**University of Pennsylvania**
**Department of Electrical and Systems Engineering**

**ESE 206: Electrical Circuits and Systems II - Lab**

# AC POWER ANALYSIS AND DESIGN

## I. Purpose and Equipment:

Provide experimental practice in AC circuit power analysis and design for maximum power transfer design.

Equipment Required

1 - Digital Multimeter
1 - Function Generator
1 - Oscilloscope
1 - Protoboard
1 - RCL Meter
1 – Resistors: one of each - 10 Ω, 820 Ω, 1 kΩ and 10 kΩ
1 – Inductors: one of each - l mH, and 100 mH Inductors
1 – Capacitor: to be determined from calculations

## II. Introduction:

We know from previous work that instantaneous power is the product of voltage and current, i.e. p(t) = v(t) i(t). Average power is obtained by averaging the instantaneous power; and for dc, where both voltage and current are constant with time, the average and instantaneous powers are the same. However, this is not the case when the voltages and currents are sinusoidal functions of time.

When the voltages and currents are sinusoidal, the instantaneous power is conveniently partitioned into two components; namely, real (P) and reactive (Q) power. The unidirectional real component (P) produces a net transfer of energy from the source to the load. The imaginary or reactive component (Q) represents an interchange between source and load with no net transfer of energy. P is also the average power. The concept of complex power S = P + jQ combines these components into a single complex quantity. The magnitude of the complex power |S| is referred to as the apparent power and is expressed in units of VA (volt-amp). The real component P is expressed in W (watt) and the reactive component Q is expressed in units of VAR (volt-amp reactive). The ratio of the average power to the apparent power is called the power factor (pf), i.e. pf = P/|S|.

In this experiment the student will calculate and measure the magnitude and phase of voltage and current phasors for the circuit in Fig. 1. These quantities will be used to determine the theoretical and measured complex power and power factor. By applying a capacitance in parallel with the load, the student will determine the value of this capacitance needed to correct the power factor to unity and verify the correction experimentally. Finally, the student will design a load circuit (impedance) for a specified circuit in order to extract maximum power from the source. The achievement of maximum power transfer will be verified experimentally.

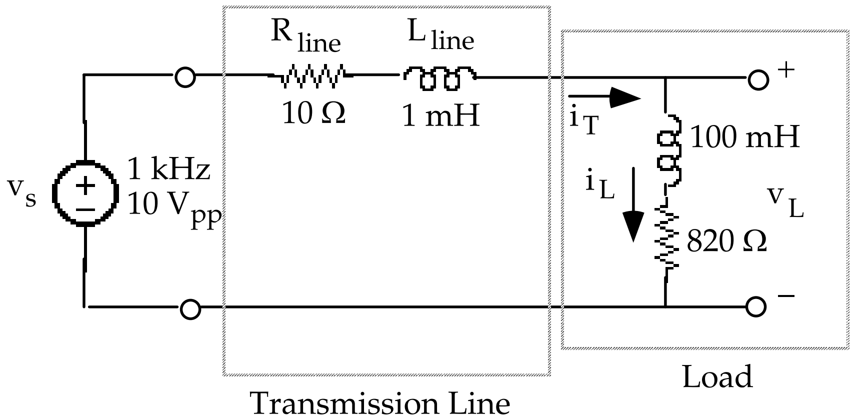



Figure 1: Schematic representation of power distribution system consisting of a source $v_s$, transmission line and load.

**III. Prelab Assignment:**

1. Review Sections 9.1 through 9.8 in the text (D. Irwin).

2. The circuit of Fig. 1 represents a model of a power system. Use phasor analysis methods to find $V_L$ and $I_L$. Find the total complex power $S_{tot}$ provided by the source $V_s$ and the complex power absorbed by the "transmission lines" $S_{line}$ and the "load" $S_L$. Remember to use rms values for these calculations. All phase angles should be referenced to $V_s$.

3. Compute the load power factor (pf) for the circuit in Fig. 1.

4. Compute the parallel capacitance needed to correct the load pf to unity.

## IV. Experimental Procedure:

1. Build the circuit

a. Measure and record the actual values of the inductors with an RCL meter and the resistors with the DMM. In your journal draw a schematic like that of Fig. 1, labeling each element with its measured value; include also the ground terminal. Recalculate the complex powers and $V_L$ using the actual element values. Take into account the parasitic series resistance of the inductors. Construct the circuit of Fig. 1 on a protoboard.

b. Set the function generator to produce a 1-kHz sine wave with an amplitude $V_s$ of 5 V ($V_{pp}$ = 10 V).

2. AC Power Analysis

Make two sets of measurements, each including the amplitude and phase of the signal.

a. For the first measurement, connect the channel one scope probe (CH1) to the source/transmission line interface, and CH2 to the transmission line/load interface. Measure the amplitude of both $V_s$ and $V_L$. Before proceeding, verify that the voltage predicted by your phasor analysis of this circuit agrees with the actual value at this interface. If it does not, check your calculations and the circuit to ensure there are no errors. Configure the oscilloscope to measure phase angle according to the given in the Appendix at the end of this document. The measured phase angle should agree with the computed phase angle. Be sure to compare these measured results to the theoretical values calculated using the actual element values.

b. Perform the same set of measurements, that is amplitude and phase, across the 820 Ω resistor in the "load". From this measurement, calculate the amplitude and phase angle of the current $I_L$ in this series circuit.

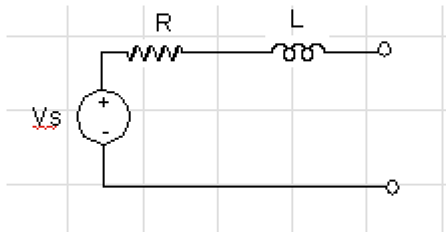
3. Power factor correction

a. Recalculate the parallel capacitance needed to correct the load power factor to unity using the actual element values.

b. Connect the required amount of capacitance to the circuit of Fig. 1. Determine the new $I_T$ and verify that the power factor has been corrected. One can find the power factor by comparing the phase of the voltage $V_L$ and the current through the corrected load. **Note: to determine the phase of the current in the line, it will be more convenient to move the line resistor $R_{line}$ to the return path to measure the voltage across the resistor (which is proportional to the current , with the phase preserved).**

4. Maximum power transfer

a. Consider the circuit of Fig. 2 below.




$V_s = 5 \angle 0^{o}$ V
f=2.5 kHz
L=100mH
R= 1 kΩ.

Figure 2: Source $V_s$ with source impedance or R=1kΩ and L=100mH; the amplitude of the source $V_s$ is 5V (or 10 Vpp) and frequency 2.5 kHz.

b. Design a load circuit that will extract maximum average power P from the load circuit. Your design should minimize the number of components (i.e. R, L, C), and must be within 5% of transferring maximum power to the load.

c. Build the circuit and make appropriate measurements to verify that your load circuit maximizes power transfer.

d. Calculate the complex power that is delivered to the load.

**V. Conclusion:**

1. AC power analysis

Use the $V_L$ and $I_L$ data collected in Experimental Procedure part 2 to compute the complex power $S_{tot}$ and $S_L$. Compare these results with the complex power calculated in Experimental Procedure part 1. From your measurements, determine the average power P and the reactive power Q delivered to the load. Use the values of P and Q computed from the measurements to compute the power factor from $pf = P/|S|$. Indicate whether the load power factor is leading or lagging.

2. Power factor correction

Use the value of $I_T$ determined in Experimental Procedure 3 to compute $S_T$ for the new combined load and the new power factor pf. From this calculation, does it appear the power factor correction improved the power factor?

3. Compute the power savings

The "efficiency" of the power system can be evaluated by comparing the amount of average power dissipated in the load $P_L$, with the amount of average power produced by the source $P_s$. Compute the efficiency of the circuit before and after the power factor correction was made.

Kenneth R. Laker, Revised 28 January 2003, Updated 2 February 2005 (JVdS)

**APPENDIX**

To make Phase Measurements automatically:

- Connect the source voltage to channel 1 and the output voltage to channel 2. Then press AUTO SCALE or make sure both signals are fully displayed on the scope.
- Press TIME key. On the menu that appears below, press the NEXT MENU twice until you see PHASE.
- Press PHASE to activate the measurement.
- The cursors that detect the thresholds for measuring PHASE automatically show up on the display and they can also be controlled manually.
- The phase angle displayed is the magnitude of the actual phase angle. To determine the sign of the phase angle, one needs to examine at the relative position of the peaks of the source and output voltage traces. When the output voltage lags the input voltage, the phase angle is negative. Correspondingly, when the output voltage leads the input voltage, the phase angle is positive.