THE UNIVERSITY OF ZAMBIA
ELECTRICAL ENGINEERING LABORATORIES

POWER MEASUREMENT IN 3-PHASE SYSTEMS
EE323

Object

To investigate methods of measuring real power and reactive power in balanced and unbalanced 3-phase circuits.

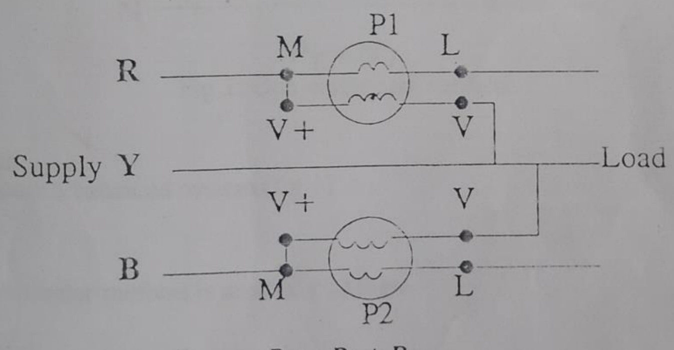
Background

In general, if there are n wires connected to a load then the total power is the sum of n-1 wattmeters. Thus

$$P_T = \sum_{i=1}^{n-1} P_{mn,i}$$

where $P_{mn,i}$ indicates that the voltage is measured between lines m and n and the current coil is in line i. Thus for a 3-phase 3-wire system two wattmeters are needed, whereas for a 3-phase 4-wire system three wattmeters must be used. These general rules may be relaxed if the system is known ot be be balanced, for then only one wattmeter need be used to measure the power in one phase, and then multiply by the number of phases to obtain the total power. The most common connections are as follows:

1. Two-wattmeter Method for Unbalanced 3-phase 3-wire System

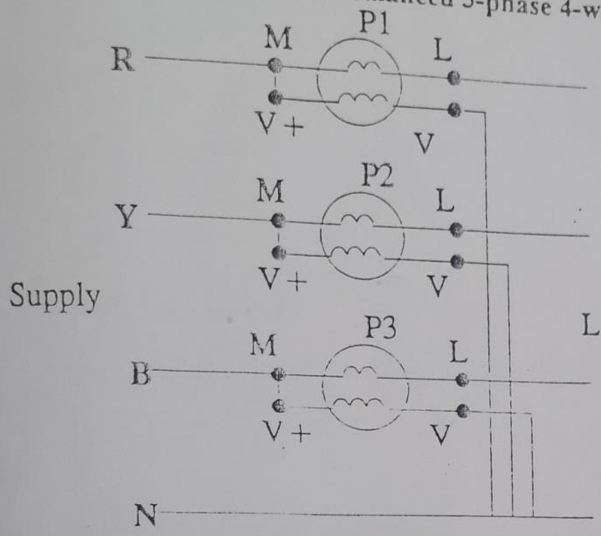


$P_T = P_1 + P_2$

Fig 1 : Two wattmeter Method

If the meter reads backwards, reverse the current connections and count the reading as negative.

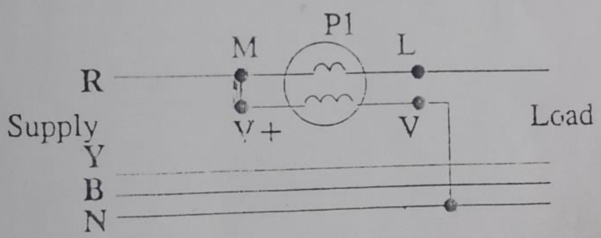
2. Three wattmeter Method for Unbalanced 3-phase 4-wire System



$P_T = P_1 + P_2 + P_3$

Fig 2: Three wattmeters

3. One-wattmeter Method for Balanced System *(with neutral available)*



$P_T = 3P_1$

Fig 3: One wattmeter method

Power Factor

Considering only a balanced system (fig 3)

$\cos\varphi = \frac{P_T}{\sqrt{3}V_L I_L}$.

If the two wattmeter method is used (fig 1) then

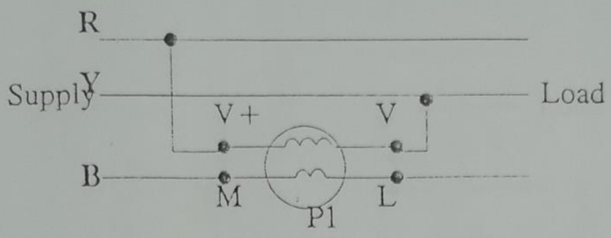
$\tan\varphi = \frac{\sqrt{3}(P_1 - P_2)}{P_1 + P_2}$.

Reacive Power

Considering only a balanced system (fig 3)

$Q_T = \sqrt{3}V_L I_L \sin\varphi = P_T \tan\varphi$.

This can easily be calculated from earlier readings. Alternatively, one wattmeter connected as $W_{RY,B}$ as shown in fig.4 can be used directly to measure reactive power.



$Q_T = \sqrt{3}\, P_1$

Fig 4: Reactive Power Measurement

Notice that this is the only case where neither end of the voltage coil is connected to a current coil terminal.

Phase Separation

By feeding an oscilloscope with a scaled down voltage of the 3-phase supply, it is possible to observe the waveforms, phase separation and phase sequence of the 3-phase system.

An approximate measurement of the phase angle of separation can be performed by first determining the duration of a complete cycle and then the time separation of the peaks of the two voltage waves on the two traces as shown below.

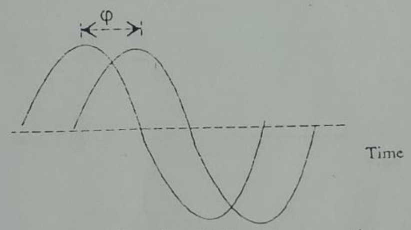
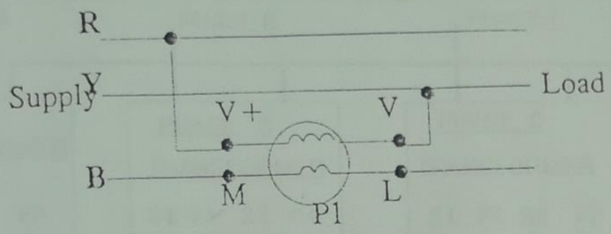


Fig 5: Dispaly of phase separation

A more accurate method for phase angle measurement uses the Lissajous figure. A Lissajous figure (elliptical display) is formed by applying one phase voltage to the X-input and the other phase voltage to the Y-input of the oscilloscope to obtain a display as in fig 6.



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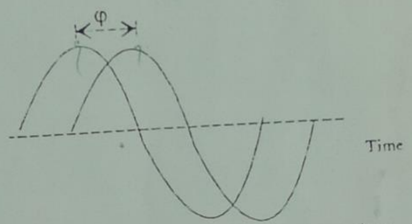

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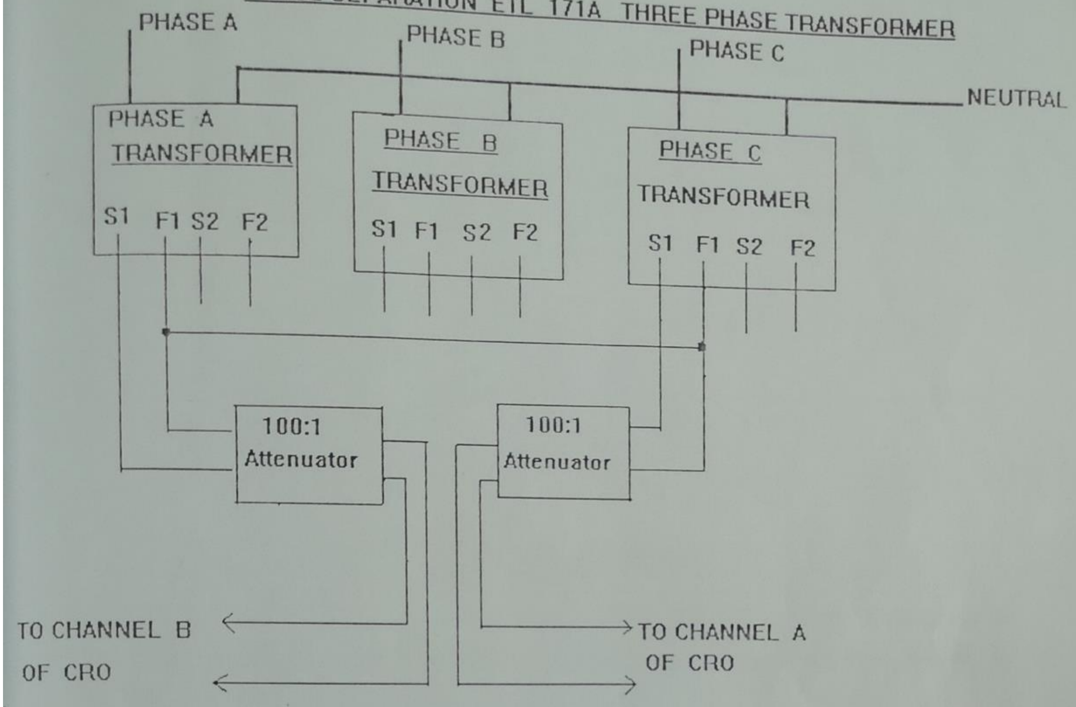
PHASE SEPARATION ETL 171A THREE PHASE TRANSFORMER



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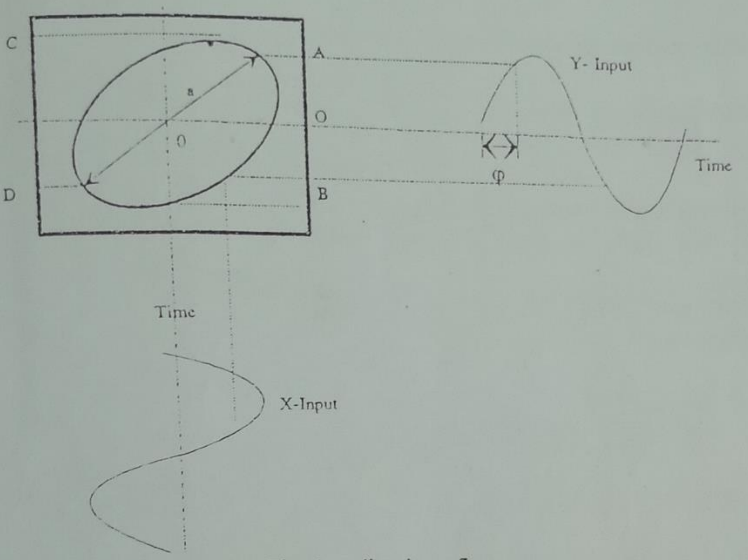

Fig 6: A lissajous figure

For the case shown in the figure, at the time the X-input is zero the Y-input has an amplitude OA, where, $OA = OC \sin\varphi$ and $\sin\varphi = \frac{OA}{OC} = \frac{AB}{CD}$ and 'a' is the axis of the lissajous figure.

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PROCEDURE

The basic circuit is as shown in Fig 7.

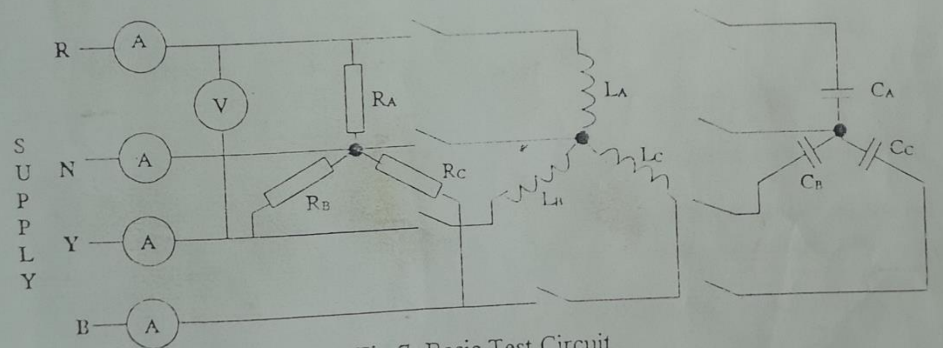

Fig 7: Basic Test Circuit

Part I Phase Separation

Before connecting the loads and the meters to the supply confirm the phase separation and phase sequence of the 3-phase supply for the ETL 171A Three Phase Supply Unit on an oscilloscope with 60 V phase voltage. Use both the time waveform display and the Lissajous figure methods and compare the results.

Part II Balanced System

(a) Switch the inductor/capacitor load switch to L

(b) To obtain a sufficient load current at 60 V phase voltage set the resistances to 60 Ω and the inductor cores to position 6.

(c) After switching on supply check that the supply (three phase and neutral) is balanced by taking the readings of V_{AN}, V_{BN}, V_{CN} and V_{AB}, V_{AC}, V_{BC}.

(d) Check that the line currents are equal and that $I_N = 0$.

(e) Using the one-wattmeter method (Connect the power factor meter as well in the same manner as the wattmeter) obtain the total power and read V_L and I_L and hence find the power factor.

(f) Read the power factor from the meter and compare with the calculated value.

(g) Switch the inductor/capacitor load switch to C with the 20 μF capacitor switched in and repeat (e) and (f).

(i) Using the two wattmeter method, with load switch set to L, again obtain the total power and power factor and compare with the results of (e).

(h) Set the load switch to C and repeat (i).

* (j) Measure the reactive power for the cases when load switch is set to L and to C.

(k) Calculate the total reactive power from a knowledge of P_T, V_L I_L and power factor for both the inductive and capacitive load and compare with measured values.

(l) Draw a complete phasor diagram.

(m) If the load were a pure *R* and and a pure *L* in parallel in each phase, calculate their values.

Part III Unbalnced Load 3-phase 3-wire (Neutral Open)

(a) Set the load switch to L.

(b) Open the neutral and unbalance the load by setting R_A=60 Ω,R_B=80 Ω, R_C=100 Ω and L_A at 8, L_B at 6 and L_C at 10.

(c) Switch on power and note ammeter readings, V_{AN}, V_{BN}, V_{CN}, V_{AB}, V_{AC} and V_{BC}.

(d) Measure the total power by the two wattmeter method and compare with (h).

(e) Reverse phase rotation to the load and repeat (c).

(f) Qualitatively explain with the aid of phasor diagrams the results of (c) and (e).

(g) Draw an accurate phasor diagram for case (c) showing all voltages and currents.

(h) Predict from the phasor diagram what readings to expect on wattmeter $P_1 = P_{AB,B}$ and $P_2 = P_{AC,C}$.

Part IV Unbalanced Load 3-Phase 4-Wire (Neutral closed)

(a) Close the neutral

(b) Note the four ammeter readings

(c) Would you expect these four ammeter readings to depend on phase rotation? Check and explain.

Discussion

Discuss your results, especially where cross-checks would be made. Consider sources of errors in the various readings and in the phasor diagrams. Would you expect all voltages and currents to be sinusoidal? Would you expect harmonics to invalidate any of the theory used?

Equipment

ETL 171 A Three Phase Supply Unit
ETL 171 B Measurement Unit, Includes:
3 off Voltmeters 150 V ac
3 off Ammeters 5 A ac
2 off Wattmeters 300/600 W
1 off Power factor meter

ETL 171 C Three Phase Load Unit (R, L and C)
1 off bench ammeter 5 A ac.
2 0ff 100/1 Voltage attenuators
1 off Philips Double Beam Oscilloscope

VT

24/6/92 Rajamani/Musaba/Mubemba
22/3/95 A A Zulu.