Experiment No. 1

Power measurement and power factor improvement

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(I) Aim

a) To measure power using Wattmeters and to determine the power factor in a three-phase balanced load.
b) To improve the power factor using capacitive load.

(II) Basic Diagram

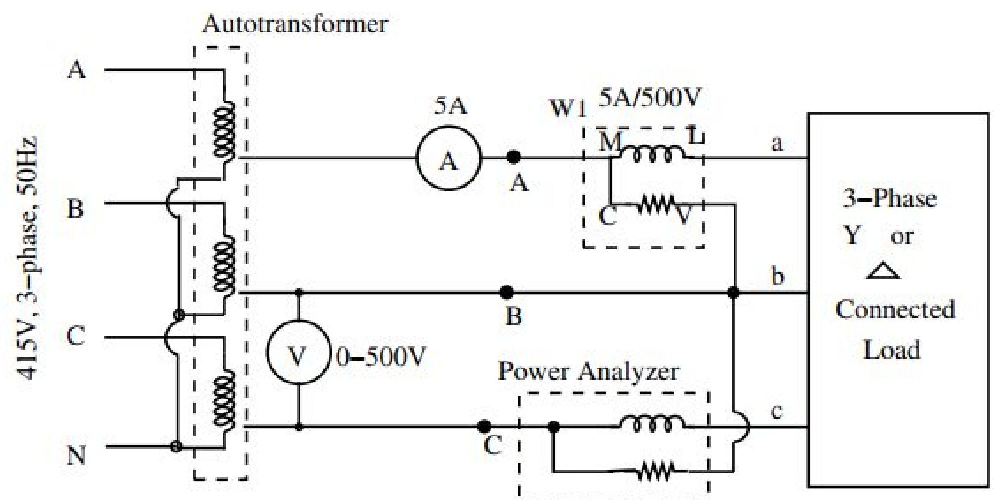


Figure 1 : The circuit diagram for measuring power consumption

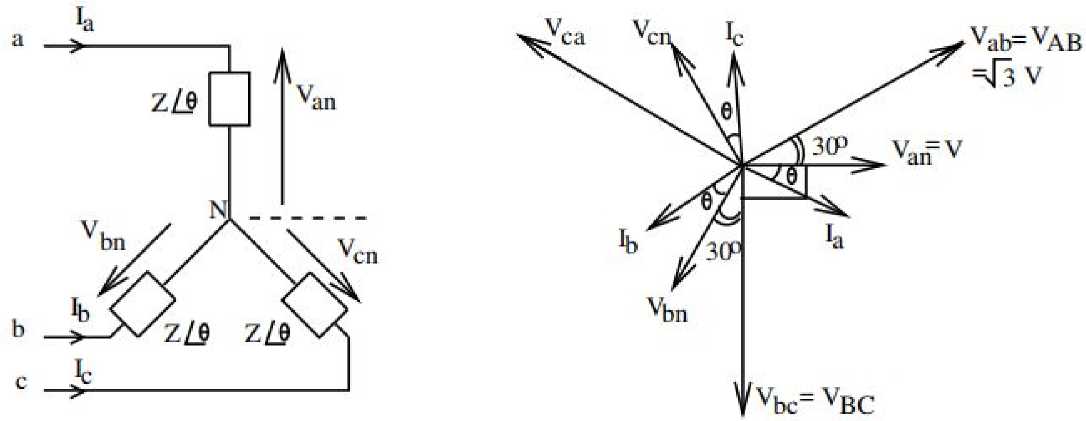


Figure 2 : a) Current and voltage distribution

b)Phasor diagram in star connected circuit

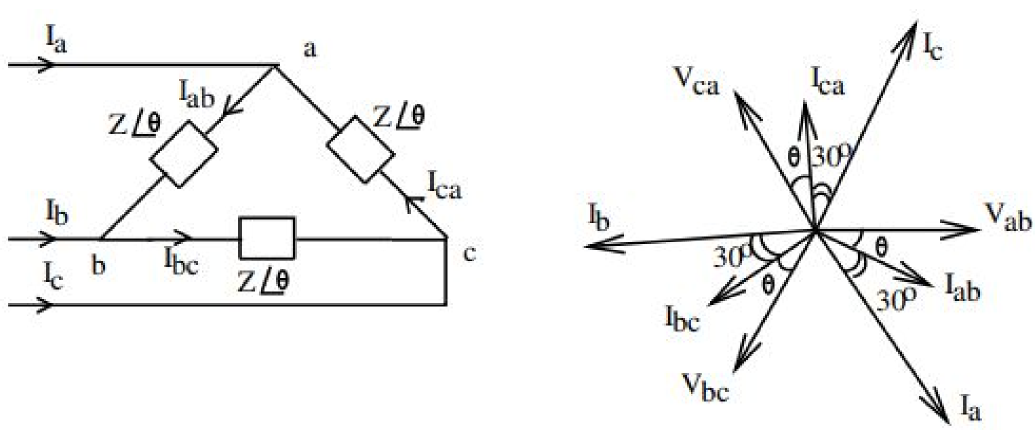


Figure 3 : a) Current and voltage distribution

b)Phasor diagram in delta connected circuit

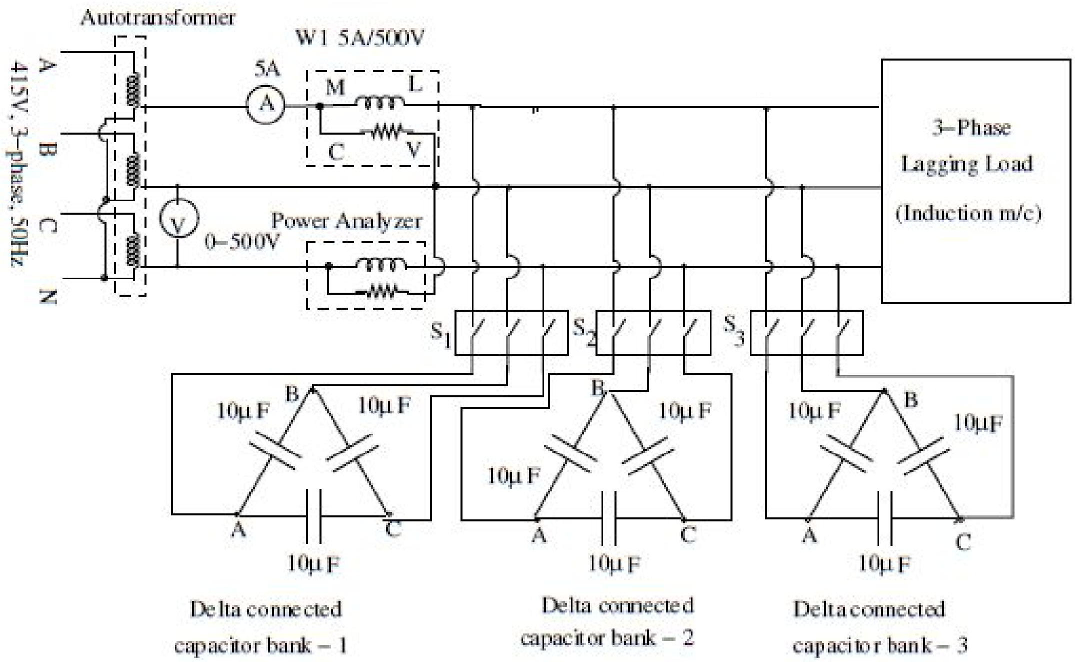


Figure 4 : Circuit Diagram for power factor improvement

(III) Observation & Calculation

(a) Star Connected Load

	W1	W2
Voltage (V)	381.9	253
Current (mA)	253.0	259.1
Power (W)	85.86	81.0
Power Factor	0.873	0.852

The reading of the wattmeters is used to calculate the total power consumed. The power from wattmeter 1 is:

$$W_1 = V_{ab} \text{ x } I_a \text{ x } \cos(30 + \theta) = \mathbf{85.86W}$$

Angle between V_{ab} and I_a is:

$$\cos^{-1}(0.873) = 29.19 \text{ degrees.}$$

The corresponding reading in wattmeter 2 is:

$$W_2 = V_{cb} \text{ x } I_c \text{ x } \cos(30 - \theta) = \text{Power of } W_2 = \mathbf{81W}$$

Angle between V_{ab} and I_a is:

$$\cos^{-1}(0.852) = 31.57 \text{ degrees.}$$

Now, $W_1 + W_2 = \sqrt{3} \text{ x } V_L \text{ x } I_L \text{ x } \cos\theta = 171.48\text{W}$

[where $V_{ab} \simeq V_{cb} \simeq V_L$]

Hence $\theta = tan^{-1}[\sqrt{3}\,(\frac{W_2 - W_1}{W_2 + W_1})\,]$

$= \mathbf{-2.89}$

Thus the power factor for this θ is $\cos\theta$ = **0.99872**

(b) Delta Connected Load

	W1	**W2**
Voltage (V)	221.8	219.7
Current (mA)	450	456.7
Power (W)	87.08	86.48
Power Factor	0.872	0.860

The reading of the wattmeters is used to calculate the total power consumed. The power from wattmeter 1 is:

$$W_1 = V_{ab} \text{ x } I_a \text{ x } \cos(30 + \theta) = \mathbf{87.08W}$$

Angle between V_{ab} and I_a is:

$\cos^{-1}(0.872) = 29.3$ degrees.

The corresponding reading in wattmeter 2 is:

$$W_2 = V_{cb} \text{ x } I_c \text{ x } \cos(30 - \theta) = \text{Power of } W_2 = \mathbf{86.48}\text{W}$$

Angle between V_{ab} and I_a is:

$\cos^{-1}(0.860) = 30.68$ degrees.

Now, $W_1 + W_2 = \sqrt{3} \times V_L \times I_L \times \cos\theta = 171.48\text{W}$

[where $V_{ab} \simeq V_{cb} \simeq V_L$]

Hence $\theta = tan^{-1}[\sqrt{3}\ (\frac{W_2 - W_1}{W_2 + W_1})\ ]$

$= \mathbf{-0.30412}$

Thus the power factor for this θ is $\cos\theta = \mathbf{0.99998}$

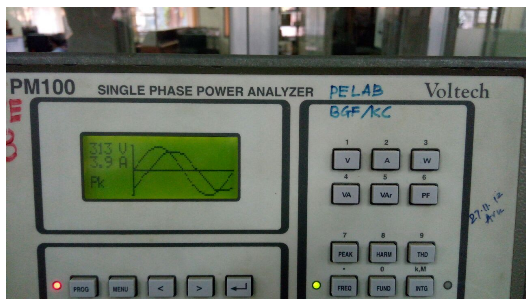
(c) Power factor Improvement

		W1	W2	Load Power Factor
No capacitor	Voltage (V)	220.6	221.6	0.1746887613
	Current (A)	2.861	2.927	
	Power (W)	389	-206.8	
	Power Factor	0.6163483468	0.3188291754	
S1 closed	Voltage (V)	223	223.6	0.2989196684
	Current (A)	1.7348	1.7664	
	Power(W)	+263.5	-78.41	
	Power Factor	0.6811242505	0.1985228945	
S2 closed	Voltage (V)	224.5	223.9	0.3049049408
	Current (A)	1.1827	1.72	
	Power(w)	254.3	-73.13	

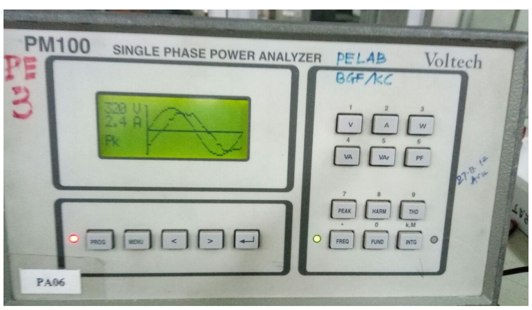
	Power Factor	0.9577571835	0.1898947828	
S3 closed	Voltage (V)	224.9	225.6	0.932574833
	Current (A)	1.05	0.799	
	Power Factor	0.432401637	0.437174282	

The waveforms observed for the above data values are as follows :-

No capacitor (W_1)

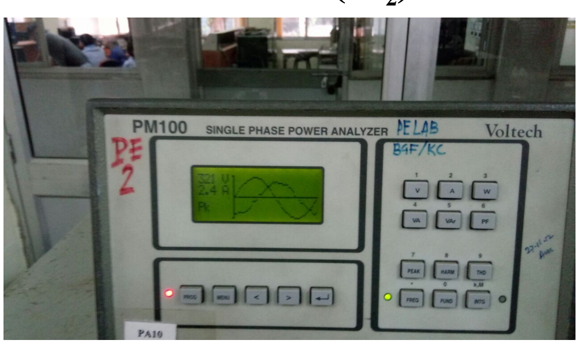


No capacitor (W_2)

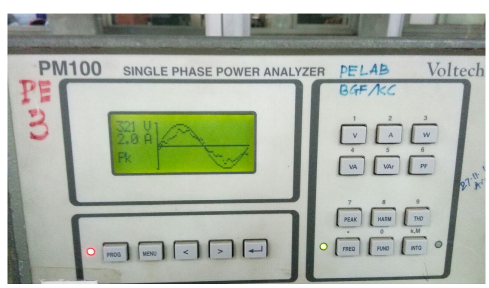


S1 closed (W_2)

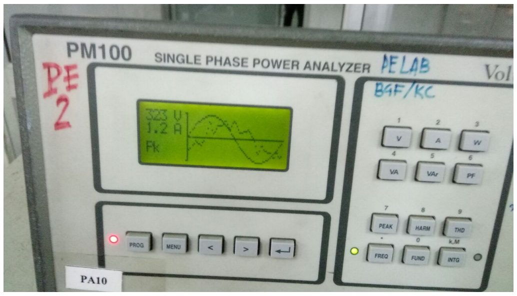
S1 closed (W_1)

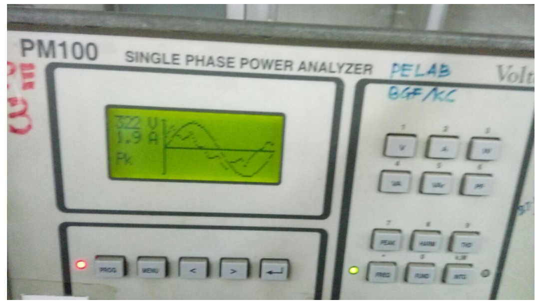


S2 closed (W_1)



S2 closed (W_2)





S3 closed (W_1) **S3 closed (W_2)**

Showing the calculations in the case of no capacitor:

$$\theta = tan^{-1}[\sqrt{3}\,(\frac{W_2 - W_1}{W_2 + W_1})\,]$$
$$= 79.98$$
$$\Rightarrow cos\,\theta = 0.1746887613$$

(IV) Conclusion

Parts a) and b)

The power factor in the two cases are0.873 and 0.852, which is pretty much close to the theoretical value of 1, since the loads are purely resistive. The phase angle in the two wattmeters are 29.19 and 31.57 in **Star connected load** and 29.3 and 30.68 in **Delta connected load.** The observed values are quite close to 30 degrees, which is the expected behaviour.

Part c)

The loads are inductive and hence the power factor is lagging. Installing capacitor improves the power factor but in turn, the current waveform distorts. We know that since inductive load is proportional to frequency but indeed inversely proportional to capacitive load. Hence, capacitive load distorts higher harmonics, the distortion in current is more in capacitive load, although improving power factor.

(V) Questions to be answered

1. With all three capacitor banks connected across the load, the source power factor might be now leading. How can you infer this from the readings? Are there any advantages of overcompensating the load?

On using capacitor banks the power factor changes significantly and increases to almost 1. Overcompensating is not required but not a problem is it happens. The current flowing is $I_L cos\,\theta$ which reduce the voltage drop as well as power loss.

2. You might have observed the voltage & current waveforms on the power analyzer (step-iv in 'section 4.1'). Why is the angle between these two waveforms is 30 o even though the load is purely resistive?

The voltage measured by a wattmeter is **NOT** the voltage and current in a single wire. The measured value is the line voltage (i.e. voltage between two lines of a three phase supply) which should ideally be 30 + θ. θ comes to be close to zero here.

3. What is the reason for reducing the voltage to zero every time before switching on the capacitors?

The voltage is reduced to zero before starting to avoid spikes in current. The spike in current may damage the device.

$$i = C\frac{Vo}{\Delta t} \sim very\ high$$

Thus, we need to reduce the voltage to zero every time before switching on capacitor.

4. You have been given thick and thin wires for connections. Which one will you use for connecting (i) an ammeter and (ii) a voltmeter? Justify your answer.

THICK wire for ammeter since resistance is inversely proportional to cross section area of wire. And since ammeter is connected in series to the circuit, we don't want ammeter to effect the circuit.
THIN wire for voltmeter since we want the current through voltmeter to be zero. Since voltmeter is connected in parallel, we ideally want voltmeter resistance to be infinite to ensure no interference.

5. During the late hours of the night you might have observed the intensity of the incandescent bulb is much higher compared to that during 7-8pm. What could be the reason?

In the evening, due to huge demand of electrical appliances, the load is often unbalanced. The effective voltage across the bulb reduces, thus reducing its intensity. In the late hours of night, the load is less and much more balanced. Hence the intensity of incandescent bulb is more.

6. Why do the single phase motor driven appliances experience vibration?

For single phase motor, the instantaneous power depends upon the phase angle. Due to this pulsating nature of instantaneous power, the appliances experiences vibration.

7. You might have observed the power sockets with two pins while, some of them with three pins. What is the difference between these power sockets?

The top pin connects ground to the device. This is to ensure no excess free charge are on the device. This saves us from unwanted charge in the body of instruments.

8. Utilities use energy meters to measure the energy consumed by consumers. From Fig. 1 it can be inferred that though the consumer is

drawing 'I' A of current, he/she is being charged only for I cos θ. In other words there is no apparent advantage of improving the power factor to unity. Is this correct? Justify your answer.

The supplier benefits in terms of energy efficiency, cost reduction etc. after increasing the power factor. Maintaining a better power factor ensures that the supplier is providing the resistive current only and not reactive power.

9. Suppose (3+j4) kVA load is being supplied at 230 V (load voltage) and the transmission line has an impedance of (1 + j1)Ω. Determine the following:

(a) voltage at the source terminals

We have the given information as:

Load = (3+j4) kVA, Voltage = $230 \angle 0^o$, Active Power = 3kW,

Transmission line impedance = (1+j1) Ω

Now,

Power Factor = $\cos(\tan^{-1}(4/3))$ = **0.6**

Load Current = $\frac{3000}{230\times0.6} \angle -37^o = \mathbf{21.74 \angle -37^o}$

Voltage drop in transmission = $21.74 \angle -37^o \times \sqrt{2} \angle 45^o = \mathbf{30.74 \angle 8^o}$

Therefore, Supply Voltage = $230 \angle 0^o + 30.74 \angle 8^o = \mathbf{260.48 \angle 0.94^o}$

(b) power loss in the transmission line

Power Loss = $i^2R = (21.74)^2 \times 1$ = **472.19 W.**

(c) the required kVAR rating of the capacitor to compensate the load fully (source supplies only the active component of current).

The reactive power is provided by the capacitor, so that the supply current remains purely resistive.

kVAR rating of capacitor **= -4j kVAR.**

(d) source current, drop is the transmission line, power loss in the transmission line after compensation.

Power Factor **= 1**

Load Current = 3000/230 **= 13.04 A**

Voltage drop in transmission = $13.04 \times \sqrt{2} \angle 45^{o}$ = $\mathbf{18.44 \angle 45^{o}}$**.**

Power Loss = $i^2R = (13.04)^2 \times 1 =$ **170W.**

10. Find the per phase capacitance necessary to improve the power factor to unity in Part-III (section-iv) for the following capacitor connections:

Active Power = $W_1 + W_2$ = -193.62 + 374.5 = **180.88W**

Power Factor = 0.180

Reactive Power (Q) = Active Power $\times$ $\tan(\cos^{-1}(0.180))$ = 180.88 $\times$ 5.465 = **988.475W**

Capacitive Reactance (X_C) = V^2 / Q = $221.2^2/988.475$ = **49.5 Ω**

Hence, capacitance required in Δ-connection is **64.30 μF.**

By Y-Δ transformation we have,

$\mathbf{Z_\Delta = 3 \times Z_Y}$

Hence, capacitance required in Δ-connection is **192.90 μF.**

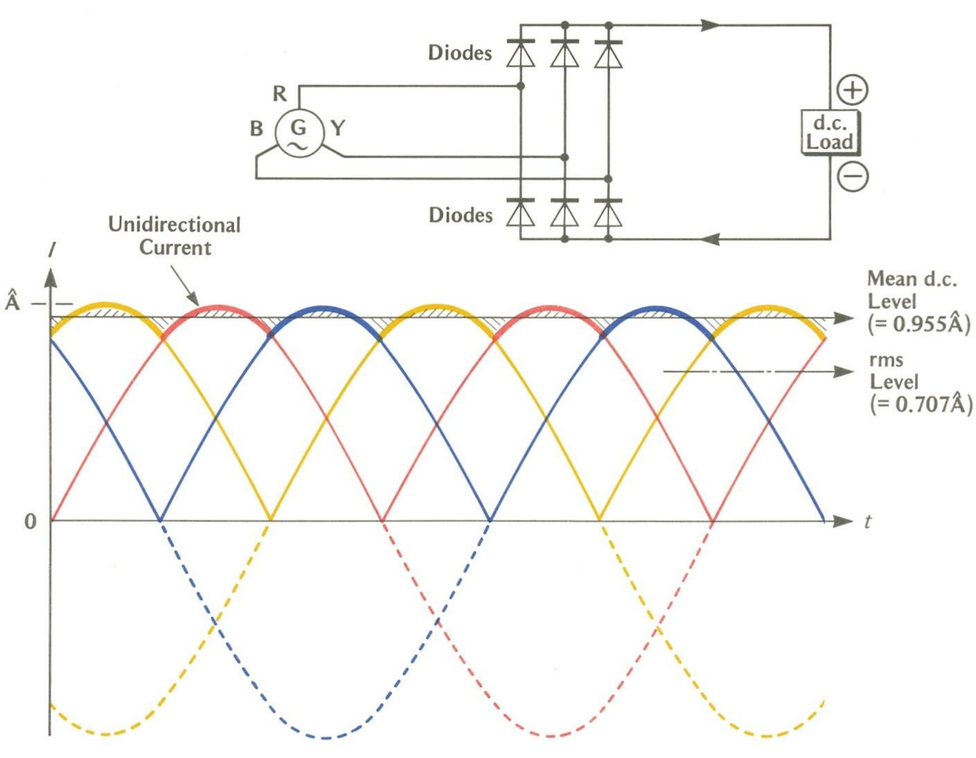
(VI) Demo experiment

Single phase rectifier:

A diode bridge is connected which converts AC input to DC output. The output ripples are rectified with capacitors connected in parallel. It was observed that current was continuous without capacitor. But in the absence of capacitor, the current had spikes.

Three phase rectifier:

The full-wave rectifier consists of a 6-diode bridge which is used to rectify the three-phase sinusoidal voltage.



Source: Internet

To obtain constant DC value of voltage across the load, the shunt capacitor is connected in parallel to the load (R). The value of capacitance (C) is chosen such that the time constant ($\tau = RC$) is sufficiently high to maintain nearly constant value till the next charging cycle waveform.

Once a capacitor is applied to maintain more or less a DC output, the input current waveform changes significantly and a spiked waveform is observed. Hence the demo experiment aimed at demonstrating the trade-off between the application of a Capacitor for constant DC rectification and the change in the input current once it is applied.