Lab 3:

Harmonics

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Power Systems I Laboratory

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1 Introduction

The primary focus of this lab is to explore the phenomena of harmonics induced by a nonlinear single- and three-phase systems. The lab will utilize a Tektronix PA4000 Power Analyzer to observe the harmonic content of several nonlinear loads. The first portion of the lab will investigate a single-phase nonlinear loads. It'll test several loads comprised of an incandescent bulb, incandescent bulb with three different dimmer levels (low, medium, and high levels) and a compact fluorescent lamp (CFL). From there we'll verify the Total Harmonic Distortion of V_{RMS} and I_{RMS} for each case, and then determine the true, distortion, and displacement power factor for all 5 loads. The second portion of the lab, will test balanced and unbalanced three-phase nonlinear loads for the three types of loads. It explore concepts of frequency of the dominant current harmonics within the neutral line and the current that flows within the neutral conductor.

In a Wye configuration for a three-phase system, it consists of three lines connected together by their negative end so that they can share a common return line (neutral). Each line has equal voltages in magnitude with a difference in phase angle by 120°. The current in the neutral is the sum of the currents flowing to each individual load in the power system. As long as the system has three equal linear loads then the return current in the neutral will be 0 A. This type of three-phase power system is called a **balanced three-phase system**. For this type of system, the neutral in the system is unnecessary and you only need three wires than the usual six.

However, must loads are nonlinear loads and they introduce harmonic content in the power system. **Harmonics** is a voltage or current at an integer multiple of the fundamental frequency of the system, produced by the action of non-linear loads. In a balanced three-phase system, triplen harmonics become a huge issue in a grounded-wye configuration. **Triplen Harmonics** are the odd multiples of the third harmonics (h = 3,9,15,21,...), and are considered the purely zero sequence. Triplen Harmonics are important for balance three-phase systems, because all three line currents will have 0° phase and will constructively add into the neutral. Two typical problems with this is the overloading of the neutral line, and loads can begin to misoperate, because the line-to-neutral voltage is badly distorted due to the triplen harmonic voltage drop in the neutral conductor. To counteract this, the neutral wire can be sized larger than the full rated current of the power wiring.

2 Single-phase Demonstration

Equations Used

Power Factor Equations

$$PF_{Distortion} = \frac{1}{\sqrt{1+\left(\frac{THD_V}{100}\right)^2}}\frac{1}{\sqrt{1+\left(\frac{THD_I}{100}\right)^2}} \tag{1}$$

$$PF_{Displacement} = \frac{P}{V_{RMS1}I_{RMS1}} \tag{2}$$

$$PF_{True} = \frac{P}{V_{RMS}I_{RMS}} = PF_{Distortion} * PF_{Displacement} \tag{3}$$

RMS Current and Voltage Equations

$$I_{RMS} = \sqrt{\sum_{n=1}^{\infty} I_{n,RMS}^2} \tag{4}$$

$$V_{RMS} = \sqrt{\sum_{n=1}^{\infty} V_{n,RMS}^2} \tag{5}$$

Total Harmonic Distortion Equations

$$THD_I = \frac{\sqrt{\sum_{n=2}^{\infty} I_{n,RMS}^2}}{I_{1,RMS}} \tag{6}$$

$$THD_V = \frac{\sqrt{\sum_{n=2}^{\infty} V_{n,RMS}^2}}{V_{1,RMS}} \tag{7}$$

Triplens and Neutral Current Equations

$$I_{RMS} = \frac{I_M}{\sqrt{2}} \tag{8}$$

$$I_{triplen}^{RMS} = \sqrt{\left(-\frac{I_M}{\sqrt{2}\,(3)\,\pi}\right)^2 + \left(-\frac{I_M}{\sqrt{2}\,(9)\,\pi}\right)^2 + \ldots} \tag{9}$$

for each odd triplen harmonic per one-phase

$$I_N = 3I_{triplen}^{RMS} \tag{10}$$

$$I_{triplen}^{RMS} \cong 0.096 I_M \tag{11}$$

PA4000 Analyzer Data for Each Type of Load

Incandescent Load - No Dimmer

Parameter	Calculated Values	PA4000 Measurements
Real Power (P)		57.7 W
V_{RMS}	120.2011 V	120.0 V
I_{RMS}	0.479849 A	0.480 A
THD_V	1.88 %	1.72 %
THD_I	1.92 %	1.77 %
$PF_{Distortion}$	1.00 (Unity)	1.00 (Unity)
$PF_{Displacement}$	1.00 (Unity)	1.00 (Unity)
PF_{True}	1.00 (Unity)	1.00 (Unity)

Table 1: Incandescent Load - No Dimmer PA4000 Analyzer

Incandescent Load - Low Dimmer

Parameter	Calculated Values	PA4000 Measurements
Real Power (P)		22.6 W
V_{RMS}	120.3201 V	120.0 V
I_{RMS}	0.339915 A	0.345 A
THD_V	1.83 %	1.65 %
THD_I	86.4 %	80.7 %
$PF_{Distortion}$	0.757 (lagging)	0.778 (lagging)
$PF_{Displacement}$	0.551 (lagging)	0.543 (lagging)
PF_{True}	0.417 (lagging)	0.422 (lagging)

Table 2: Incandescent Load - Low Dimmer PA4000 Analyzer

Incandescent Load - Medium Dimmer

Parameter	Calculated Values	PA4000 Measurements
Real Power (P)		37.8 W
V_{RMS}	120.0924 V	120.0 V
I_{RMS}	0.409986 A	0.413 A
THD_V	1.93 %	1.78 %
THD_I	57.2 %	53.9 %
$PF_{Distortion}$	0.868 (lagging)	0.880 (lagging)
$PF_{Displacement}$	0.768 (lagging)	0.761 (lagging)
PF_{True}	0.666 (lagging)	0.670 (lagging)

Table 3: Incandescent Load - Medium Dimmer PA4000 Analyzer

Incandescent Load - High Dimmer

Parameter	Calculated Values	PA4000 Measurements
Real Power (P)		57.3 W
V_{RMS}	119.9698 V	120.0 V
I_{RMS}	0.477582 A	0.478 A
THD_V	1.82 %	1.65 %
THD_I	1.85 %	1.69 %
$PF_{Distortion}$	1.00 (Unity)	1.00 (Unity)
$PF_{Displacement}$	1.00 (Unity)	1.00 (Unity)
PF_{True}	1.00 (Unity)	1.00 (Unity)

Table 4: Incandescent Load - High Dimmer PA4000 Analyzer

CFL (Compact Fluorescent Lamp) Load

Parameter	Calculated Values	PA4000 Measurements
Real Power (P)		13.5 W
V_{RMS}	120.5904 V	121.0 V
I_{RMS}	0.174367 A	0.177 A
THD_V	1.84 %	1.67 %
THD_I	97.3 %	89.5 %
$PF_{Distortion}$	0.717 (lagging)	0.745 (lagging)
$PF_{Displacement}$	0.643 (lagging)	0.632 (lagging)
PF_{True}	0.461 (lagging)	0.471 (lagging)

Table 5: CFL (Compact Fluorescent Lamp) - PA4000 Analyzer

From the PA4000 Power Analyzer User Manual the PA4000 displays the Fundamental Power Factor of the load. This Power Factor is Equivalent to the Displacement Power Factor listed for each load. The other measurements regarding true and distortion power factor were determined from the associated parameters from the equations observed above with the measured parameters by the PA4000 Analyzer.

The calculations from Table 1-5 are very similar to the measurements from the PA4000 Power Analyzer. Since this was a single-phase system the RMS voltage remained the same, because of the insignificance of the distorted harmonics. However, the RMS current had a higher Total Harmonic Distortion (THD) as the dimmer was progressively set to its lowest setting. When the incandescent bulb was set to a low dimmer setting that's when the system was consuming the most reactive power, and we believe this has a correlation to the increase in THD_I percentage. The harmonics after the fundamental were significantly greater in magnitude compared to the fundamental when compared to harmonics of the high and no dimmer incandescent loads.

This setting also displays how the power factor is affected due to the increase reactive component in the single-phase system. When the dimmer was at a high setting or no dimmer was placed in the system at all, we observe the system working at an unity power factor. As the dimmer setting was set to the lowest, we observed that the increased duration of the incandescent load being off during the sinusoidal cycle is proportional to the operating power factor of the load. For example, the low dimmer has a distortion power factor of 0.757 lagging and a displacement power factor of 0.551 compared to the medium dimmer having a distortion power factor of 0.868 lagging and a displacement power factor of 0.768 lagging.

Lastly, the CFL bulb displayed interesting characteristics compared to the incandescent loads. The CFL bulb had significantly less RMS current flowing throughout the single-phase system than the incandescent loads, but had more reactive power in the total system than real power and significantly greater THD_I than any other load. The CFL bulb is the more energy efficient bulb when compared to the incandescent bulb and the results due to display this to be correct. Overall, we observe how the measurements and calculations match the observation and theory when compared to these different types of loads.

Lagging Nature of the Loads

For the Incandescent Loads with no dimmer and the incandescent load with high dimmer have no reactive element acting upon the load. Therefore, they are functioning at an unity power factor. This result is expected since the incandescent bulb remains on throughout the whole cycle of AC current. However, once the dimmer is initiated on the incandescent bulb, we observed a lagging nature for when the dimmer was either low or medium setting. Then is due to the load consuming reactive power and appearing as an inductive load. For the Incandescent Load with Low Dimmer we observed the load consuming 34.9 VARs upon the load for a Displacement Power Factor of 0.551 (lagging). For the Incandescent Load with Medium Dimmer we observe a reduction in the total reactive element upon the load. We observed the load was consuming 32.2 VARs lagging to increase the Displacement Power Factor to 0.786 lagging. This reduction in reactive power is cause because the duration when the incandescent load is off during the cycle is dramatically reduced when compare to the low dimmer setting. Therefore, we can conclude that the dimmer switch setting reduces the efficiency of the bulb and the work done upon the load as the dimmer switch is progressively set to the minimum amount of brightness.

Lastly, the CFL (Compact Fluorescent Lamp) bulb also displayed a lagging nature on the load. For this bulb we observed more reactive power that was consumed when compares to the real power upon the load. However, the CFL bulb is consuming less reactive power than either the low or medium dimmer switch setting. The CFL bulb only consumes approximately 21.4 VARs compared to the 32.2 Vars for the medium dimmer incandescent bulb. These results make sense due to that a CFL bulb is an energy efficient bulb that consumes one-fifth to one-third of the power of an Incandescent bulb. By consuming more reactive power this load appears as an inductive load with a Displacement Power factor of 0.643.

Triplen and Neutral Currents For Balanced Three-Phase System

A three-phase power system in which the three generators have voltages that are exactly equal in magnitude and 120° different in phase, and which all three loads are identical, is called a **balanced three-phase** system. As long as the three loads are equal, the return current in the Neutral is zero.

$$I_N = I_A + I_B + I_C$$

Where $I_N = 0$ for a linear load in a three-phase system

However, for a nonlinear load the odd triplen harmonics (zero sequence) are all in-phase with each other and add constructively through the neutral conductor. The triplen harmonics are the odd multiples of 3 harmonics (h=3,9,15,21,...). Since the three lines from the Grounded-Wye configuration are in-phase with each other the neutral current is three time that of the triplen current.

	I_M	$I_{triplen}^{RMS}$	I_N
No Dimmer	0.6788 A	0.05512 A	0.1654 A
Low Dimmer	0.4880 A	0.038985 A	0.11695 A
Medium Dimmer	0.5841 A	0.04743 A	0.14228 A
High Dimmer	0.6759 A	0.05489 A	0.16467 A
CFL	0.2505 A	0.02034 A	0.06102 A

Table 6: Current in the Neutral for a Balanced Three-Phase System

From equations 8-11, the values we calculated in the neutral conductor are close to what we should expect. All the calculated values are within 14% of the theoretical neutral currents. We did observe that the amount of neutral current is proportional to that of I_M. The lower the magnitude of the current determined the lower the triplen current was. Since we knew the odd triplen harmonics are considered the zero sequence with all three lines in phase with each other we knew that the neutral currents would be the summation of these three lines. We do understand that these models are assuming that each load would behave equally in an ideal situation, but for the real application we don't expect that to be the case.

Dimmer Switch Functionality

Modern dimmer switches rapidly shut off/on to reduce the total amount of energy that flows throughout the circuit. This is done, by switching the light bulb off many times every second. The switching cycle is designed around the fluctuation of the Alternating Current (AC) within the household. AC Current fluctuates due to the changing of voltage polarity through a sinusoidal signal (sine wave). A modern dimmer switch "chops off" the sine wave, by automatically shutting the light bulb off every time the direction of current changes. This happens twice per cycle, or 120 time per second (In the United States a standard operating frequency is 60 Hz). Then turns the light circuit back on when the voltage reaches back to a certain level.

The time where the light circuit turns back on is due to the position of the dimmer switch's knob or slider. If the dimmer is turned to a brighter setting, then it will switch on rapidly after the bulb turns off. If the dimmer is set for a lower brightness setting, then the turn on will be substantially delayed in the cycle compared to a brighter setting. To maintain brightness, the light circuit is turned on for most of the cycle causing more energy per second to be supplied to the light bulb.

The dimmer is built with a variable resistor called a Triac (Triode Alternating Current Switch). The Triac is a semiconductor device and is similar to a diode and transistor. It contains multiple layers of N-type and P-type semiconductor. The Triac is arranged with two terminals at both ends of the circuit. There's difference in voltage across these two terminals that are dependent on the change of AC Current. When the current moves one way then the top terminal is positively charged, while the bottom is negatively charged. Coincidently, if the current moves the opposite direction then the top terminal is negatively, while the bottom terminal is positively charged. The basic functionality of the Triac is that the variable resistor controls the voltage applied across the gate, and the voltages on the gate control the switching action (duration of off time during cycle).

3 Three-phase Demonstration

For the three phase system, there were essentially two cases in the demonstration. One was using linear loads. In this case, incandescent bulbs were used for the loads in the demonstration. The other case, was using non-linear loads, where CFLs (Compact Fluorescent Lamp) were used as the loads.

For the linear case, there were three sub-cases. The first sub-case is when the system is unbalanced with all three loads connected (one of the three bulbs are out of spec). The second is when the system is balanced with all three loads connected. The third sub-case is when only one or two bulbs were connected in the three phase system. We will mostly be looking at the first two sub-cases of the linear case and the non-linear case for this report. The third sub-case was only for a brief moment and no data was collected. That being said, we can relate the first sub-case with the third sub-case as they are very similar in nature and theory. To make things simple, these two cases can be lumped together to be called an unbalanced system.

One Phase Calculation Comparison

In the previous, single phase section, we made some calculations as to what the current in the neutral of the three phase system would look like. We can now compare the measurements to see if the theory can be confirmed. The first case would be be the balanced linear load using incandescent bulbs. The calculated current to be in the neutral of the balanced three phase system was .165A, the measured value is .02A. These values are not very close. In fact, this calculated value is closer to the unbalanced three phase system's current in the neutral, which is .11A. The second calculation was for the non-linear CFL case. The expected calculated current in the neutral is .06A and the measured value is 0A in the neutral of the three phase system.

Three Phase Harmonics

Before we head straight into the harmonics from the demonstration, we should go over the expectations. Afterwards, we can delve into the measured harmonics to confirm the expectations. For an ideal balanced three phase system, from theory we can expect the current in the neutral to be zero, having nonexistent harmonics. However, the ideal model is never the case in real world situations. That being said, we can assume the harmonics or distortion to be very low, very close to zero. Especially, when compared to the unbalanced system case, where we can expect the harmonics or distortion to be greater in magnitude. In other words, we are expecting the unbalanced system to be rich in harmonics and the balanced system to have harmonics but at very low magnitudes when compared with the unbalanced system.

Now looking at the data presented from the demonstrations. We can see that the results are concurrent with our expectations. The magnitudes of the unbalanced systems are indeed greater than that of the balanced system. Also, the balanced system does indeed have non-zero harmonics that are much closer to zero when compared to the unbalanced system's harmonics. However, there are harmonics where the differences in magnitudes are much less than other harmonics. Those lie in the triplen harmonics. Balanced systems are most effected by the triplen harmonics. That is why the triplen harmonics are much closer in magnitude in each case. We will see later that this relationship is what builds the expressions for the current in the neutral line for both balanced and unbalanced systems.

Which leads us to the most dominant current harmonic in the neutral line. This can be shown from the power analyzer using the harmonics graph. The graph shows odd multiples of 3 having a magnitude. The magnitudes are decreasing as n increases for the odd multiples of 3 (i.e. x = 3n on the x-axis, where n = odd integers). The graph also shows that amongst the triplen harmonics which of those is most dominant. In other words, which amongst the triplen harmonics has the greatest magnitude. In this case, it would the third harmonic or the first of the triplen harmonics. The frequency of this harmonic is simply the harmonic multiplied by the fundamental frequency. In this demonstration, the third harmonic is 180Hz where the fundamental frequency is 60Hz (i.e. 180Hz = 3*60Hz). Therefore, the frequency of the most dominant current harmonic in the neutral is 180Hz.

Reactance and Frequency

In the previous section, we found the frequency of the most dominant harmonic within the system. If we consider reactance of a power system, we can see that frequency plays a major role. In that both capactive and inductive reactances are related to frequency.

$$X_L = j2\pi fL \tag{12}$$

$$X_C = 1/j2\pi fC \tag{13}$$

Reactance potentially creates a system that can be out-of-phase. When a system is out-of-phase, real power is not transferred even though current is flowing. This is power loss, through heat dissipation (can lead to overloading the system) and other means depending on the system. Power loss with current still flowing results in a voltage drop, according to the electric power relationship (P = VI). In summary, we can see that frequency can create this out-of-phase system, therefore, creating a voltage drop within the neutral for the cases in the demonstration.

Three Phase Calculations

Earlier we mentioned expressions for the current in the neutral line could be formed from the relationships of harmonics. For the balanced load we look only at the odd triplen harmonics and for the unbalanced load we look at all harmonics above fundamental. The following are these said expression for both balanced and unbalanced loads (respectively):

$$I_{rms,n} = \sqrt{\sum_{n=3}^{\infty} I^2_{n(oddtriplen),rms}} \tag{14}$$

$$I_{rms,n} = \sqrt{\sum_{n=2}^{\infty} I^2_{n,rms}} \tag{15}$$

Also, if given all of the harmonics in the neutral we use the following:

$$I_{rms,n} = \sqrt{\sum_{n=1}^{\infty} I_{n,rms}^2} \tag{16}$$

	Calculated	Measured
Unbalanced System	.116 A	.117 A

Table 7: Neutral Current for Unbalanced Three Phase System

When comparing calculations with the measurements, we can see that the equations are off quite significantly. Especially, when comparing the one phase calculations with the three phase. So comparing the calculations when considering a single bulb or two bulbs is out of the question. Looking at the display within the demonstration, we can see great variance within the neutral currents. This goes to prove that theoretical computation may just be a simplification for the initial design of a power system. However, earlier we noticed that the calculated values were much closer to the measured values of the unbalanced systems. This just further backs up the non-ideal case of real world simulations and design.

4 Conclusion

The primary focus of this lab is to explore the phenomena of harmonics induced by a nonlinear single- and three-phase systems. The lab will utilize a Tektronix PA4000 Power Analyzer to observe the harmonic content of several nonlinear loads. The first portion of the lab will investigate a single-phase nonlinear loads. It'll test several loads comprised of an incandescent bulb, incandescent bulb with three different dimmer levels (low, medium, and high levels) and a compact fluorescent lamp (CFL). From there we'll verify the Total Harmonic Distortion of V_{RMS} and I_{RMS} for each case, and then determine the true, distortion, and displacement power factor for all 5 loads. The second portion of the lab, will test balanced and unbalanced three-phase nonlinear loads for the three types of loads. It explore concepts of frequency of the dominant current harmonics within the neutral line and the current that flows within the neutral conductor.

For the first portion of the lab we explored a single-phase system with five total types of loads. The calculation of the power factor, Total Harmonic Distrotion (THD) and RMS values for the incandescent, dimmer (3 positions), and the CFL cases were as expected. We observed that the dimmer adds inductance reactance into the systems for the during the duration when the bulb was turned off. This causes a lagging power factor when the dimmer is set to a medium or low position. When there's reactance placed into the system, we observed the Total Harmonic Distortion of the current to be significantly greater than when the load was acting an an unity power factor. Then we calculated the RMS current that would arise in the neutral for a balanced three-phase configuration. The equations 8-11 that we used shows that the values we calculated were similar to that what we expect in the neutral for a three-phase load. However, for the second portion of the experiment our data doesn't seem to match what the PA4000 Power Analyzer measured in the neutral conductor. Besides this one discontinuity the results from part 1 of the lab experiment were as we expected.

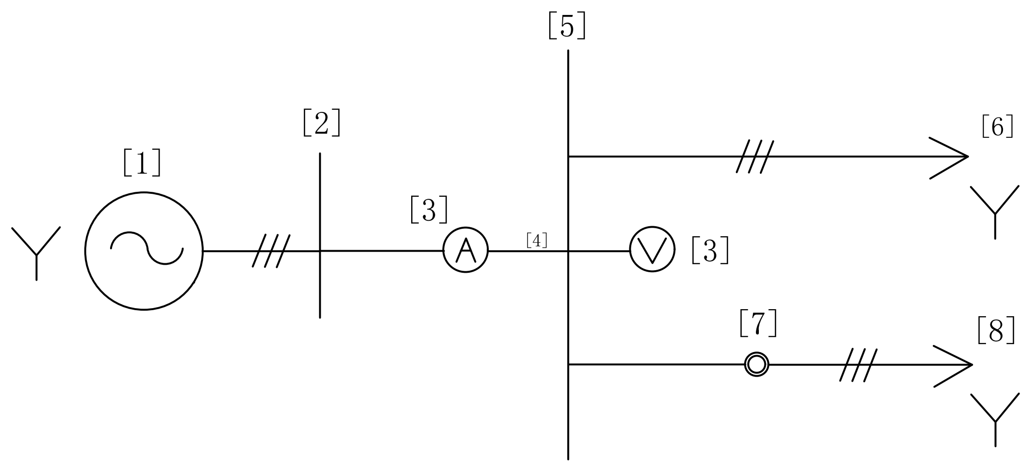
For the second portion of the lab, we confirmed that the three-phase calculations for the balanced system doesn't match the results measured from the PA4000 Power Analyzer. The current in the neutral conductor was significantly less than what was calculated. We observe the calculation results were closer to the unbalanced three-phase system than the balanced three-phase system. While we couldn't come with an exact reasoning behind this, we did speculate that this was due to many factors when it comes to approximating a theoretical model for practical application. We know the triplen current equation used is an approximation to simplify the calculation and the standard deviation between the three loads. Especially Incandescent bulbs are known to be rather inefficient, by approximately turning only 5% of its total energy into visible light.

Overall the requirements from the lab were straight forward. Having the lab sessions remotely makes the understanding of how the lab is conducted to be harder. You can gain only so much by viewing a video demonstration rather than conducting the lab in person. However, we gained a better perspective on how harmonics can distort a respective signal when it comes to a single-phase or a three-phase system. While not all results were desirable in the lab, we have made conclusions on why these discrepancies are and how we would correct that for next time.

A Appendix: Engineering Documents

	Items	Vendor	Part Number	Quantity	List Price	Net Price
1	Supply, Var. 3ph, 24Vac	Lab-Volt	8821-20	1	$2,870.00	$2,870.00
2	Tektronix PA4000/4CH Multi-phase Power Analyzer	TestEquity	21301.2	1	$9,995.00	$9,995.00
3	Junction Box	Garvin	52171-SDR	3	$3.00	$9.00
4	Junction Box Cover	Garvin	LVP41D	3	$4.44	$13.32
5	Blade Receptacle, Duplex, 2-Pole3-Wire, 20A 125V, 5-20R	Zoro	G0333444	3	$2.26	$6.78
6	Lighting Dimmer	Zoro	G6759193	3	$13.36	$40.08
7	Socket Adapter	Rejuvenation	A0250	3	$4.00	$12.00
8	Incandescent Bulb 60W	Zoro	G0309696	3	$3.47	$10.41
9	CFL Bulb 60W	Walmart	ES9M814DIM2	3	$7.50	$22.50
10	Black-36.0" (914.40mm) Banana Plug, Stackable Patch Cord 14AWG (5kV)	Pomona Electronics	B-36-0	4	$6.09	$24.36
11	Red-36.0" (914.40mm) Banana Plug, Stackable Patch Cord 14AWG (5kV)	Pomona Electronics	B-36-2	4	$6.09	$24.36
12	Blue-36.0" (914.40mm) Banana Plug, Stackable Patch Cord 14AWG (5kV)	Pomona Electronics	B-36-6	1	$6.09	$6.09
13	White-36.0" (914.40mm) Banana Plug, Stackable Patch Cord 14AWG (5kV)	Pomona Electronics	B-36-9	6	$6.09	$36.54
14	Green-36.0" (914.40mm) Banana Plug, Stackable Patch Cord 14AWG (5kV)	Pomona Electronics	B-36-5	1	$6.09	$6.09
					Total	$13061.53

Table 8: Bill of Materials



Notes:

[1] Power Supply 3ph: 8821-20

[2] Power Supply connect bus for banana jacks (B-36)

[3] Tektronix PA4000/ 4CH Multi-phase Power Analyzer

[4] Banana cables (B-36) are used to connect between Power Analyzer and junction box.

[5] Junction box

[6] Loads in three phase with fixed voltage

[7] Lighting dimmer

[8] Loads in three phase with variable voltage

File No. *.DWG file name	Sheet 1 of 1
Portland State UNIVERSITY	PORTLAND STATE UNIVERSITY DEPT. OF ELECTRICAL AND COMPUTER ENGINEERING
EE 347 Lab 3 One-line Diagram	Designed Team 3 5/7; Drawn Lihong 5/9; Checked
Approved ______ Date ____	Title ______

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POINT ASSIGNMENT INDEX		
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2	2	LabVolt Power Supply, 8821 (Single Phase and Three Phase)
3	2	Tektronix PA4000/4CH Multi-phase Power Analyzer (Single Phase and Three Phase)
4	2	Junction Box (Single Phase and Three Phase)

NOTES

REV	DATE	DESCRIPTION	Created By	Checked by
1	5/14/2020	LabVolt Power Supply connection to PA4000 Power Analyzer	LZ	RN
2	5/14/2020	PA4000 Power Analyzer connection to Junction Box in Wye-connection	LZ	KB

Single Phase										
LabVolt Power Supply, 8821		POINT TYPE								
		Hardware Point					Virtual Point			
Point Description	Origin Address	DO	DI	AO	AI	Pwr		Destination	Destination Description	Notes
AC fixed 120/208 V Phase A	1	0	0	0	0	1	0	CH1 Blue	Power Analyzer Part 1 A_1A	
AC fixed 120/208 V Netural	N	0	0	0	0	1	0	NL1	Netural line (Juction box 1)	
	Total Points	0	0	0	0	2	0			

Three Phase										
LabVolt Power Supply, 8821		POINT TYPE								
		Hardware Point					Virtual Point			
Point Description	Origin Address	DO	DI	AO	AI	Pwr		Destination	Destination Description	Notes
AC fixed 120/208 V Phase A	1	0	0	0	0	1	0	CH1 Blue	Power Analyzer Channel 1 A_1A	
AC fixed 120/208 V Phase B	2	0	0	0	0	1	0	CH2 Blue	Power Analyzer Channel 2 A_1A	
AC fixed 120/208 V Phase C	3	0	0	0	0	1	0	CH3 Blue	Power Analyzer Channel 3 A_1A	
AC fixed 120/208 V Netural	N	0	0	0	0	1	0	CH4 Black bottom	Power Analyzer Channel 4 A_LO	
	Total Points	0	0	0	0	4	0			

Single Phase

Tektronix PA4000/4CH Multi-phase Power Analyzer		POINT TYPE								
		Hardware Point					Virtual Point			
Point Description	Origin Address	DO	DI	AO	AI	Pwr		Destination	Destination Description	Notes
Power Analyzer Channel 1 V_HI	CH1 Yellow top	0	0	0	0	1	0	HL1	Hot line (Juction box 1)	
Power Analyzer Channel 1 V_LO	CH1 Black top	0	0	0	0	1	0	NL1	Netural line (Juction box 1)	
Power Analyzer Channel 1 A_LO	CH1 Black bottom	0	0	0	0	1	0	HL1	Hot line (Juction box 1)	
Power Analyzer Channel 1 A_1A	CH1 Blue	0	0	0	0	1	0	1	AC fixed 120/208 V Phase A	
	Total Points	0	0	0	0	4	0			

Three Phase

Tektronix PA4000/4CH Multi-phase Power Analyzer		POINT TYPE								
		Hardware Point					Virtual Point			
Point Description	Origin Address	DO	DI	AO	AI	Pwr		Destination	Destination Description	Notes
Power Analyzer Channel 1 V_HI	CH1 Yellow top	0	0	0	0	1	0	HL1	Hot line (Juction box 1)	
Power Analyzer Channel 1 V_LO	CH1 Black top	0	0	0	0	1	0	NL1	Netural line (Juction box 1)	
Power Analyzer Channel 1 A_LO	CH1 Black bottom	0	0	0	0	1	0	HL1	Hot line (Juction box 1)	
Power Analyzer Channel 1 A_1A	CH1 Blue	0	0	0	0	1	0	1	AC fixed 120/208 V Phase A	
Power Analyzer Channel 2 V_HI	CH2 Yellow top	0	0	0	0	1	0	HL2	Hot line (Juction box 2)	
Power Analyzer Channel 2 V_LO	CH2 Black top	0	0	0	0	1	0	NL2	Netural line (Juction box 2)	
Power Analyzer Channel 2 A_LO	CH2 Black bottom	0	0	0	0	1	0	HL2	Hot line (Juction box 2)	
Power Analyzer Channel 2 A_1A	CH2 Blue	0	0	0	0	1	0	2	AC fixed 120/208 V Phase B	
Power Analyzer Channel 3 V_HI	CH3 Yellow top	0	0	0	0	1	0	HL3	Hot line (Juction box 3)	
Power Analyzer Channel 3 V_LO	CH3 Black top	0	0	0	0	1	0	NL3	Netural line (Juction box 3)	
Power Analyzer Channel 3 A_LO	CH3 Black bottom	0	0	0	0	1	0	HL3	Hot line (Juction box 3)	
Power Analyzer Channel 3 A_1A	CH3 Blue	0	0	0	0	1	0	3	AC fixed 120/208 V Phase C	
Power Analyzer Channel 4 A_1A	CH4 Blue	0	0	0	0	1	0	NL1	Netural line (Juction box 1)	
Power Analyzer Channel 4 A_1A	CH4 Blue	0	0	0	0	1	0	NL2	Netural line (Juction box 2)	
Power Analyzer Channel 4 A_1A	CH4 Blue	0	0	0	0	1	0	NL3	Netural line (Juction box 3)	
Power Analyzer Channel 4 A_LO	CH4 Black bottom	0	0	0	0	1	0	N	AC fixed 120/208 V Netural	
	Total Points	0	0	0	0	16	0			

Single Phase

Junction Box		POINT TYPE								
		Hardware Point					Virtual Point			
Point Description	Origin Address	DO	DI	AO	AI	Pwr		Destination Address	Destination Description	Notes
Hot line (Juction box 1)	HL1	0	0	0	0	1	0	CH1 Yellow top	Power Analyzer Channel 1 V_HI	
Hot line (Juction box 1)	HL1	0	0	0	0	1	0	CH1 Black bottom	Power Analyzer Channel 1 A_LO	
Netural line (Juction box 1)	NL1	0	0	0	0	1	0	CH1 Black top	Power Analyzer Channel 1 V_LO	
Netural line (Juction box 1)	NL1	0	0	0	0	1	0	N	AC fixed 120/208 V Netural	
	Total Points	0	0	0	0	4	0			

Three Phase

Junction Box		POINT TYPE								
		Hardware Point					Virtual Point			
Point Description	Origin Address	DO	DI	AO	AI	Pwr		Destination Address	Destination Description	Notes
Hot line (Juction box 1)	HL1	0	0	0	0	1	0	CH1 Yellow top	Power Analyzer Channel 1 V_HI	
Hot line (Juction box 1)	HL1	0	0	0	0	1	0	CH1 Black bottom	Power Analyzer Channel 1 A_LO	
Netural line (Juction box 1)	NL1	0	0	0	0	1	0	CH1 Black top	Power Analyzer Channel 1 V_LO	
Netural line (Juction box 1)	NL1	0	0	0	0	1	0	CH4 Blue	Power Analyzer Channel 4 A_1A	
Hot line (Juction box 2)	HL2	0	0	0	0	1	0	CH2 Yellow top	Power Analyzer Channel 2 V_HI	
Hot line (Juction box 2)	HL2	0	0	0	0	1	0	CH2 Black bottom	Power Analyzer Channel 2 A_LO	
Netural line (Juction box 2)	NL2	0	0	0	0	1	0	CH2 Black top	Power Analyzer Channel 2 V_LO	
Netural line (Juction box 2)	NL2	0	0	0	0	1	0	CH4 Blue	Power Analyzer Channel 4 A_1A	
Hot line (Juction box 3)	HL3	0	0	0	0	1	0	CH3 Yellow top	Power Analyzer Channel 3 V_HI	
Hot line (Juction box 3)	HL3	0	0	0	0	1	0	CH3 Black bottom	Power Analyzer Channel 3 A_LO	
Netural line (Juction box 3)	NL3	0	0	0	0	1	0	CH3 Black top	Power Analyzer Channel 3 V_LO	
Netural line (Juction box 3)	NL3	0	0	0	0	1	0	CH4 Blue	Power Analyzer Channel 4 A_1A	
	Total Points	0	0	0	0	12	0			

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