EE3541, Experiment 12
Transmission Lines

Jonathan Kimball, August 31, 2020

Abstract

This experiment uses LabVolt equipment that emulates common power system components, such as transmission lines and transformers. At a small scale, you will explore voltage regulation of a transmission line with different types of load.

1   Introduction

A transmission line which delivers electric power dissipates heat owing to the resistance of its conductors. It acts, therefore, as a resistance which in some cases is many miles long. The transmission line also behaves like an inductance, because each conductor is surrounded by a magnetic field which also stretches the full length of the line. Finally transmission line behaves like a capacitor, the conductor acting as its more or less widely-separated plates.

The resistance, inductance and capacitance of a transmission line are uniformly distributed over its length, the magnetic field around the conductors existing side by side with the electric field created by the potential difference between them. We can picture transmission line as being made of thousands of elementary resistors, inductors and capacitors as shown in Figure 1.

In high frequency work, this is precisely the circuit which has to be used to explain the behavior of a transmission line. Fortunately, at low frequencies of $50\,\mathrm{Hz}$ or $60\,\mathrm{Hz}$, we can simplify most lines so that they comprise one inductance, one resistance and one (or sometimes two) capacitor. Such an arrangement is shown in Figure 2. Here the inductance L is equal to the sum of the inductors of Figure 1, and the same is true for the resistance R. The capacitance C is equal to one half of the sum of the capacitors shown in Figure 1. Inductance and capacitances are replaced by X_L and X_C, respectively, in Figure 3.

The relative values of R, X_L, and X_C depend upon the type of transmission line. Short, low-voltage lines such as in a house wiring are mainly resistive, and the inductive and capacitive reactance can be neglected (Figure 4(a)). Medium-voltage lines and medium length
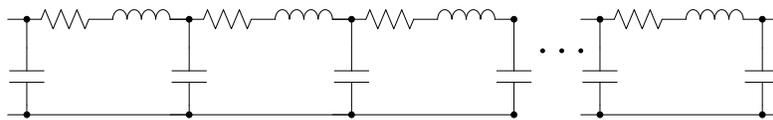

Figure 1: Ladder equivalent circuit for transmission line.
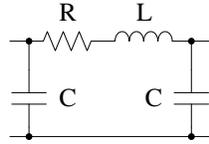
Figure 2: Time-domain π model.
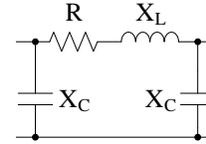
Figure 3: Phasor-domain π model.

(a)   (b)   (c)
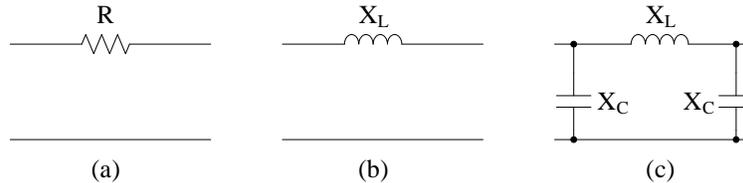
Figure 4: Simplified models of transmission line depending on application and length.

high-voltage lines (e.g. 100 kV and several miles long) will have negligible resistance and capacitive reactance compared with the inductive reactance. Such lines can be represented by a single reactance X_L, shown in Figure 4(b). Finally very high voltage lines which run for many miles have appreciable capacitive *and* inductive reactances and may be designated by a circuit similar to Figure 4(c).

Most transmission lines can be represented by Figure 4(b), a single inductive reactance, so this model will be used in this experiment.

As for a transformer, the voltage regulation of a transmission line,

$$VR[\%] = \frac{V_{nl} - V_{fl}}{V_{nl}} \times 100\% \tag{1}$$

describes the change in voltage at the receiving end of the line for fixed voltage at the sending end and changing load of a specified power factor. Here, V_{nl} is the no-load voltage and V_{fl} is the full-load voltage (at specified power factor), magnitude. Notice that the denominator is the *no-load* voltage.

Resistive and inductive loads produce unacceptably large voltage drop. Therefore, some mechanism for maintaining voltage is required. A typical approach is to add capacitors at the receiving end to provide the reactive power needed by the load and the line.

2   Laboratory Software

In this set of experiments, you will use the LabVolt rack shown in Figure 5. Use four-wire wye connections throughout, and make sure that loads are always balanced.

The Yokogawa will be used to make two or three single-phase power measurements. Always measure phase A line-to-neutral.

The oscilloscope and two voltage probes will be used to measure phase angles.
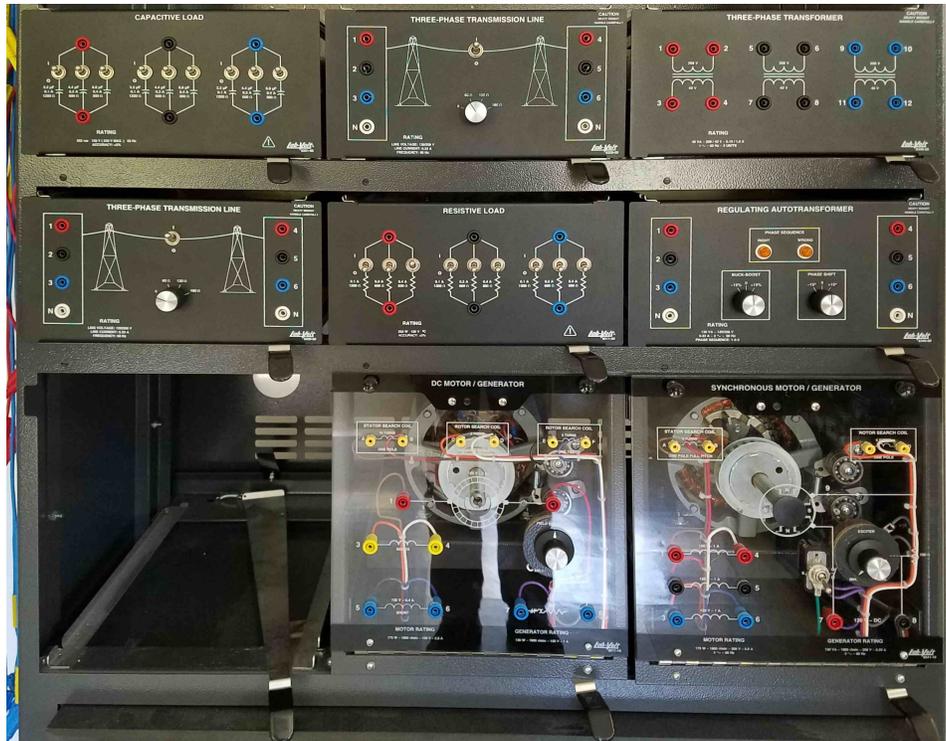
Figure 5: LabVolt equipment for low-power experiments on power distribution networks.

3 Laboratory Experiment

Part 1

Connect as in Figure 6. Notice that both power meter channels are connected to phase A, line-to-neutral. Set the transmission line impedance to $120\,\Omega$.

First, leave the load unconnected entirely. Turn on the variac and adjust to $150\,V$ line-to-line. Record Yokogawa readings for channels 1 and 2 (sending and receiving ends of the transmission line). Label this test point "open circuit." Turn off the breaker but leave the variac setting constant.

Then test each of the following conditions. For each test, connect the load appropriately, turn on the breaker, record Yokogawa readings, then turn off the breaker.

- Short circuit—place shorting wires in place of the load

- Resistive load—use the EMS 8311 set to $300\,\Omega$

- Capacitive load—use the EMS 8331 set to $300\,\Omega$

- Inductive load—use the EMS 8241 synchronous machine stator windings

Part 2

Return to a purely resistive load (exactly as shown in Figure 6) and record Yokogawa readings for the resistance settings listed in Table 1. You do not need to turn off the breaker between
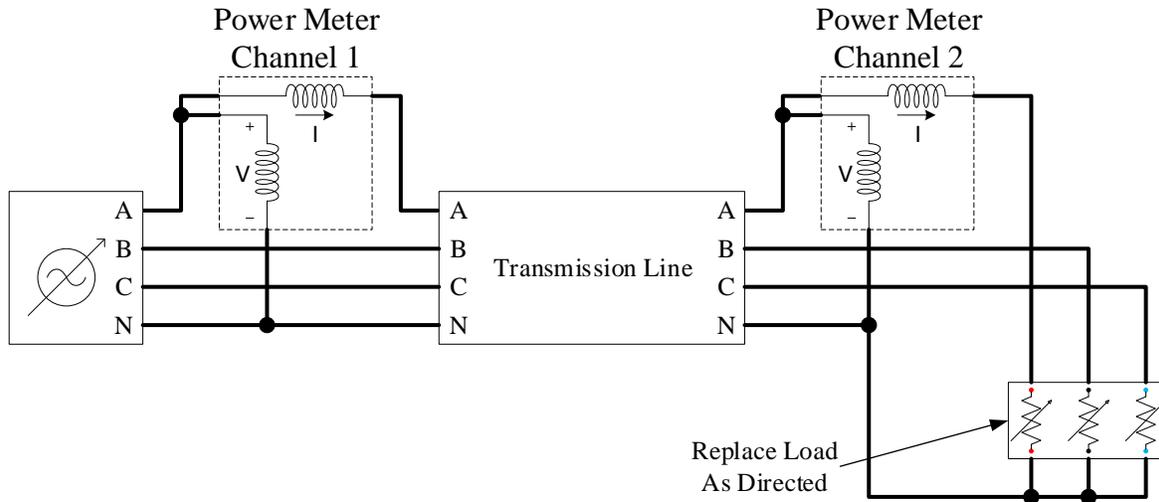
Figure 6: Configuration for experiment with a single load (swap out the resistive load box).

test points, but you do need to make sure all three phases are set the same before taking data. The effective resistance is listed in the first column, and the switch settings in the remaining columns.

Table 1: Resistive Load Settings

Total Resistance [$\Omega/phase$]	1200 Ω	600 Ω	300 Ω
∞	0	0	0
1200	1	0	0
600	0	1	0
400	1	1	0
300	0	0	1
240	1	0	1
200	0	1	1
171.4	1	1	1

As discussed above, a common solution to regulate the voltage is to add capacitors. Reconnect as in Figure 7. Now there are both resistance and capacitance in parallel. Test each of the load conditions listed in Table 2, again recording Yokogawa readings.

4   Calculations and Question

1. Find the percent voltage regulation in part 1. What does a positive/negative voltage regulation indicate?

2. Draw the terminal voltage vs. active power at the load terminal of part 2, both with and without VAR compensation. Discuss.
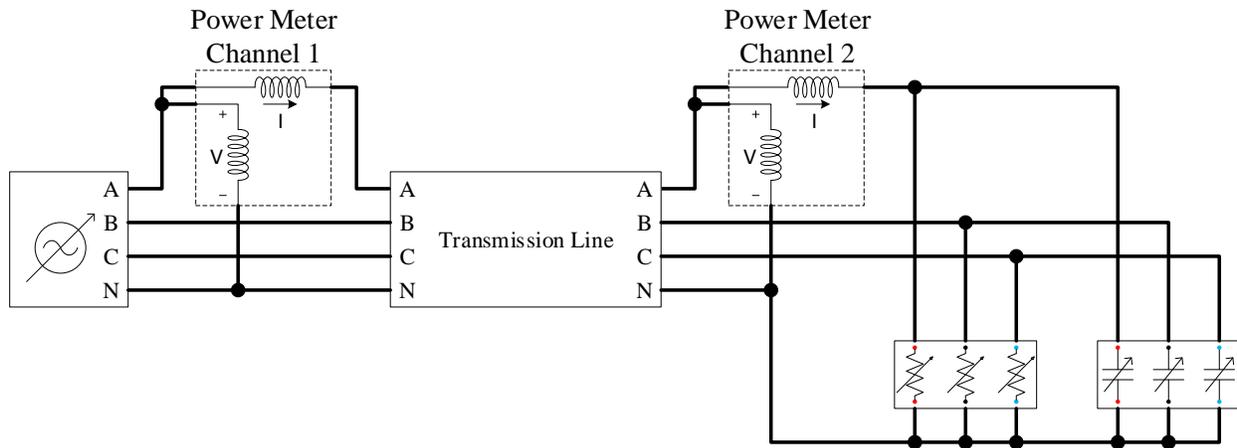
Figure 7: Experimental configuration with VAR compensation.

Table 2: Resistive Load Settings With VAR Compensation Capacitors

Resistance	Reactance
∞	∞
1200	∞
600	1200
400	1200
300	600
240	600
200	400
171.4	240

3. If the transmission line were purely resistive, would it be possible to raise the receiving end voltage by using static capacitors? Explain.