ELECTRIC POWER SYSTEMS

Experiment 4
THREE PHASE POWER

Purpose:
To investigate the behavior of a three phase power systems under various loading conditions.

Background:
As in all ac systems, the apparent power delivered in a three phase system is related to both the real and reactive power delivered. Depending on the actual components used, therefore, different amounts of current can flow for the same amount of real power delivered. By adjusting the reactive component of the load the current in being used to feed the load can be reduced.

Measurement of power in a three phase system is done by measuring voltages and currents as in any electrical system. These systems become more complicated since the total power is the sum of the power in all three phases. If each of the three phases are balanced the power in each phase is equal and the total average power is give by three times the power in a single phase or

$$P_{3\varphi} = 3\, V_{LN}\, I_L \cos\theta$$

where

$P_{3\varphi}$ = average real power
V_{LN} = rms line to neutral voltage
I_L = rms line current
θ = phase angle between voltage and current

Often only the line to line voltage is capable of being measured. But knowing the relationship between the magnitudes of line to neutral and line to line voltages the above relationship can be given as

$$P_{3\varphi} = \sqrt{3}\, V_{LL}\, I_L \cos\theta$$

where

V_{LL} = rms line to line voltage

Note the power factor angle in this equation is the angle between line to neutral and line current. This is desirable for calculating the power factor.

Wattmeters

Wattmeters work by finding the average of the product of voltage and current . This is done either electronically in newer meters or with the interaction of magnetic fields as in meters with coil movements. In either case connects must be made for both the current and the voltage. A typical wattmeter connection is shown in fig. 1. It is always a good idea to put an ammeter in series with the wattmeter to make sure the current coil of the wattmeter is not being overloaded.

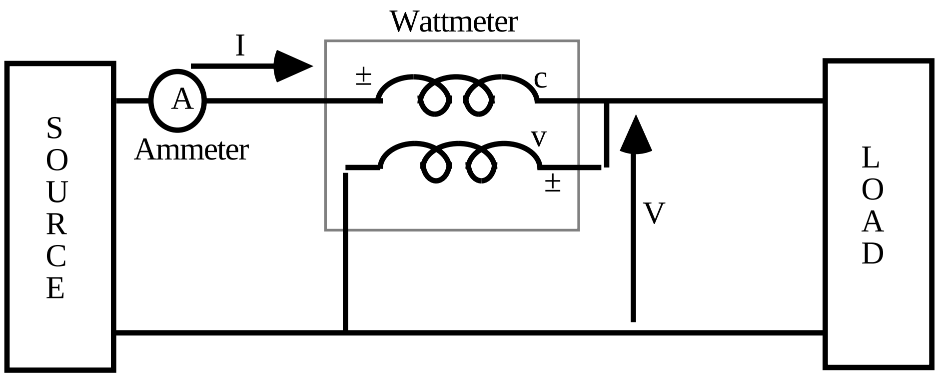

Fig. 1. Typical single phase wattmeter connection.

A standard wattmeter measures only single phase power. If a it is desired to measure power in a completely balanced three phase system, a wattmeter could be used to measure the power in one phase and the result multiplied by three. Most systems, however, have slight voltages imbalances between the phases making this method of measurement inaccurate. To measure the power more accurately power could be measured in all three phases and summed together. The result of this measurement is could be mathematically represented by

$$P_{3\varphi} = \frac{1}{T}\int_0^T i_a(t)\, v_{an}(t)\, dt + \frac{1}{T}\int_0^T i_b(t)\, v_{bn}(t)\, dt + \frac{1}{T}\int_0^T i_c(t)\, v_{cn}(t)\, dt$$

this can be simplified to

$$P_{3\varphi} = \frac{1}{T}\int_0^T (i_a(t)\, v_{an}(t) + i_b(t)\, v_{bn}(t) + i_c(t)\, v_{cn}(t))dt$$

For a system with no neutral connection

$$i_a + i_b + i_c = 0$$

or

$$i_b = -(i_a + i_c)$$

The three phase power becomes

$$P_{3\varphi} = \frac{1}{T}\int_0^T (i_a(t)\, v_{an}(t) - (i_a(t)+i_c(t))\, v_{bn}(t) + i_c(t)\, v_{cn}(t))dt$$

or

$$P_{3\varphi} = \frac{1}{T}\int_0^T (i_a(t)\,(v_{an}(t)-v_{bn}(t)) + i_c(t)\,(v_{cn}(t)-v_{bn}(t)))dt$$

which can be further simplified to

$$P_{3\varphi} = \frac{1}{T}\int_0^T (i_a(t)\,v_{ab}(t) + i_c(t)\,v_{cb}(t))dt$$

This power relationship can be measured using two wattmeters as shown in fig. 2. It is usually referred to as the two wattmeter method of measuring power. Note that because of the phase relationships between current and voltage one of these wattmeters could read a negative value but the sum of the wattmeter readings will be positive.

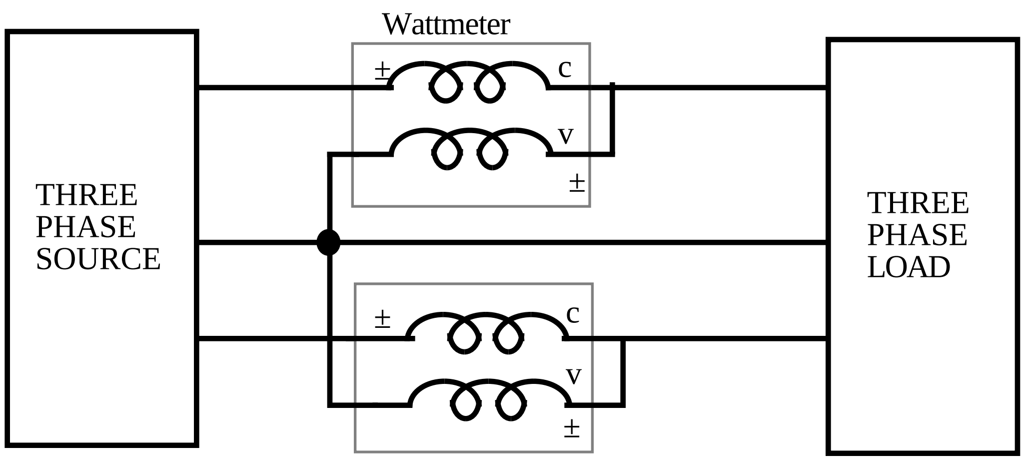

Fig. 2. Two wattmeter method of measuring power.

Procedure:

1) Connect the circuit shown in fig. 4. For the current meters use a current probe and connect to each line independently. Adjust the resistive load for minimum resistance.
2) For several settings of the reactive loads measure power, line currents, reactive load currents, and line-to-line voltages. Take readings through the full range of loads including several readings with leading and lagging power factor. Be sure the reactive loads are balanced at each reading.

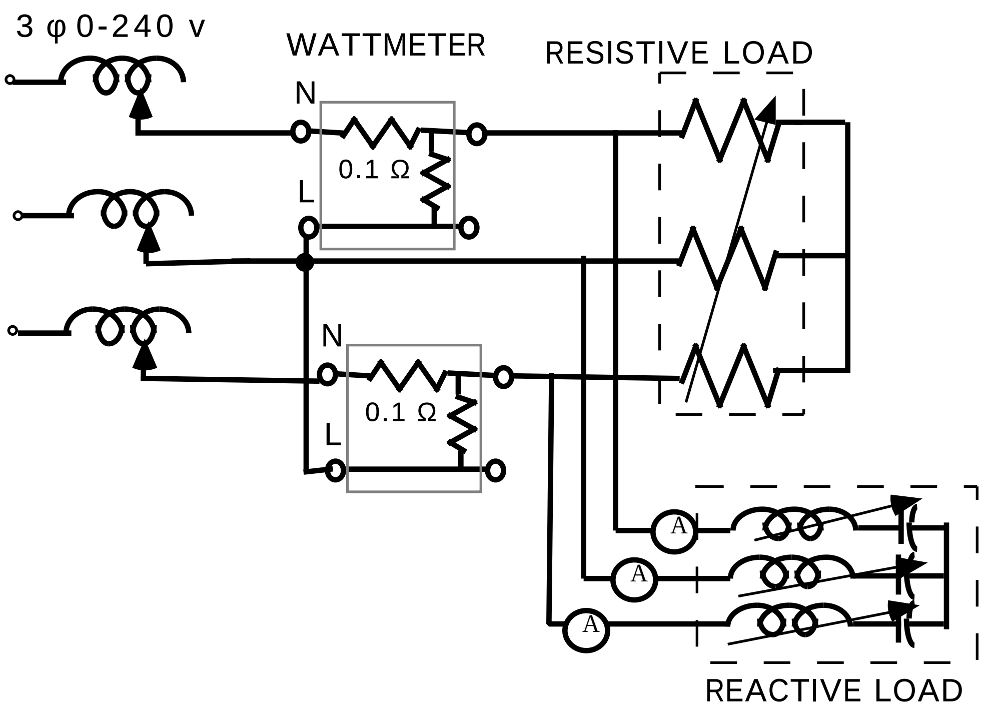

Fig. 3. Experimental circuit.

Report

Calculate the reactive power absorbed in the reactive load bank for each load condition. Plot the current, power factor, real power, reactive power and power factor as functions of the reactive power. Does the reactive load bank have an optimum setting at each resistive load?

The report is to be turned in before leaving the lab.

Appendix A

TWO WATTMETER CALCULATIONS

1) Real power

$$P = W_1 + W_2$$

2) Reactive power

$$Q = \sqrt{3}\ (W_2 - W_1)$$

3) Power Factor

$$\cos\theta = \frac{P}{\sqrt{P^2+Q^2}}$$

$$\cos\theta = \sqrt{\frac{P^2}{P^2+Q^2}}$$

$$\cos\theta = \sqrt{\frac{(W_1+W_2)^2}{(W_1+W_2)^2+3(W_2-W_1)^2}}$$

$$\cos\theta = \sqrt{\frac{1}{1+\frac{3(W_2-W_1)^2}{(W_1+W_2)^2}}}$$

$$\cos\theta = \sqrt{\frac{1}{1+\frac{3(1-W_1/W_2)^2}{(1+W_1/W_2)^2}}}$$