Experiment 1
Power Measurement in Balanced Three Phase Circuits and Power Factor Improvement

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1 Aim of the Experiment

- Measurement of power in
  - Star Connected Load
  - Delta Connected Load
- Power factor improvement

The following is the diagram of Star and Delta connected balanced loads respectively. The phasor diagrams denoting the line currents and voltages are also included.

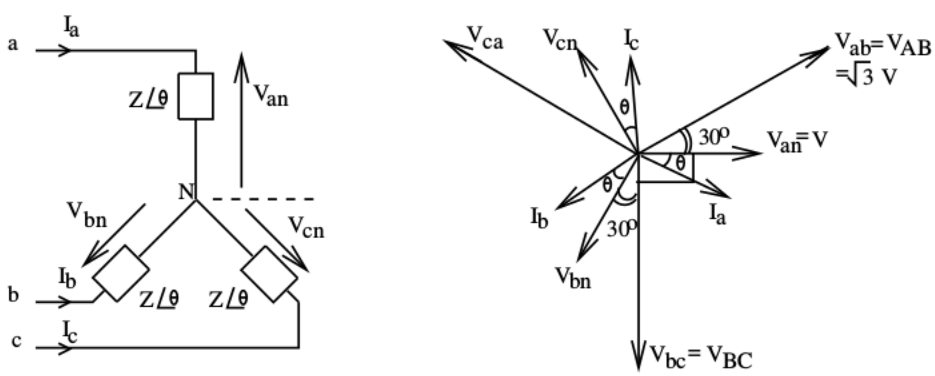


Fig. 3(a) Vector Diagram for a 3−phase system supplying a balanced star connected load

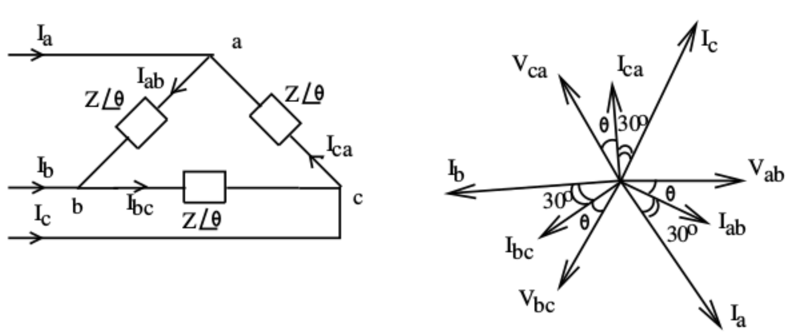


Fig. 3(b) Vector Diagram for a 3−phase system supplying a balanced delta connected load

fig1

2 Observations

2.1 Part I

Power measurement in star and delta connected balanced load

Readings	Wattmeter 1			Wattmeter 2		
Type of Load	Voltage	Current	Power	Voltage	Current	Power
Star Connection	382.6 V	266.9 mA	88.22 W	386.7 V	266.8 mA	89.91 W
Delta Connection	225.7 V	465.9 mA	90.7 W	224.6 V	462.9 mA	91.17 W

2.2 Part II

Power measurement using the induction motor as load which is delta connected. We then connected capacitor banks across the load to improve the power factor.

Readings	Wattmeter 1			Wattmeter 2		
Number of Capacitor Banks	Voltage	Current	Power	Voltage	Current	Power
0	218.6 V	3.126 A	455 W	216.5 V	2.916 A	-254 W
1	219.6 V	1.93 A	326.9 W	217.4 V	1.815 A	-133.25 W
2	218.5 V	979 mA	204.3 W	218.4 V	841 mA	-2.5 W
3	218.7 V	1.25 A	46.29 W	222.4 V	873.1 mA	161.9 W

3 Calculations

Formula for the calculation of the angle between Voltage and Current under load :

$$tan\phi = \sqrt{3}(\frac{W_1 - W_2}{W_1 + W_2})$$

And we also know that :

$$cos\phi = \frac{1}{\sqrt{1 + tan^2\phi}}$$

So we get :

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

So for example in case 1 when we had a star connected load we had:

$$W_1 = 88.22W$$

and

$$W_2 = 89.91W$$

So substituting in the first formula we get:

$$tan\phi = \sqrt{3}(\frac{88.22 - 89.91}{88.22 + 89.91}) = 155.695$$

$$cos\phi = \frac{1}{\sqrt{1 + 155.695^2}} = 0.999$$

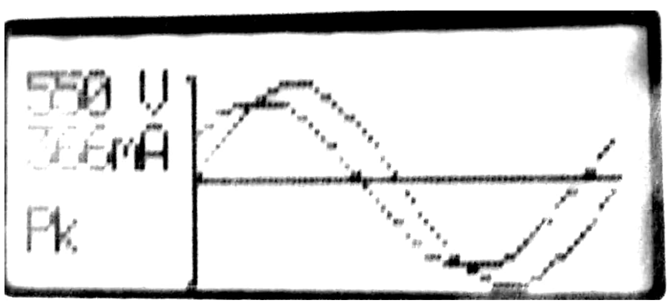
3.1 Part I

Type of Load	Power factor	Power Watt(in Watts)
Star connection	0.999	178.13
Delta Connection	0.999	181.87

3.2 Part II

Number of Capacitor Banks	Power factor	Power Watt(in Watts)
0	0.161	201
1	0.236	193.65
2	0.49	201.8
3	0.72	208.19

4 Graph



Voltage and current waveform for Star Connected load

5 Conclusion

5.1 Part (a) and (b)

We observe that the measured power factor in both the parts is 0.99 which is very close to theoretical value of 1 as the load is purely resistive. We also see that there is a phase difference of 30° between the voltage and current waveforms measured by the wattmeters which matches with the theory.

5.2 Part (c)

In this part, we observe that the current measured by each wattmeter reduces as the number of capacitor banks connected in parallel is increases. This implies that the VA requirement of load is decreasing as we can see that the resistive power requirement is remaining almost constant.This can also be observed by the shift in waveforms due to reduction in power factor.

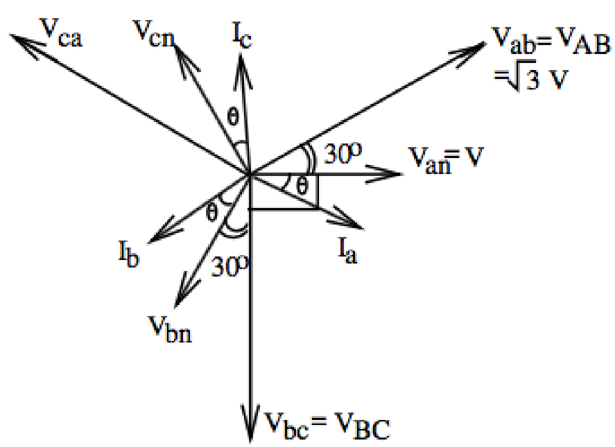
We also observed that the waveform of current distorts as the number of capacitor banks connected is increased.

This is because of the harmonics present in the current waveform. The reactance of the capacitor decrease with increase in voltage and hence in case of higher frequency harmonics, it is unable to provide the required reactive power.

6 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?**
   Answer: We can observe this from the readings of the two wattmeter. Initially when no capacitor is connected the reading of Wattmeter 2 is smaller than that of Wattmeter 1 and the power factor is lagging. As we increase the number of capacitors, the reading of Wattmeter 2 increases and for 3 capacitors reading of Wattmeter 2 becomes higher than Wattmeter 1 which shows that the power factor is now leading.
   There isn't any advantage in overcompensating the load because then the source will have to supply leading reactive power which would again increase the VA rating of the generator.

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° even though the load is purely resistive?**
   Answer: The power analyzer measures the angle between $V_{applied}$ and $I_{flowing}$. In the case of star connected load, $V_{applied}$ is the line to line(V_{l-l}) voltage whereas $I_{flowing}$ is the line current(I_l). As the load is purely resistive the angle between the line current and phase voltage is 0° but the line to line voltage leads the phase voltage by 30°. Hence the angle between V_{l-l} and I_l is 30° which is what the power analyzer measures. The following figure shows the phasor diagram for star connected load.



Phasor Diagram for star connected load

3. **What is the reason for reducing the voltage to zero every time before switching on the capacitors?**
   Answer: We know that the voltage across a capacitor cannot change suddenly. If we connect the capacitor banks in parallel to the load without first reducing the voltage to 0, the voltage across the capacitor would suddenly increase to the applied voltage leading to very high current flowing through the capacitors which can lead to damage of the 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.**
   Answer: We can use thin or thick wires for connecting voltmeter but we should use thick wires to connect ammeter. This is because ammeter is connected in series with the load and should have very small impedance and thick wires wont add series resistance to the circuit. Voltmeter is connected in parallel and has very high impedance as it draws negligible amount of current hence any type of wire can be used.

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?**
Answer: 7-8 pm is very active time of the day and hence a larger current is being drawn. Due to this, the voltage drop in the transmission line increases and hence the potential faced by the bulb reduces. Late hours of the night are less active and the current drawn is low, hence the drop across the transmission line is also lower and the bulb faces higher potential difference. Thus the intensity of the bulb is higher late at night.

6. **Why do the single phase motor driven appliances experience vibration?**
Answer: Single phase motor is driven by single voltage supply hence instantaneous power available at the motor is given by

$$P = VI = V_m I_m Cos(\omega t) Cos(\omega t - \theta)$$

From this we can infer that P is oscillating with respect to time hence due to varying power single phase motor driven appliances experience 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?**
Answer:The third pin is used to ground the device. This means that the third pin connects directly to the ground outside of the building through a series of wires . This ensures that in the situation when there is any fault in the current flow, the extra current would flow through the earth wire to the earth keeping the device safe. The grounding is done outside the house because if done inside the house,it could cause a fire; it is safer to have it grounded outside.

8. **Utilities use energy meters to measure the energy consumed by consumers. Energy is given by**

$$E = \int P dt$$
$$E = \int (VI cos\theta) dt$$

where P is the power consumed by the load. From Fig. 1 it can be inferred that though the consumer is drawing 'I' A of current, he/she is being charged only for $Icos\theta$. In other words there is no apparent advantage of improving the power factor to unity. Is this correct? Justify your answer.
Answer: No, power factor improvement is still necessary and crucial since, real power is the power that actually powers the equipment and performs useful productive work. However, reactive power is only required by some loads (like motors and relays) to produce a magnetic field for operation; but otherwise does no real work. If the system has a poor power factor it may lead to equipment instability and failure.It may also result is notably higher than necessary energy costs, since to use a given amount of power in a particular setting, the system with less power factor has to generate more power compared to a unity gain system to compensate for the useful power. A lot of power goes as losses due to such low power factor conditions. By optimizing and improving the power factor, power quality is improved, reducing the load on the electricity distribution system and full capacity of the distribution system can be realized.

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:**
   - **voltage at the source terminals**
   - **power loss in the transmission line**
   - **the required kVAR rating of the capacitor to compensate the load fully (source supplies only the active component of current).**
   - **source current, drop is the transmission line, power loss in the transmission line after compensation.**

Answer: Ans:

$$V_L = 230V$$
$$Z_L = 3 + 4j$$
$$Z_L - 1 = \frac{(3 - 4j)}{25}$$

We know,

$$Z_L \times I_L = V_L \implies I_L = (27.6 - 36.8j)A$$

Voltage drop across the load line (V1)

$$V1 = (64.4 - 9.2j)V = 65.054V$$

Source voltage (Vs)

$$\begin{aligned} Vs = V_L + V_1 &= (230) + (64.4 - 9.2j) \\ &= (294.4 - 9.2j) \\ &= 294.54V \\ |V1| &= 65.05V \\ |Vs| &= 294.54V \end{aligned}$$

$$Power = I_{L2} Z_L = (2.116 + 8.864)kVA$$
$$Required\ KVar = Im(I_{L2} Z_L) = 8.864kVARr$$
$$Required\ power\ loss = Real(I_{L2} Z_L) = 2.116kW$$

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

    Answer: As the switch S1 is closed, the power factor is almost changed to unity. Hence, the per-phase capacitance for the unity power factor gain is clearly 10μF in a delta connection.
    As for the per phase capacitance for a star connected capacitor bank it comes out to be 3.34μF per phase capacitance.

7 Demo Experiment

7.1 Single-Phase Diode

We use the Diode bridge to convert AC signal into DC signal but as it had large ripples, we connected a capacitor in parallel to the load to reduce the ripples. We observed that the current was continuous without capacitor but when the capacitor was connected it became discontinuous with spikes in every half cycle. At zero line current, the capacitor supplies the current to the load.

7.2 Three Phase diode

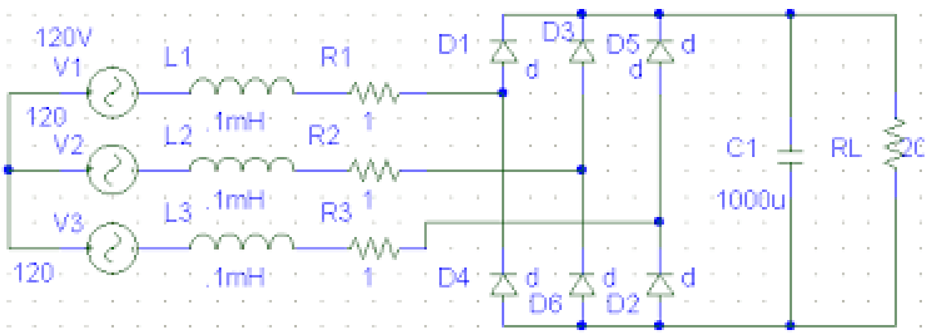
The 3-phase rectifier circuit is just an extension of the single phase rectifier circuit previously discussed. This converted a three phase AC voltage at the input side to a DC voltage at the output end.
The full wave rectifier were discussed with and without the capacitive load.

7.2.1 Without Capacitive Load

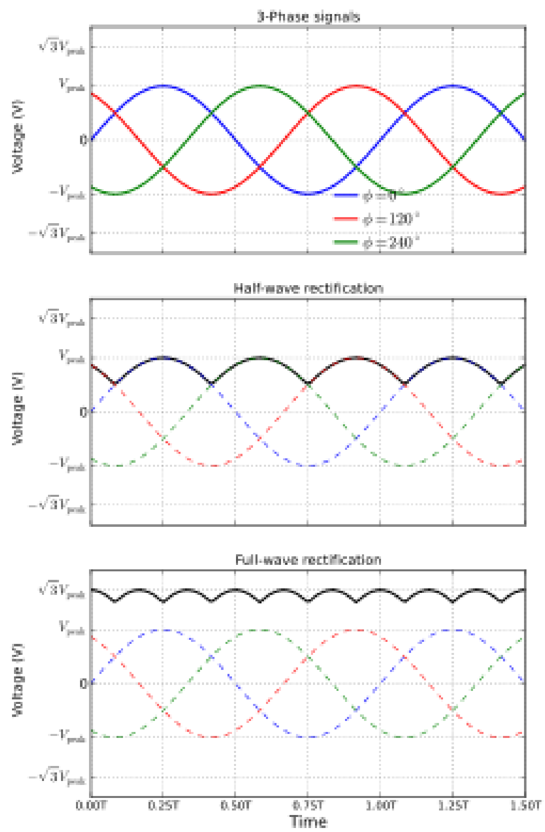
The DC voltage is divided into six segments within one fundamental source period that corresponds to the different line to line source voltage combinations. In each segment there is a minimum and maximum DC voltage.

7.2.2 With Capacitive Load

The output will almost be a constant DC. Due to the discharge and charge of the capacitor.



Circuit diagram of 3 Phase full wave rectifier



Voltage Waveform of the 3 phase half and full wave rectifier