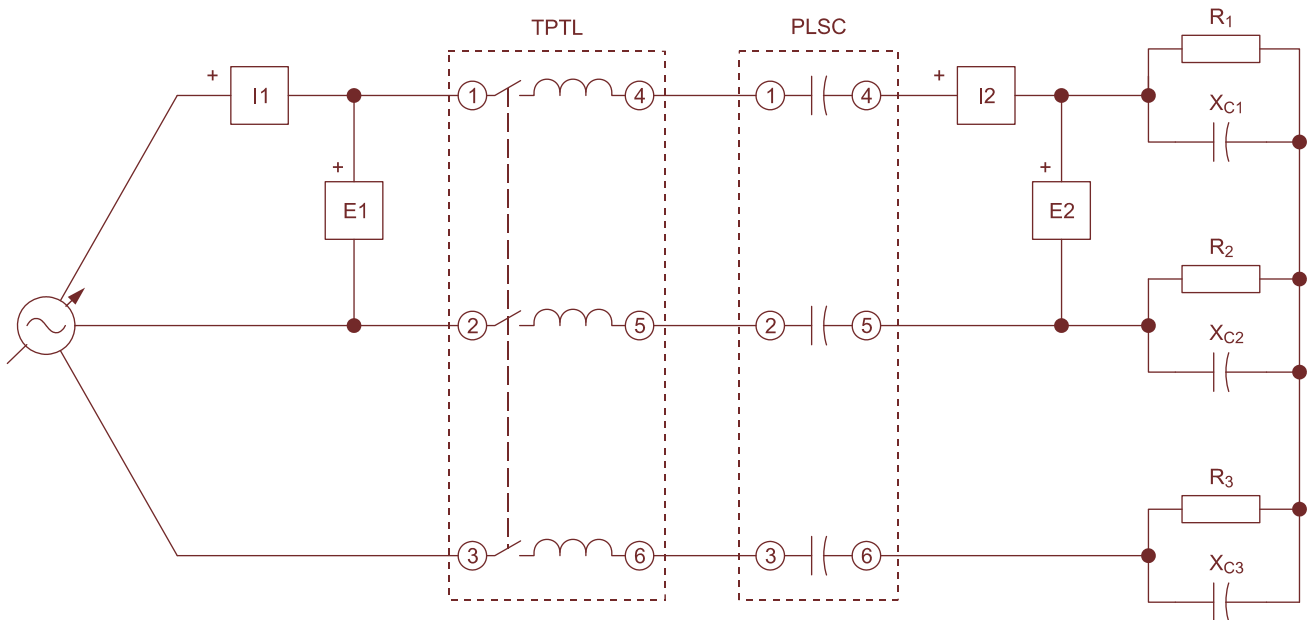


Figure 41. Transmission line with series compensation.

PLSC in Figure 41 means Power Line Series Compensator.

3. Set the Three-Phase Transmission Line to simulate a 125-km long transmission line (50 Ω).

Note: The Power Line Series Compensator requires 220 V for its operation. Connect its terminals L and N to a fixed-voltage line terminal and a neutral terminal on the Power Supply.

Set the Power Line Series Compensator to 0 Ω.

4. Set the Resistive Load and Capacitive Load modules to obtain the maximum power transfer capability of the 125-km long transmission line without series

compensation found in the previous exercise (values from the last row of Table 18).

Power Measurements

Caution!



High voltages are present in this laboratory exercise! Do not make or modify any connections with the power on!

- Turn on the Power Supply, and set the line voltage E_S to 380 V.

Run the LVDAM application and open configuration file 85279.dai. Make sure that the configuration file corresponds to the exercise needs.

- Enter the measured values of voltage, power, and phase angle in the 0 Ω row of Table 19.

Table 19. Power flow without series compensation.

X_{CS} (Ω)	E_S (V)	P_S (W)	E_R (V)	P_R (W)	θ ($^\circ$)
0	380				
8,5	380				
17	380				

- Insert compensation by setting the Power Line Series Compensator to 8,5 Ω while observing the phase angle value.

Note: Series compensation has decreased the phase angle required to transfer the same amount of power, which improves the stability of the system.

- Increase the load by setting the Resistive Load modules to 125 Ω .

Make sure the line voltage E_S is still set to 380 V, and readjust the shunt capacitor.

Enter the measured values of voltage, power, and phase angle in the appropriate row of Table 19.

- Calculate the increase in power at the receiver end using your measured values and Equation (29).

$$\text{increase in power (\%)} = \frac{P_{\text{compensated}} - P_{\text{uncompensated}}}{P_{\text{uncompensated}}} \times 100 \quad (28)$$

Increase in power from the measured values: _____

10. Calculate the increase in power transfer capability using Equation (27).

Increase in power transfer capability: _____

11. Increase the series compensation by setting the Power Line Series Compensator to 17 Ω while observing the phase angle value.

Note: *Observe that the phase angle decreases when series compensation is increased.*

12. Increase the load by setting the Resistive Load modules to 97 Ω .

Repeat Procedure step 8.

13. Calculate the increase in power at the receiver end from the measured values and the increase in power transfer capability.

Increase in power from the measured values: _____

Increase in power transfer capability: _____

Note: *Both values should be approximately equal. However, the values will differ if the phase angle θ measured with compensation and without compensation is different.*

14. Turn off the Power Supply, disconnect the circuit, and return the equipment to the storage location.

CONCLUSION

In this exercise you observed that series compensation can improve the power transfer capability and the stability of a transmission line.

REVIEW QUESTIONS

1. How does series compensation increase the power handling capability of a transmission line?

2. The power transfer capability of a transmission line decreases as the compensation factor is increased.

Yes No

3. Explain why series compensation also increases the system stability.

Instructor Guide
Sample Exercise
Extracted from
2-kW Electric Power
Transmission System

Exercise 11 Transmission Line Networks and the Three-Phase Regulating Autotransformer

ANSWERS TO PROCEDURE STEP QUESTIONS

4.

Table 28. Regulating autotransformer.

Buck Boost (%)	Phase Shift (°)	Supply Voltage (V)	Output Voltage (V)	Phase Angle (°)	Leading or Lagging ¹
0	0	380	380	0	—
0	+15	380	380	+15	leading
0	-15	380	380	-15	lagging
+15	0	380	437	0	—
+15	+15	380	437	+15	leading
+15	-15	380	437	-15	lagging
-15	0	380	323	0	—
-15	+15	380	323	+15	leading
-15	-15	380	323	-15	lagging

(1) Use E1 as the reference phasor

5. Yes.

6. Buck-boost settings are still correct but the phase shift settings are inverted.

Note: Note that the Phase Sequence pilot lights show a wrong sequence.

10.

Table 29. Power flow and voltage measurements (TL1 and TL2 = 43.5 km).

Buck Boost (%)	Phase Shift (°)	TL1				TL2				E _R (V)
		X _L (Ω)	E _s (V)	P _s (W)	Q _s (var)	X _L (Ω)	E _s (V)	P _s (W)	Q _s (var)	
0	0	17	220	29	29	17	220	29	29	220
0	+15	17	218	389	69	17	220	-324	83	215
0	-15	17	223	-328	79	17	220	394	73	218
+15	0	17	254	56	280	17	220	15	-181	236
-15	0	17	189	11	-162	17	220	44	243	203
+15	+15	17	250	471	318	17	220	-395	-114	231
-15	-15	17	190	-300	-116	17	220	358	279	202
Resistive and inductive loads: 880 Ω per phase										

11. Each line carries the same amount of active and reactive power when there is no phase shift and no buck-boost.

12. The active power is positive on the line when the voltage is leading. Conversely it is negative on the line when the voltage is lagging.

13.

Table 30. Power flow and voltage measurements (TL1 = 43,5 km, TL2 = 0 km).

Buck Boost (%)	Phase Shift (°)	TL1				TL2				E _R (V)
		X ¹ (Ω)	E _s (V)	P _s (W)	Q _s (var)	X ¹ (Ω)	E _s (V)	P _s (W)	Q _s (var)	
0	0	17	220	0	0	0	220	61	56	220
0	+15	17	216	692	49	0	220	-617	191	220
0	-15	17	224	-696	132	0	220	763	106	220
+15	0	17	252	42	475	0	220	20	-355	220
-15	0	17	186	-32	-355	0	220	96	474	220
+15	+15	17	245	842	498	0	220	-763	-178	217
-15	-15	17	189	-639	-238	0	220	709	507	218
Resistive and inductive loads: 880 Ω per phase. (1) Inductance of the transmission line.										

Note: Setting the inductance of the Three-Phase Transmission Line module to 0 Ω corresponds to a very short line, which naturally would tend to carry the entire active and reactive load. Observe that by changing the phase-shift and the voltage ratio (buck-boost) of the Three-Phase Regulating Autotransformer, the flow of power can be drastically modified.

**ANSWERS TO REVIEW
QUESTIONS**

1. Maximum active power delivered: 100 MW.
Phase angle: 60° leading.

2. The maximum power through the $200\ \Omega$ line: 50 MW.
The maximum power through the $100\ \Omega$ line: 100 MW.
Total maximum power: 150 MW.

3. No.

4. Phase shift of T1: 15° .
Voltage ratio: 1.04 (E_R/E_S).

Bibliography

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