Three Phase AC Measurements

Soham Karanjikar (Leader)

Partners: Luis Aragon, Matt Baughman (Recorders)
Performed: January 31st 2020
Written: February 2nd 2020

1 INTRODUCTION

The main purpose of this first hands on lab was to get familiar with the use of lab equipment. The safety, functionality and proper technique. This was achieved by measuring 3 Phase Power, Voltages, Currents; all which helped us get familiar with current probes, voltage probes, watt meters etc. We worked with a Wye connected resistive, a Delta Connected complex load and a real 3 phase machine: the induction motor.

2 RESULTS

2.1 *One and Two Wattmeter Method*

While measuring the total magnitude of power may be possible by simply being able to access one phase and neutral, it is not possible to find the exact Real and Reactive power by doing so. Hence, the one and two wattmeter methods are very useful.

The One wattmeter method measure current through one phase and the line voltage across 2 other phases. For our experiment we measured current through *Phase A* and Voltage from *Phase B to C, Vbc*. Through this we can perform a calculation to achieve total reactive power:

$$Q = VI\cos(\theta) = \sqrt{3}P_{\mathrm{wm}} \text{ , where } \theta = \angle V - \angle I$$

Using the two wattmeter method we can compute the real power by measuring current through 2 phases and voltage from those phases to another common phase. Measuring current through *Phase A*, *Phase C* and voltage *Vab*, *Vcb*, we can do the following to get total real power:

$$P = P1 + P2 \text{ ,}$$

$$P1 = \sqrt{3}Vab * Ia\cos(30+\theta)$$

$$P2 = \sqrt{3}Vcb * Ic\cos(-30+\theta)$$

Here it is visible that P_2 will be 0 if θ is either $\angle$-60 or $\angle$120. P_1 = P_2, if the $\cos(\pm 30+\theta) = \pm 1$, this occurs when θ = is ± 30 or ± 150

With this information, finding the total power is trivial as you can just sum the two together.

2.2 *Wye Connected Load*

In our case our wye connected load was purely resistive so there was no reactive power involved in measurements. This meant the calculations were a lot simpler as no complex numbers were involved and current was always in phase with voltage. The results are shown in the table below.

	Line Current (A)	Phase Current (A)	L-L Voltage (V)	Phase Voltage (V)	Phase Shift θ (deg)	Real power P (W)	Reactive power Q (VAR)	Total power S (VA)
Phase A (A-B	1.16	1.16	205.35	116	0	475.06	0	475.06
Phase B (B-C	1.15	1.15	205.30	115	0	-	-	-
Phase C (C-B	-	-	-	-	-	-	-	-

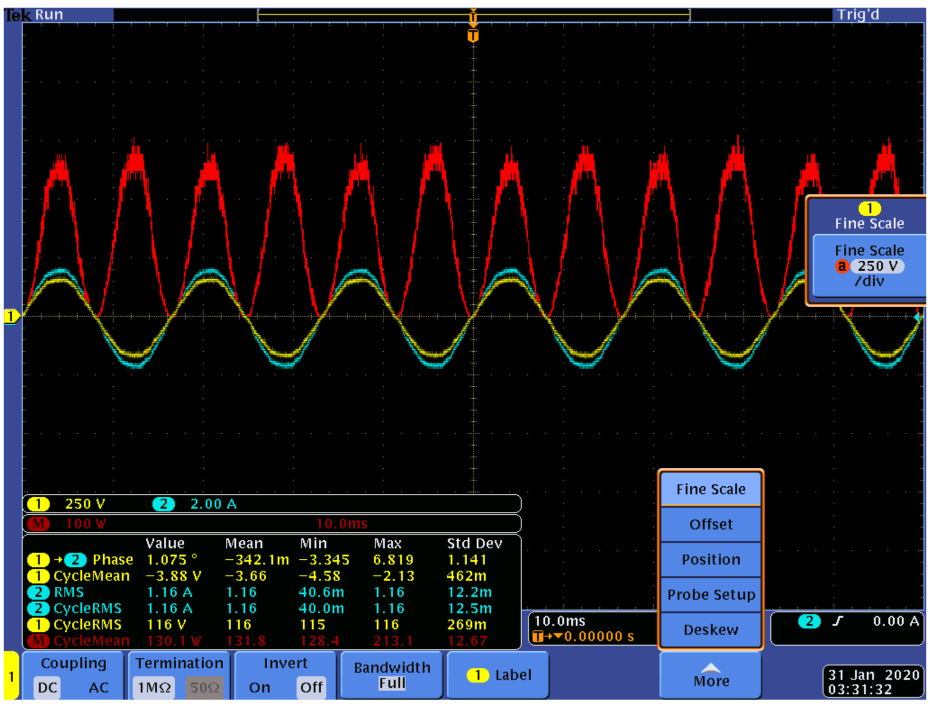
In Wye connected loads Phase and Line Voltages/Currents are related by these equations:

$$V_{\text{phase}} = \frac{\text{ll}}{\sqrt{3}}$$

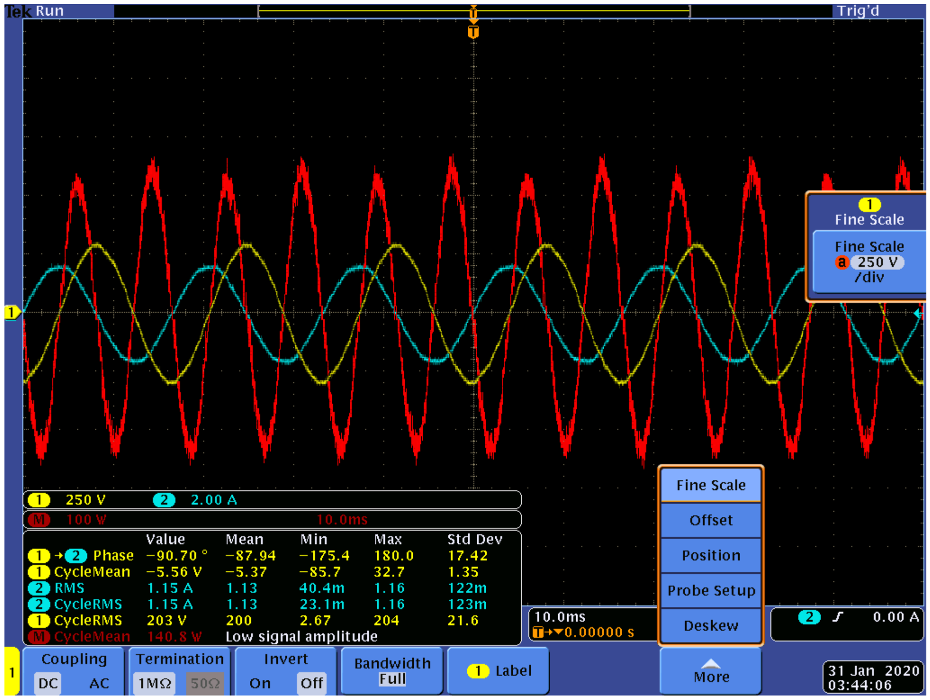
$$I_{\text{phase}} = I_{\text{ll}}$$

This can be verified from the table above as I_{phase} is exactly the same as I_{l}, and V_{ll} is exactly $\sqrt{3}$ times larger than V_{phase}.

The reason the reactive power is 0 can be observed through this screenshot, the voltage and current are exactly in phase:



Further, through using the one wattemeter method it is visible that current and voltage are $\angle 90$ out of phase and $\cos 90 = 0$:



Through this information we can also calculate power factor which is:

$$p.f. = \frac{P^{\text{Real Power}}}{S^{\text{Total Power}}} = 1$$

2.3 *Delta Connected Complex Load*

This next part consisted of resistors in parallel with capacitors arranged in a delta fashion. This meant that now reactive power is not strictly 0 but actually exists and affects the power factor. The results from the experiment are in the table below:

	Line Current (A)	Phase Current (A)	L-L Voltage (V)	Phase Voltage (V)	Phase Shift θ (deg)	Real power P (W)	Reactive power Q (VAR)	Total power S (VA)
Phase A (A-B	4.32	2.48	209.1	209.1	-57.88	973.6	-1148	1505.3
Phase B (B-C	-	-	-	-	-	-	-	-
Phase C (C-B	4.28	2.44	209.3	209.3	-44.19	-	-	-

In a Delta connected load Phase and Line Voltages/Currents are related by these equations:

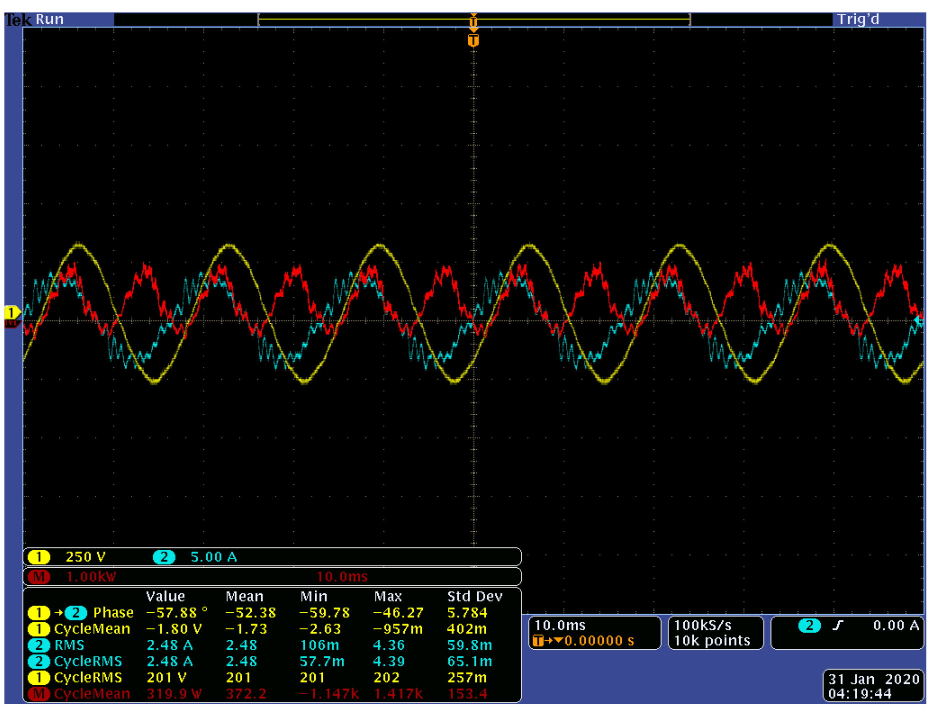
$$V_{\text{phase}} = V_{\text{ll}}$$

$$I_{\text{phase}} = \frac{I_{\text{ll}}}{\sqrt{3}}$$

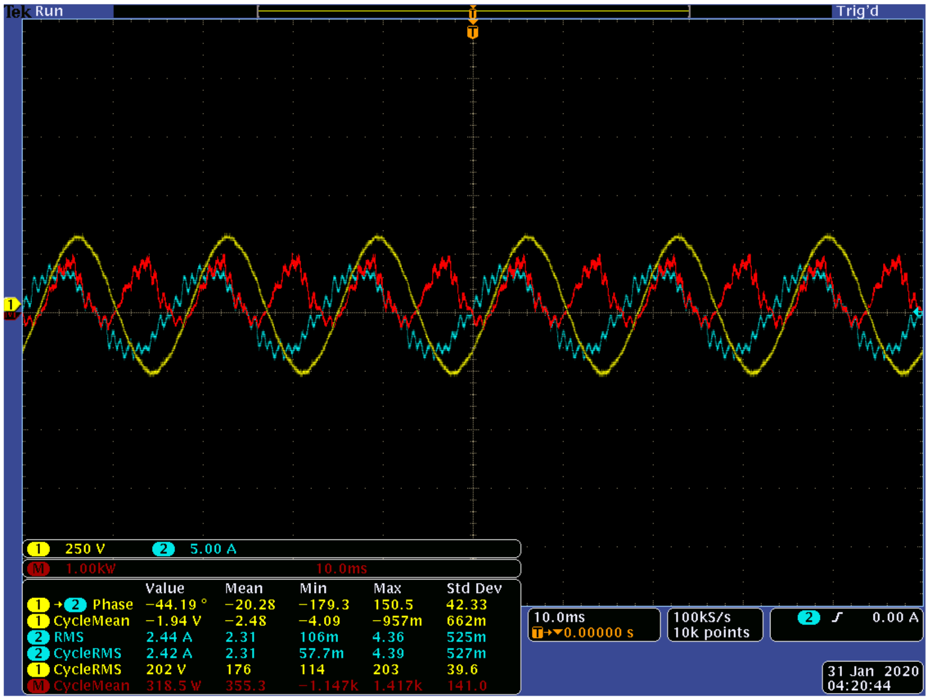
This can be verified from the table above as V_{phase} is exactly the same as V_{ll}, and I_{l} is exactly $\sqrt{3}$ times larger than I_{phase}.

These screenshots of oscilloscopes show the different curves and how the current and voltage are out of phase, giving rise to reactive power:

Phase A-B



Phase C-B



The power factor in this case would be:

$$\frac{973.6}{1505.3} = .65 \text{ leading}$$

The power factor is leading since the only reactive power comes from capacitors which makes the reactive power negative. This causes an angle which is negative, meaning a leading power factor.

The theoretical power factor can also be computed through the given Values of 125ohms and 24uF per phase. Delta connected 25ohms and 24uF converts to 18.28+20.67j ohms per phase in a Wye connected manner. The voltage we applied V_{ll} = 208V, which is V_{phase} = 120V.

$$\frac{120^2}{18.28+20.67j} = 1036 - 1172.6jVA$$

$$\cos\left(\arctan\left(\frac{-1172.6}{1036)}\right) = .66210$$

This result of theoretical power factor is very close to the experimental. Giving only a 1.8% error.

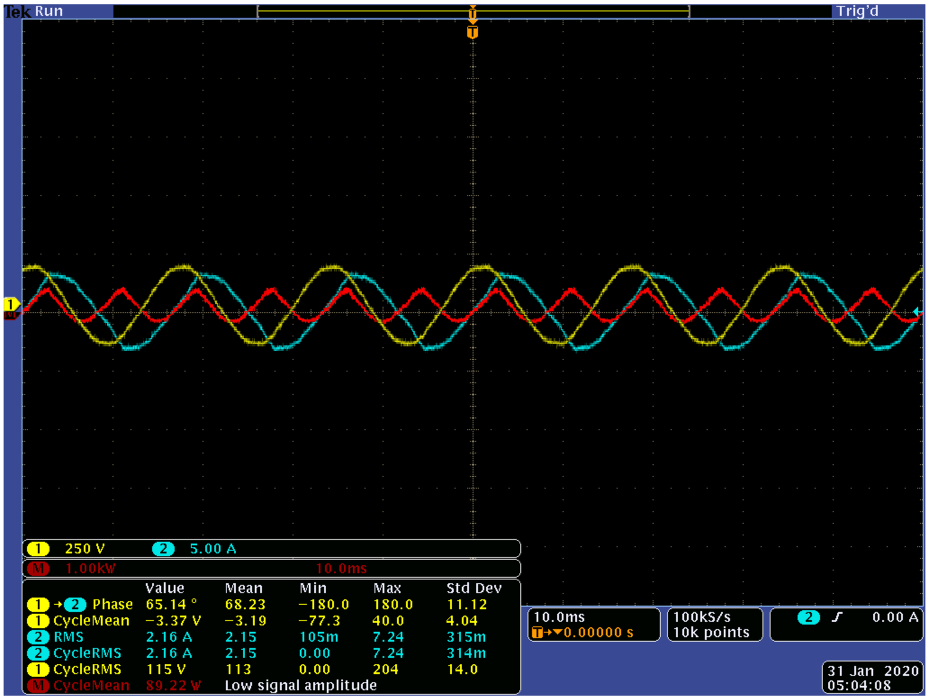
2.4 *Induction motor Load*

The third part of the experiment was to run an induction motor and take similar readings that were taken before. This time however, we actually observed how machines could operate using 3-Phases and its benefits. The results from this experiment are shown below:

	Line Current (A)	Phase Current (A)	L-L Voltage (V)	Phase Voltage (V)	Phase Shift θ (deg)	Real power P (W)	Reactive power Q (VAR)	Total power S (VA)
Phase A (A-B	2.21	-	205.9	-	-29	268	689.06	765.9
Phase B (B-C	-	-	-	-	-	-	-	-
Phase C (C-B	2.17	-	205.82	-	-	-	-	-

The screenshots of the waveform showing phase shift between voltage and current along with the values:

Phase A-B



Finally to verify the readings from the one-wattmeter method we can use the P_1, P_2, voltmeter and ammeter readings.

$$Q = \sqrt{S^2 - P^2} = \sqrt{(\sqrt{3}V_{ll}I_l)^2 - (P_1 + P_2)^2)} = \sqrt{(\sqrt{3}(205.9)(2.21))^2 - (268)^2)} = 741.19VAR$$

$$\frac{741.19 - 689.06}{741.19} = 7\% error$$

3 CONCLUSION

The goals of this experiment were to get familiar with lab equipment and learn how to take 3 phase measurements in a real environment. It was evident that the calculations assumed no losses and were ideal, but in a real situation there are some errors accumulated due to various things. For example, when we calculated power in a Balanced wye connected resistive load, we expected the power to be purely resistive. Though it mainly was, there is some capacitance that is created in connections, wires, and components themselves that cause some reactive power to rise. The use of one and two wattmeter methods truly has some good benefits as you do not need to be at the load to compute total power. Again there are some errors in calculating real power, but they are within the acceptable ranges as the highest error we had was 7%, which was this high because we used a measured value and did theoretical calculations with it to approximate the actual value. So the error was squared. In conclusion however, the data was mostly consistent with calculations and is something that is very useful in the power industry.

4 REFERENCES

[1] P.W. Sauer, P.T. Krein, P.L. Chapman, *ECE 431 Electric Machinery Course Guide and Laboratory Information*, University of Illinois at Urbana-Champaign, 2005.

5 APPENDIX

All the Raw data collected has been presented in tables above for explanation.