Harmonic Analysis:

Lab 3

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Abstract

Harmonic currents, generated by non-linear electronic loads, increase power system heat losses and power bills of end-users. These harmonic-related losses reduce system efficiency, cause apparatus overheating, and increase power and air conditioning costs. As the number of harmonics-producing loads has increased over the years, it has become increasingly necessary to address their influence when making any additions or changes to an installation.

Harmonic currents can have a significant impact on electrical distribution systems and the facilities they feed. It is important to consider their impact when planning additions or changes to a system. In addition, identifying the size and location of non-linear loads should be an important part of any maintenance, troubleshooting and repair program.

Troubles presented from harmonics in power systems:

- Overheating of electrical distribution equipment, cables, transformers, standby generators, etc.
- High voltages and circulating currents caused by harmonic resonance
- Equipment malfunctions due to excessive voltage distortion
- Increased internal energy losses in connected equipment, causing component failure and shortened life span
- False tripping of branch circuit breakers
- Metering errors
- Fires in wiring and distribution systems
- Generator failures
- Crest factors and related problems
- Lower system power factor, resulting in penalties on monthly utility bills

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1 Introduction

This lab explores the phenomena of harmonics induced by nonlinear single- and three-phase loads. Students use a Tektronix PA4000 Power Analyzer to observe harmonics and study their characteristics. Students investigate the harmonic content of several types of nonlinear loads, calculate harmonic distortion, calculate several metrics of power factor and make observations of distorted waveforms within both hot and neutral lines. Students also consider the impacts that harmonics may have on the sizing of and voltage drop across conductors.

Objectives Students learn:

- how harmonics arise from different loads and in different configurations
- to characterize harmonic currents as spectral components
- to quantify harmonic distortion and various measures of power factor
- the causes of harmonic currents in the neutral line of balanced three-phase loads.

Analyze and interpret data, and draw conclusions Develop engineering documentation:

- One-line diagram
- Bill of materials
- Points list

2 Circuit Build and Data Gathering

The build consisted of two different phases, a single phase non-linear load and a three phase non-linear load. With each load data was collected using the PA4000 Power Analyzer for a single phase non-linear load incandescent light bulb and a compact fluorescent light bulb. As well as the three phase non-linear load for the incandescent light bulb and compact fluorescent light bulb.

2.1 Single Phase Non-linear Load

Incandescent Light Bulb

Using the PA4000, we started by measuring the harmonic content of a linear load on a 60 W incandescent light bulb in a non-dimmer receptacle of a junction box. After recording the measurements (data dump) for the non-dimmer, we switched the incandescent light bulb into the dimmer receptacle of the junction box and collected the data at a low and high range.

Compact Fluorescent Light Bulb (CFL)

After measuring the non-dimmer, low and high dimmer for the incandescent light bulb, we plugged a CFL bulb into the non-dimmer receptacle of the junction box to measure the harmonic content and collected the data (data dump).

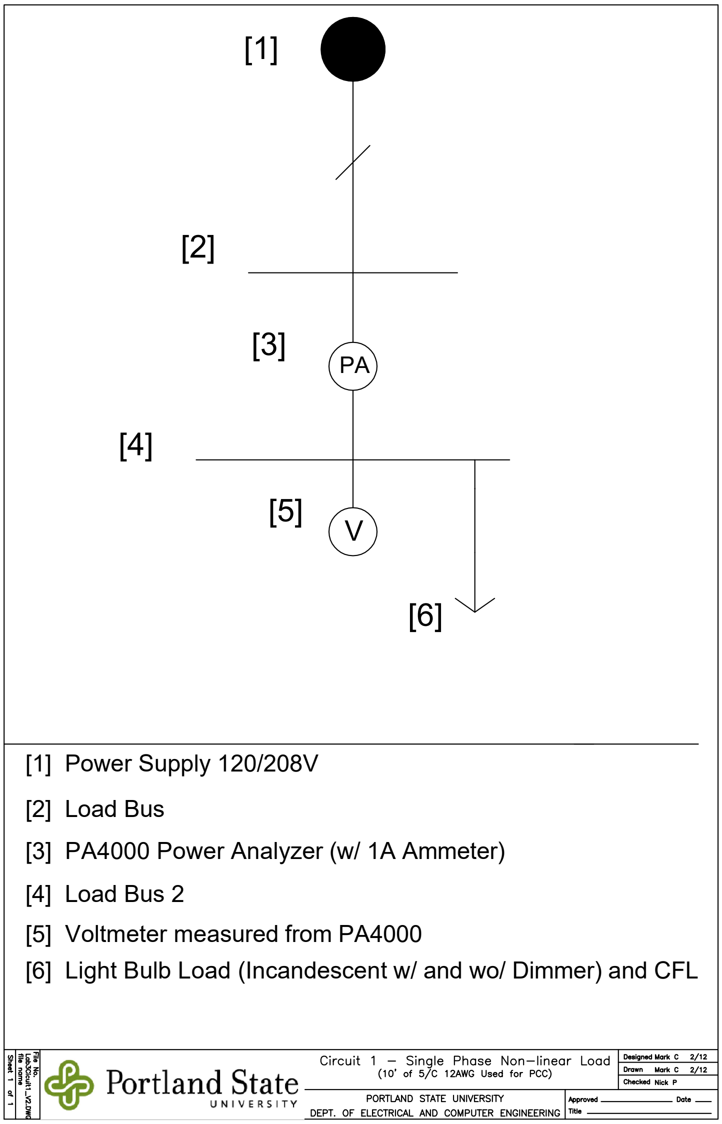

Figure 1: One-line diagram of Circuit 1

The one line diagram for the Single Phase Non-Linear Load

2.2 Three Phase Non-linear Loads

Incandescent Light Bulb

For the three phase load incandescent light bulb, we plugged the bulb into the non-dimmer receptacle and collected the data from the PA4000 Power Analyzer (data dump).

Compact Fluorescent Light Bulb (CFL)

Replacing the incandescent with the CFL bulb into the non-dimmer receptacle and collect the data as well (data dump).

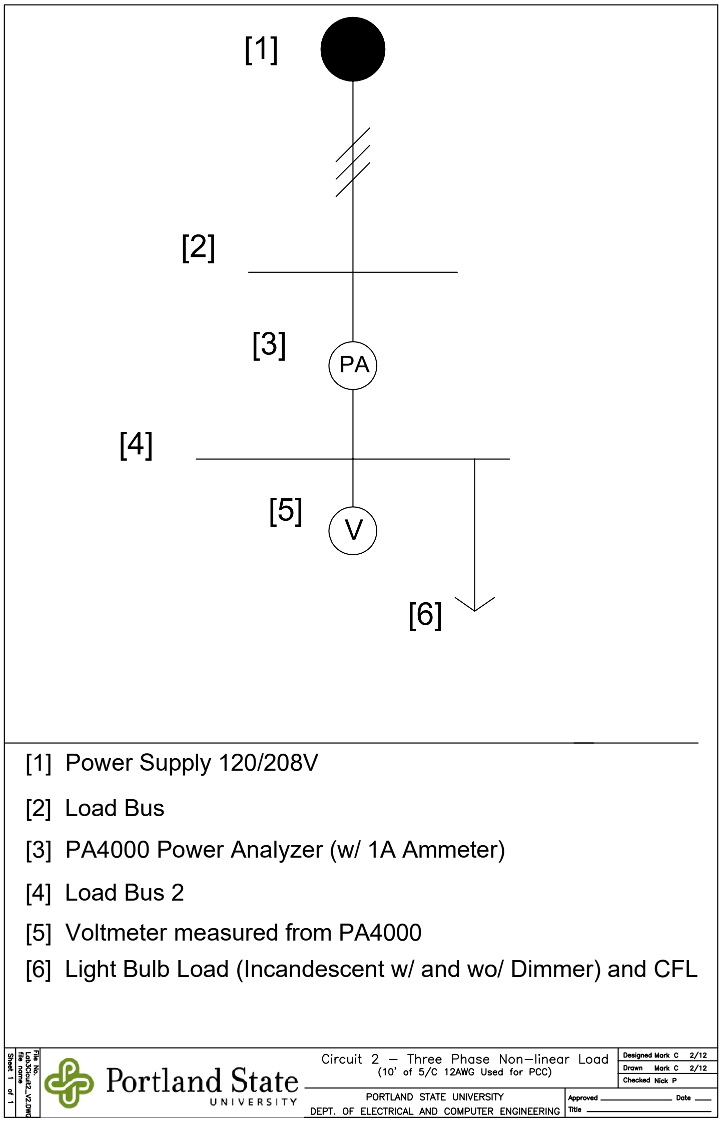

Figure 2: One-line diagram of Circuit 2

The one line diagram for the Three Phase Non-Linear Load

3 Data Analysis and Interpretation, Drawing Conclusions

When measuring with the PA4000 analyzer, we found that it is measuring (true power factor) when comparing the values to our calculated values. For each of the following tables, we show our values calculated using Vrms, Irms, and the phase angle of the fundamental. The measured values are the ones given by the PA4000 analyzer.

The true PF is given by $\cos(\theta)$ where $\theta =$ the phase angle of the current fundamental. The distortion PF found using the calculated current THD. The displacement PF can then be found from those two PF values.

Table 1: Incandescent single phase non-dimmer PF values

PF using Current fundamental phase angle			PF using measured values		
true	distortion	displacement	true	distortion	displacement
0.982	0.962	1.02	0.942	0.967	0.974

The calculated current THD value was found by the square root of the sum of squares of current harmonics (not including the fundamental), then dividing that value by the fundamental RMS magnitude.

Table 2: Incandescent current THD values for non-dimmer single phase

Ithd calculated	Ithd measured
28.58%	26.44%

Table 3: Incandescent single phase low dimmer PF values

PF using Current fundamental phase angle			PF using measured values		
true	distortion	displacement	true	distortion	displacement
0.7111	0.7379	0.9637	0.5232	0.7614	0.6871

Table 4: Incandescent current THD values for low dimmer single phase

I_thd calculated	I_thd measured
91.46%	85.14%

Table 5: Incandescent single phase high dimmer PF values

PF using Current fundamental phase angle			PF using measured values		
true	distortion	displacement	true	distortion	displacement
0.9315	0.9081	1.0258	0.8377	0.9191	0.9115

Table 6: Incandescent current THD values for high dimmer single phase

I_thd calculated	I_thd measured
46.11%	42.87%

Table 7: CFL non-dimmer single phase PF values

PF using Current fundamental phase angle			PF using measured values		
true	distortion	displacement	true	distortion	displacement
0.8749	0.6770	1.2923	0.5746	0.7164	0.8021

Table 8: CFL current THD values for non dimmer single phase

I_thd calculated	I_thd measured
108.70%	97.37%

With the CFL bulb, the leading PF is due to how the bulb acts as a kind of capacitor to operate.

For the incandescent bulb, the lagging PF is caused by the minor inductance in the circuit. The dimmer switch introduces more inductive reactance, lowering the PF.

The dimmer has a voltage threshold, below which it blocks current, and above which it allows current to flow until it reaches zero when it blocks again. This introduces harmonics into the current waveform, causing increased distortion. Lowering the dimmer increases the voltage threshold on the current.

Regarding Table 7, Displacement PF, we know that this value is incorrect but not sure why.

To consider if the neutral loads were connected in a balanced three phase configuration for the single phase incandescent load, we averaged the time series values for each triplen harmonic (A3,A9,A15,A21), then took the square of the sum of squares of each of those values and multiplied it by three to create a hypothetical neutral line current, $I_{N,RMS} = 0.3A$. The separate triplen harmonics are shown in Figure 3 below.

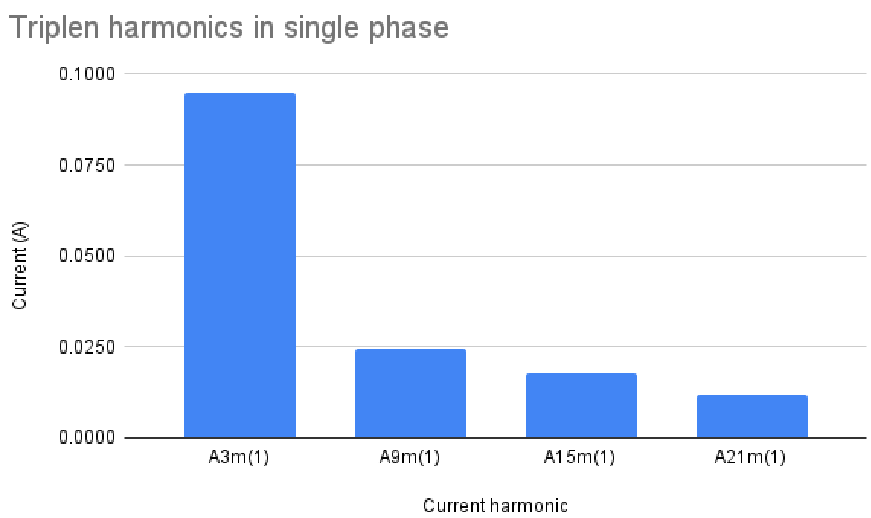

Figure 3: Incandescent non-dimmer single phase triplen harmonics

We used the same method to find the hypothetical neutral line current using the single phase CFL triplen values to get $I_{N,RMS} = 0.33A$. The separate triplen harmonics are shown in Figure 4.

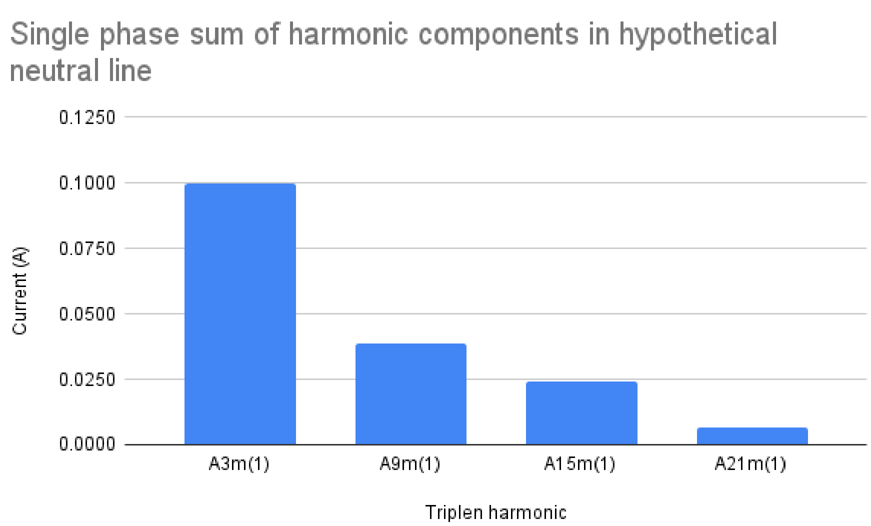

Figure 4: CFL non-dimmer single phase triplen harmonics

3.1 Three Phase Circuits

The calculations for PF and THD for the 3 phase system were done in the same way as for the single phase system. The current THD was calculated for each phase, but since the values weren't significantly different between phases, a single phase current THD was used for comparison in each of the following tables.

Table 9: Incandescent 3 phase non dimmer PF values

PF using Current fundamental phase angle			PF using measured values		
true	distortion	displacement	true	distortion	displacement
0.98	0.98	1.00	0.95	0.98	0.97

Table 10: Incandescent 3 phase non dimmer current THD values

I_thd calculated	I_thd measured
22.16%	20.40%

Table 11: CFL 3 phase non dimmer PF values

PF using Current fundamental phase angle			PF using measured values		
true	distortion	displacement	true	distortion	displacement
0.9665	0.7371	1.3112	0.6920	0.7536	0.9183

Table 12: CFL 3 phase non dimmer current THD values

I_thd calculated	I_thd measured
91.67%	87.23%

The calculated neutral line current in the 3 phase system was significantly lower than the calculated hypothetical neutral line current found using the single phase measurements. We are not sure how to explain this, and have repeatedly checked to make sure our formulas were correct.

The frequency of the dominant harmonic in the neutral line of the harmonic for the incandescent is the 9th harmonic in the first phase. This is a frequency of Hz. For the CFL harmonics, the 21st harmonic of the first phase is the dominant harmonic giving a frequency of 1260Hz.

Considering the frequency dependence of the reactance of the line, this relationship is the higher the frequency the less reactance, and the lower the frequency the greater the reactance.

To calculate the triplen harmonics for each phase, the time series values for each triplen (A3,A9,A15,A21) were averaged for each phase separately. Then the square of the sum of squares of each triplen was calculated (for instance, the square of the sum of squares of all three A3 triplens). Finally, to find the neutral line current, the square of the sum of squares of all of those triplens was calculated.

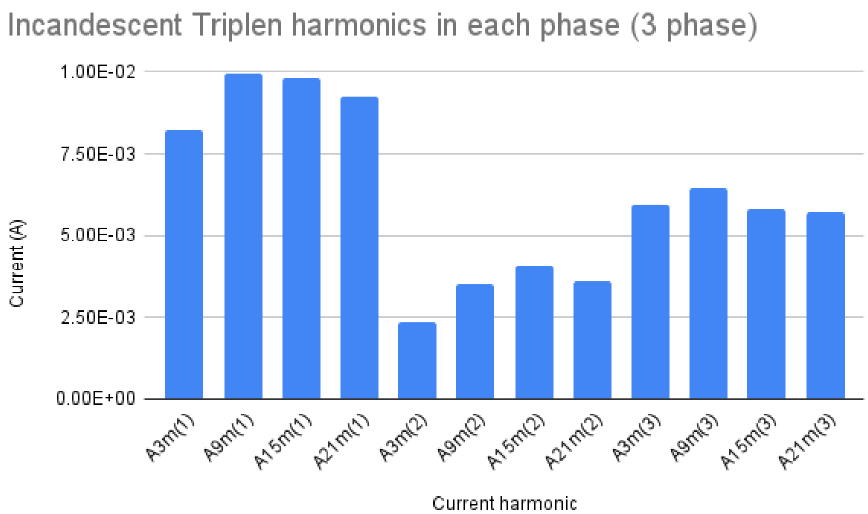

Figure 5: Incandescent non-dimmer 3 phase triplen harmonics

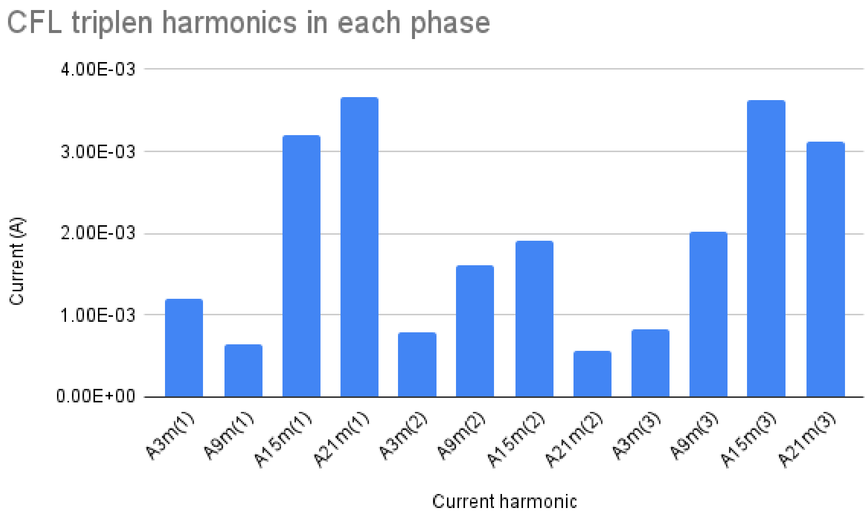

Figure 6: CFL non-dimmer 3 phase triplen harmonics

Figure 5 and 6 were calculated by taking the average of each harmonic in each phase and comparing them to see any outliers between the each graph. For figure 5, phase 1 is shown to contain the most current within the harmonics. While, figure 6 shows that the 15th and 21st harmonics in the first and third phase show that they contain the highest current between the 4 triplens.

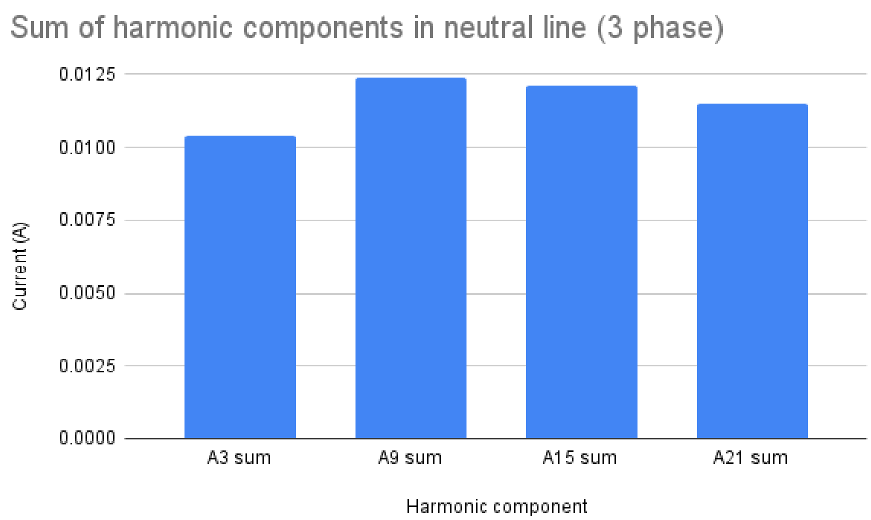

Figure 7: Incandescent non-dimmer 3 phase neutral line triplen harmonics

For the incandescent, the neutral line current was found to be $I_{N,RMS} = 0.0232A$.

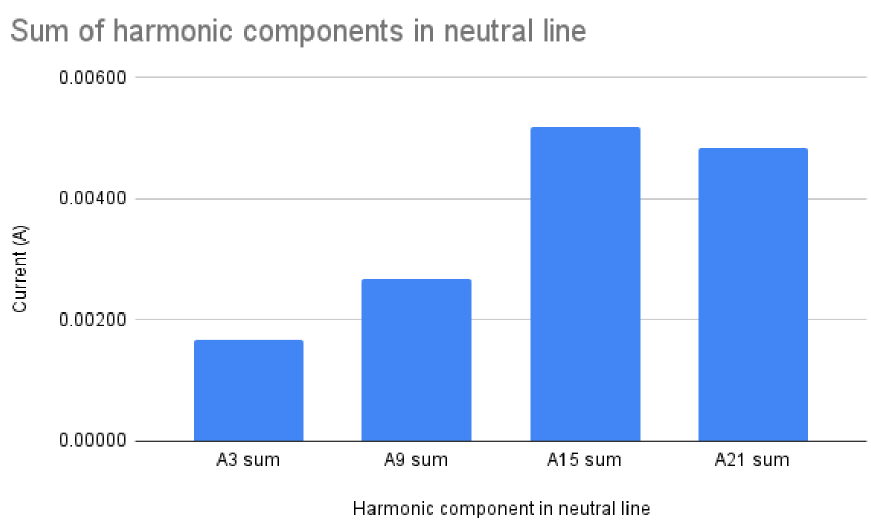

Figure 8: CFL non-dimmer 3 phase neutral line triplen harmonics

For the CFL, the neutral line current was found to be $I_{N,RMS} = 0.00777A$.

4 Conclusion

In this lab, we learned from analyzing the data that we collected from the PA4000 Power Analyzing and the calculations that we made with values, how harmonics arose from the varies loads and in varies configurations. Established the causes of harmonic currents in the neutral line of the balanced three-phase loads from the incandescent and compact fluorescent light bulb. Shown in the data, we quantified the harmonic distortion and other measures of power factor

A Appendix:

A.1 Bill Of Materials

No.	Item	Vendor	Part Number	Qt.	List Price	Net Price
1	Safety Lockout Hasp	Gralnger	1U177	1	$7.98	$7.98
2	Power Supply	Labvolt	8821-20	1	$2,870.00	$2,870.00
3	Data Acquisition and Control Interface	Labvolt	9063-B0	1	$3,499.00	$3,499.00
4	EE 347 Lab Kit	EPL Portland State Uni.	N/A	1	$7.50	$7.50
5	PA4000 Power Analyzer	Used-Line	PA4000	1	$12,474.00	$12,474.00
6	60-Watt Incandescent Light Bulb (2-Pack)	Home Depot	Sylvania A15	2	$4.94	$9.92
7	60-Watt Non-Dimmable CFL Light Bulb (4-Pack)	Home Depot	N/A	1	$7.97	$7.97
8	Outlet-to-Socket Light Plug	Home Depot	N/A	8	$2.81	$22.48
9	4 in. Square Box with Raised Ground	Home Depot	N/A	3	$1.61	$4.83
10	4 in. Square Metal Electrical Box Flat Cover	Home Depot	N/A	3	$0.92	$2.76
11	3/8 in. Non-Metallic Twin-Screw Cable Clamp Connectors (5-Pack)	Home Depot	N/A	1	$2.34	$2.34
12	600-Watt Single-Pole/3-Way Universal Push On/Off Rotary Dimmer	Home Depot	N/A	3	$11.52	$34.56
13	Banana Plug Patch Cord (Black)	Allied Electronics	B-36-0	6	$6.59	$39.54
14	Banana Plug Patch Cord (Red)	Allied Electronics	B-36-2	10	$6.59	$65.90
15	Banana Plug Patch Cord (Blue)	Allied Electronics	B-36-6	6	$6.59	$39.54
16	Banana Plug Patch Cord (Green)	Allied Electronics	B-36-5	6	$6.59	$39.54
	Total Price					$19,101.50

A.2 Point List Power Analyzer

PA4000 Power Analyzer	Point Type								
Point Description	Origin Address	DO	DI	AO	AI	Pwr	Virutal Point	Destination Address	Destination Description
PA4000 Power Analyzer Phase A	Aa	0	0	1	0	1	0	BO1	Light Box A
PA4000 Power Analyzer Phase A	Ab	0	0	0	1	1	0	1	Channel 1 VHi
PA4000 Power Analyzer Phase B	Ba	0	0	0	1	1	0	2	Channel 2 VHi
PA4000 Power Analyzer Phase B	Bb	0	0	1	0	1	0	BO2	Light Box B
PA4000 Power Analyzer Phase C	Ca	0	0	0	1	1	0	3	Channel 3 VHi
PA4000 Power Analyzer Phase C	Cb	0	0	0	1	1	0	BO3	Light Box C
PA4000 Power Analyzer Neutral	N	0	0	0	0	1	0		
Ground	Ground Symbol	0	0	0	0	1	0		
	Total	0	0	3	3	8	0		

A.3 Light Boxes

Light Boxes	Point Type								
Point Description	Origin Address	DO	DI	AO	AI	Pwr	Virtual Point	Destination Address	Destination Description
Light Box A	Aa	0	0	1	1	1	0	BO1	Channel 1 AHi
Light Box B	Ba	0	0	1	1	1	0	1	Channel 2 AHi
Light Box C	Ca	0	0	0	1	1	0	1	Channel 3 AHi
Light Box Neutral	N	0	0	0	0	1	0		
Ground	Ground Symbol	0	0	0	0	1	0		
	Total	0	0	3	3	5	0		

References

Authors

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Jonathan-Rey Villanueva, is a BS candidate in the Electrical Engineering department at Portland State University. He is a machine.

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YES

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