EE234 Experiment 1: Power measurement in balanced 3 phase circuits and power factor improvement

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1 Overview of the experiment

- The aim of this experiment is to realise the voltage, current and power used in single phase and three phase connections, hence finding the power factor as well.
- Furthermore, this experiment involves the testing of power factor improvement by adding elements such as capacitor banks, and testing how this form of improvement can have both advantages and disadvantages.

2 Design and Experimental Observations

In the first part we connected the load in a star-connected configuration and applied a voltage which is $\sqrt{3}$ times the required phase voltage. Note that in the process voltage was increased slowly. All the quantities of interest such as power, angle and power factor was measured by connecting two wattmeter in any of the two lines. This same procedure was repeated for delta connected load as well. In the final part, we set out to find the relation between power factor and increase in capacitive load.

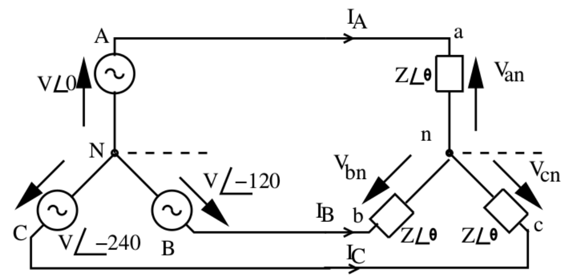

Figure 1: Circuit for star-connection

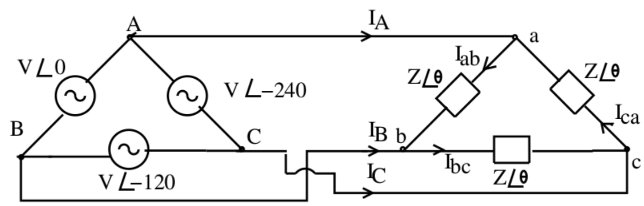

Figure 2: Circuit for delta-connection

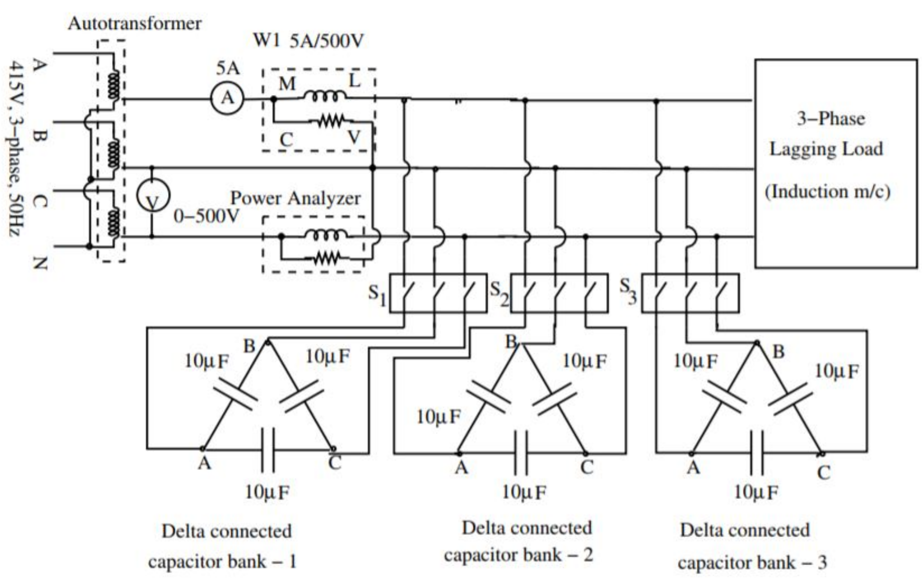

Figure 3: Circuit Diagram

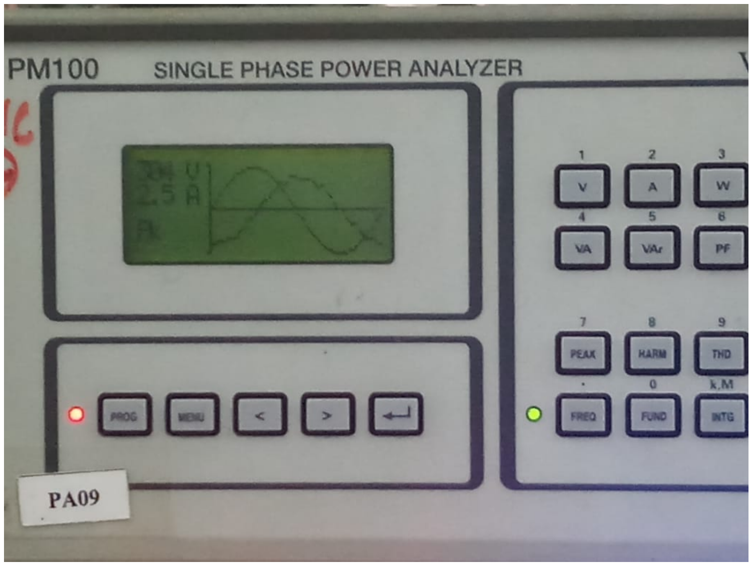

Figure 4: Observed Loss of Sinusoidality

3 Readings

3.1 Part 1: Star-Connected Load

Quantity	Value	Quantity	Value
V_{ab}	391.1 V_{rms}	V_{cb}	389.2 V_{rms}
I_A	433.2 mA_{rms}	I_C	432.7 mA_{rms}
W_1	147.45 W	W_2	144.79 W
PF_1	0.867	PF_2	0.860

Total Power = 147.45 + 144.79 = 292.24W
30 + $\theta = \cos^{-1}(0.867) = 33.209$
30 - $\theta = \cos^{-1}(0.860) = 34.093$
Hence, $\theta = -0.442^o$
The load can be considered resistive.

3.2 Part 2: Delta-Connected Load

Quantity	Value	Quantity	Value
V_{ab}	222.2 V_{rms}	V_{cb}	218.6 V_{rms}
I_A	745.6 mA_{rms}	I_C	731.7 mA_{rms}
W_1	143.97 W	W_2	136.98 W
PF_1	0.871	PF_2	0.859

Total Power = 143.97 + 138.98 = 282.95W
30 + θ = $\cos^{-1}(0.871)$ = 29.425
30 - θ = $\cos^{-1}(0.859)$ = 30.796
Hence, $\theta = -0.685^o$
The load can be considered resistive.

3.3 Part 3: Power Factor Improvement

Induction Motor Specifications

Quantity	Value	Quantity	Value
Rated Voltage	220 V	ν	50 Hz
Rated Current	5.12A	Rated Speed	1427 rpm
Efficiency	77.5 %	Rated Power	1.1 kW

3.3.1 Case 1: S1, S2, S3 open

Quantity	Value	Quantity	Value
V_{ab}	217.6 V_{rms}	V_{cb}	216.8 V_{rms}
I_A	2.873 A_{rms}	I_C	2.727 A_{rms}
W_1	-211.8 W	W_2	385.6 W
PF_1	0.337	PF_2	0.649

Total Power = -211.8 + 385.6 = 173.8W
θ - 30 = $\cos^{-1}(0.649)$ = 49.534
Hence, $\theta = 79.92^o$
Thus, positive angle indicates that voltage leads the current which happens in the presence of inductive load.

3.3.2 Case 2: S1 closed; S2, S3 open

Quantity	Value	Quantity	Value
V_{ab}	212.7 V_{rms}	V_{cb}	209.2 V_{rms}
I_A	1.7145 A_{rms}	I_C	1.2669 A_{rms}
W_1	-47.03 W	W_2	210.2 W
PF_1	0.121	PF_2	0.801

Total Power = -47.03 + 210.2 = 163.17W
θ - 30 = $\cos^{-1}(0.801)$ = 36.774
Hence, $\theta = 66.774^o$
Thus, positive angle indicates that voltage leads the current which happens in the presence of inductive load. However the value is decreased owing to the compensation offered by capacitive load.

3.3.3 Case 3: S1, S2 closed; S3 open

Quantity	Value	Quantity	Value
V_{ab}	217.5 V_{rms}	V_{cb}	213.9 V_{rms}
I_A	1.5481 A_{rms}	I_C	868.7 mA_{rms}
W_1	$-11.515\ W$	W_2	179.26 W
PF_1	0.032	PF_2	0.970

Total Power = -11.515 + 179.26 = 167.745W
θ - 30 = $\cos^{-1}(0.970)$ = 14.07
Hence, $\theta = 44.07^o$
Thus, positive angle indicates that voltage leads the current which happens in the presence of inductive load. However the value is decreased owing to the compensation offered by capacitive load.

3.3.4 Case 4: S1, S2, S3 closed

Quantity	Value	Quantity	Value
V_{ab}	218.4 V_{rms}	V_{cb}	218.8 V_{rms}
I_A	734.1 mA_{rms}	I_C	876.0 mA_{rms}
W_1	131.41 W	W_2	45.61 W
PF_1	0.848	PF_2	0.225

Total Power = 45.61 + 131.41 = 177.02W
$\theta + 30 = \cos^{-1}(0.225) = 76.997$
Hence, $\theta = 46.997^o$
Thus, positive angle indicates that voltage leads the current which happens in the presence of inductive load. However the value is decreased owing to the compensation offered by capacitive load.

4 Answers

1. Power factor can be calculated using readings for voltage, current and power from the two wattmeters. A change in sign for power factor implies that there is a change from lagging to leading power factor. Overcompensating is not desirable since as it also leads to higher voltage drop.

2. Power analyzer gives line to line voltage and the line current. Line current is same as phase current where as line to line voltage is the difference between 2 phase voltages separated by an angle of 120 degrees. This difference between two vectors results into a phase shift of 30 degrees.

3. High voltage will result into rapidly charging capacitor which in turn will cause a high current. Such a high current beyond the rating of device may lead to severe damages and therefore, voltage is reduced to zero before switching on the capacitors.

4. Thicker wires should be used for ammeters as they are connected in series and therefore offer less resistance. On the other hand because voltmeter are connected in parallel therefore no load current should pass trough them. Hence corresponding wires for voltmeter should offer higher resistance which makes thinner diameters favourable.

5. There is a higher load current drawn during the peak hours leading to a lower voltage at the load. Whereas during night, bulb is able to extract required voltage and glows to its rated power. A higher load current as in peak hours also leads to lower efficiency.

6. Torque developed by the induction motor is directly related to power. In the single phase induction motor power varies with the square of time which leads to the vibrations.

7. If in case there is a short circuit, a huge amount of current flows through the device which puts the user on risk. Therefore a third pin called as earth is used to carry the excess charge to a metal plate which is installed underground.

8. A low powerfactor implies higher amount of drawn current which will lead to greater losses during transmission but with no advantage on useful power extracted. Therefore, suppliers make sure that consumers draw current at a high power factor.

9. (a)
$$Current = (3 + 4j) * 1000/(230) = 13 + 17.3$$
   Applying KVL gives,
$$V_{terminal} = 225.7 + 30j\ Volts$$
   (b) Power loss = $|I|^2 * R$ = 472W
   (c) Capacitor rating to compensate the load fully = -4kVAr
   (d) Expected parameters after compensation are:
   Source current = 3000/230=13.04A
   Drop = 13.04+13.04j
   Power loss = $13.04^2 * 1$ = 170.04W

10. The reactive power due to capacitor must be equal to that of inductive load. The reading obtained from 1^{st} subpart of part 3 is used to ascertain per phase reactive power. Total Reactive power = Real Power$\times$ $\tan(\theta)$. Thus reactive power per phase is = 325.89W. This must be equal to reactive power per phase of the capacitive load. Using this we arrive at the following solutions: a)$64.3\mu F$, b)$21.43\mu F$