12.4.1: Apparent Power and Power Factor

Overview:

This lab assignment emphasizes the use of apparent power and power factor to quantify the AC power delivered to a load and the power dissipated by the process of transmitting this power.

Initially, our load will be inductive in nature. The power delivered to the load will be transmitted via a resistive network. The apparent power, average power, and power factor associated with the circuit will be measured and related to expectations based on analysis of the circuit. It will be seen that the difference between the apparent power and the average power, as quantified by the power factor, influences the amount of power which is dissipated during power delivery relative to the power provided to the load. We will see that a low power factor corresponds to a situation in which a relatively large amount of power is dissipated in the process of delivering power to a load.

After examining the inductive load, we will modify the load impedance by adding a capacitive component to the load. This will increase the power factor of the load, which will result in more efficient power delivery to the load.

Before beginning this lab, you should be able to:

- Perform frequency-domain analysis of electrical circuits
- Use peak and RMS values to calculate average power
- Calculate power factor from given voltage and current waveforms
- Use peak and RMS values to calculate apparent power

After completing this lab, you should be able to:

- Measure the power factor and apparent power delivered to a load by an AC source
- State the effect of power factor on the power dissipation due to transmitting power to a load

This lab exercise requires:

- Analog Discovery module
- Digilent Analog Parts Kit
- Digital multimeter (optional)

Symbol Key:

DEMO — Demonstrate circuit operation to teaching assistant; teaching assistant should initial lab notebook and grade sheet, indicating that circuit operation is acceptable.

ANALYSIS — Analysis; include principle results of analysis in laboratory report.

SIM — Numerical simulation (using PSPICE or MATLAB as indicated); include results of MATLAB numerical analysis and/or simulation in laboratory report.

DATA — Record data in your lab notebook.

General Discussion:

A typical power delivery system is shown in Figure 1. The source provides power to some load via a transmission line. The transmission line typically has some resistance, R_T. The process of delivering power to the load results in undesirable power losses due to the transmission line resistance. One primary goal of power delivery is to provide the necessary average power to a load with a minimum of power lost during the process of the power delivery. Unfortunately, the reactive power (which is not useful to the load) causes power losses during transmission. Thus, it is desirable to minimize the reactive power delivered to the load in order to reduce the average power dissipated during transmission, relative to the average power delivered to the load. The apparent power and the power factor make it relatively easy to quantify these effects.

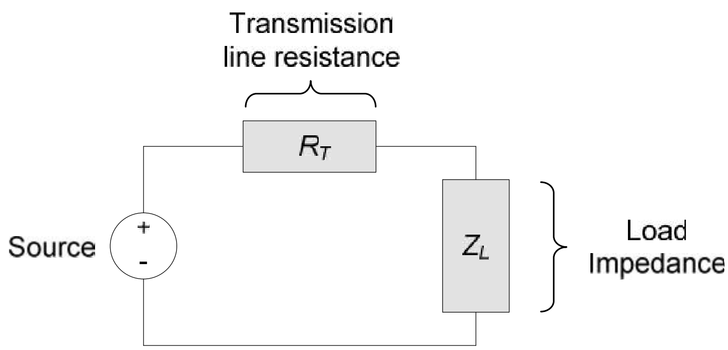

Figure 1. Power delivery system block diagram.

In this lab assignment, we will emulate the system of Figure 1 with the circuit shown in Figure 2. The load is composed of a series combination of an inductor, L, and a load resistance, R_L. The "transmission line" resistance is represented by the resistor R_T. In this lab assignment, we will examine the effects of the load's power factor on the power dissipated by the resistor R_T. For the purposes of this lab assignment, we will emphasize the transmission line effects by making the resistance R_T large relative to the load impedance.

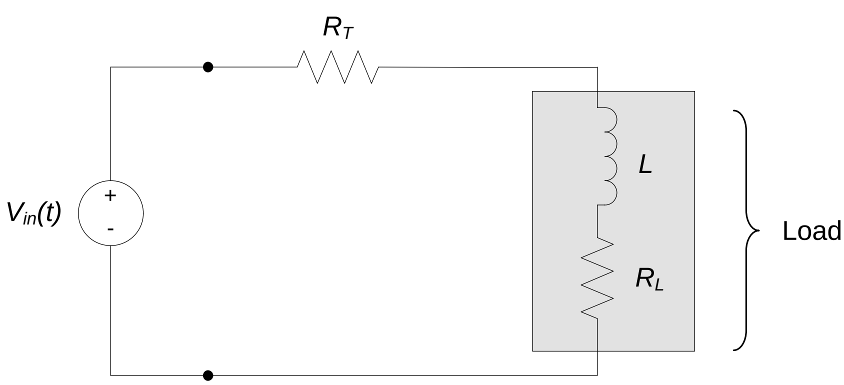

Figure 2. Circuit used to implement the system of Figure 1.

Pre-lab:

Nominal values for the parameters in the circuit of Figure 2 are:

- $V_{in}(t) = 1\cos(2\pi \cdot 5000t)$ (e.g. the input sinusoid has a $1V_{0\text{-}P}$ amplitude and a 5kHz frequency.)
- L = 1mH
- $R_T = 10\Omega$
- $R_L = 10\Omega$, 47Ω, and 100Ω.

ANALYSIS

Analyze the circuit of Figure 2 to determine, for each value of R_L[1],

a. the RMS current delivered by the source,
b. the RMS load voltage,
c. the average power delivered to the load,
d. the apparent power delivered to the load,
e. the load's power factor,
f. the average power dissipated by the resistor R_T[2], and
g. the ratio between the average power dissipated by the resistor R_T and the average power delivered to the load.

Create a table providing the above parameters for each load resistance value.

Lab Procedures:

a. Construct the circuit of Figure 2 using the 10Ω load resistance and the other component values as given in the pre-lab.

DATA

i. Be sure to measure and record actual resistance values of the components, including the inductor resistance.

ii. Use one channel of your arbitrary waveform generator to apply the sinusoidal input voltage provided in the pre-lab. Do not turn on the waveform generator yet.

iii. Use channel 1 (CH1) of your oscilloscope to measure the input voltage and channel 2 (CH2) of your oscilloscope to measure the voltage across the load. Set up a math channel as follows:
- Channel M1: the current through the load. This can be calculated from the voltage difference across the resistor R_T, divided by the resistance R_T.

iv. Create measurements using the Measure button to display:
- The RMS value of the load current (channel M1)
- The RMS value of the load voltage (CH2)

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[1] The calculations are simple, but rather tedious. The MATLAB m-file associated with this lab can be used to streamline these calculations. Run the m-file and input the appropriate resistance values when prompted. Assume that the inductor resistance is zero for the pre-lab calculations.

[2] The power dissipated by the transmission line resistance can be determined from $P = R \cdot I_{RMS}^2$.

b. Turn on the waveform generator to apply power to your circuit.

i. Record an image of the oscilloscope window, showing the three waveforms and two measurements listed in part a above. Record the following measurements in your lab notebook:
- The RMS value of the load voltage
- The RMS value of the load current
- The phase difference between the load voltage and the load current

ii. Repeat the measurements of part b, for the other two load resistors provided in the pre-lab. (R_L = 47Ω and 100Ω.)

iii. Replace the 10Ω load resistor in the circuit. Modify the load to include a 1μF capacitor in parallel with the previous load, as shown in Figure 3 below. Repeat the measurements of part b above.

iv. Demonstrate operation of your circuit to the TA and have them initial the appropriate page(s) of your lab notebook and the lab worksheet.

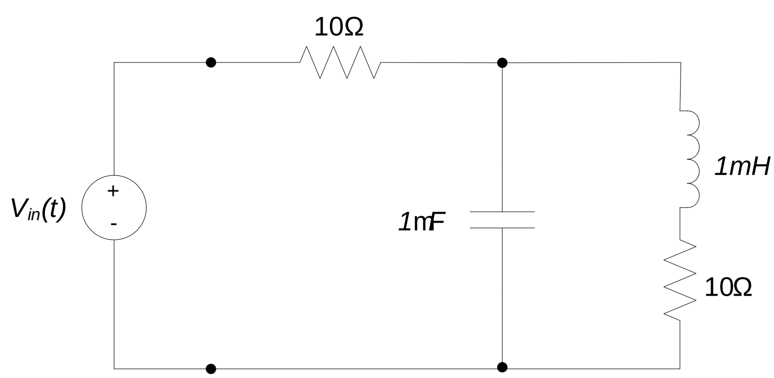

Figure 3. Circuit with capacitor in parallel with load.

Post-lab Exercises:

1. Re-run the pre-lab calculations using your measured values of R_T, R_L, and inductor resistance, for each value of load resistance.

ANALYSIS

2. Use the measurements you made in the lab procedures to calculate the following parameters, for each value of load resistance in parts a through c of the lab procedures:
   a. The power factor of the load
   b. The apparent power delivered to the load, as determined from the RMS load voltage and the RMS load current: $|S| = V_{RMS} I_{RMS}$
   c. The average power delivered to the load, as determined from the RMS load voltage, the RMS load current, and the power factor: $P_L = V_{RMS} I_{RMS} \cos(\theta_v - \theta_i)$.
   d. The power dissipated by the transmission line resistor R_T: $P_T = R_T \cdot I_{RMS}^2$.
   e. The ratio between the average power dissipated by the transmission resistor and the average power delivered to the load, P_T / P_L.

ANALYSIS

Also perform the above calculations for the circuit of part d of the lab procedures. (e.g., the circuit with the capacitor in parallel with the load.)