Microgrid Power Quality Analysis

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Abstract

The microgrid power quality analysis senior project addresses power quality assessment. Our senior project uses the PowerSight 3000 power measurement tool to record and analyze various electrical measurements including voltage, current, power, power factor, harmonics and AC frequency.

Our project will analyze power quality issues that result from switching from the utility grid to a smart grid run on primarily photovoltaic distributed generation. In the event of a utility failure, the smart grid can serve as an isolated grid for the system, this is called islanded mode. Our project assesses the reliability of operation in islanded mode. Our analysis should identify if the power quality remains adequate to support the required loads of a system.

Chapter 1: Introduction

This project aims to identify power quality problems in various power systems by using a power measurement tool to extract and analyze the electrical parameters of a system. The power measurement tool used is the PowerSight 3000. The first phase of the project involves becoming familiar with the functionality of the PowerSight 3000 by performing various tests in one of the EE departments Power Labs. We will gain access to a power lab and connect the PowerSight 3000 to a 208V 3- φ source. The tests performed will involve the following:

- Monitoring the 3- φ source for a brief time period (1 hour).
- Monitoring the 3- φ source for an extended time period (over 24 hours).
- Monitoring the 3- φ source while applying a variable load (Induction motor).

The second phase of the project involves analyzing and characterizing the collected data from the tests performed. Characterizing the data will involve the following:

- Producing plots of Voltage vs. Time for the tests performed.
- Analyzing the phase differences of the 3- φ Voltage and Current.
- Analyzing the Reactive and Real Powers of the system.
- Identifying how data in the measurements can relate to power systems problems.

The third phase of the project will involve characterizing and analyzing data from a power system used in a working environment during various times of the day. The system will be analyzed at the start of the day when employees arrive to work, when the AC system turns on, and when employees leave work.

Chapter 2: Requirements and Specifications

Customer Needs Assessment

Power assessment of micro grid: measure and analyze power quality characteristics.

Requirements and Specifications

Knowing what the customer wanted we determined what specifications and requirements we will need. We wanted to make sure we were not going to burden the company while taking the measurements so we wanted to be out of their way during this time while still sustaining a safe environment. We didn't want to miss any changes in power so we need have the equipment set up for a long period time (continuously). The last thing, as with all projects, we want to keep the cost down for the customer; we will do this by using equipment that we already have, which has the end result of saving the company thousands of dollars.

All engineering specifications and marketing requirements can be seen in Table 1.

TABLE 1

POWER QUALITY MEASUREMENTS AND ANALYSIS REQUIREMENTS AND SPECIFICATIONS

Marketing Requirements	Engineering Specifications	Justification
1	Ability to measure and analyze voltage, current, frequency, harmonics, and power factor	To monitor all instances of power quality issues with precise accuracy and continuous measurements
1,5	Ability to setup, measure, and analyze the power system safely	Setup not exposed to the workplace in order to avoid accidents
2,3,5	Setup should not interfere with client workplace for longer than two work days	To avoid injury and cause little disturbance to clients business
1,3	Sampling of less than 5 second intervals	Ability to take more precise measurements and thus increase accuracy
3	Should not use excessively expensive equipment	To keep costs down, equipment and hardware chosen to both perform the necessary measurement and analysis tasks and minimize costs
1,4,6	Results identify power quality problems such as voltage spikes, sags, frequency and phase synchronization, and harmonic distortion	Measured and characterized power quality data presented in a way that clearly and accurately identifies problems in the power quality of the system

Marketing Requirements

1. Accurately measure Power Quality
2. Minimal setup/breakdown time
3. Keep equipment and hardware costs down
4. User friendly results
5. Perform all measurements and analysis safely
6. Identify failures in PV systems due to power inefficiencies

Chapter 3: Functional Decomposition

The level Zero block diagram of our project, seen in Figure 1 below, consists of 3-Phase voltage and current inputs and Characterized Data as an output. A more detailed description of the function requirements can be seen in Table 3.

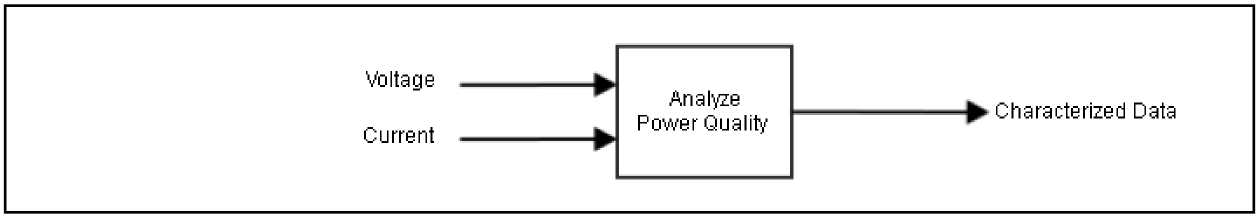


Figure 1: Level Zero Block Diagram

Table 3: Function requirements for Level Zero block diagram

Module	Power Quality Analysis
Inputs	• 3-ϕ Voltage from generator • 3-ϕ Current from generator
Outputs	• Characterized Data
Functionality	Measure 3-ϕ voltage and current with a PS3000 Power Analyzer to obtain Power Parameters. From the data retrieved by PS3000 analyze and output characterized data.

The level One block diagram, seen below in Figure 2, consists of the same inputs but contains a more detailed description of the main Power Quality Analysis block. The 3-Phase voltage and current inputs are feed into the PowerSight power measurement tool. The PowerSight stores the data onto a computer hard drive. The stored data is then processed via the pre-installed PowerSight software. Voltage, Current, Total Harmonic Distortion, and Real and Reactive power measurements are retrieved from the PowerSight software. The data is then analyzed and characterized by our group to be presented in a way that meets the customer's needs.

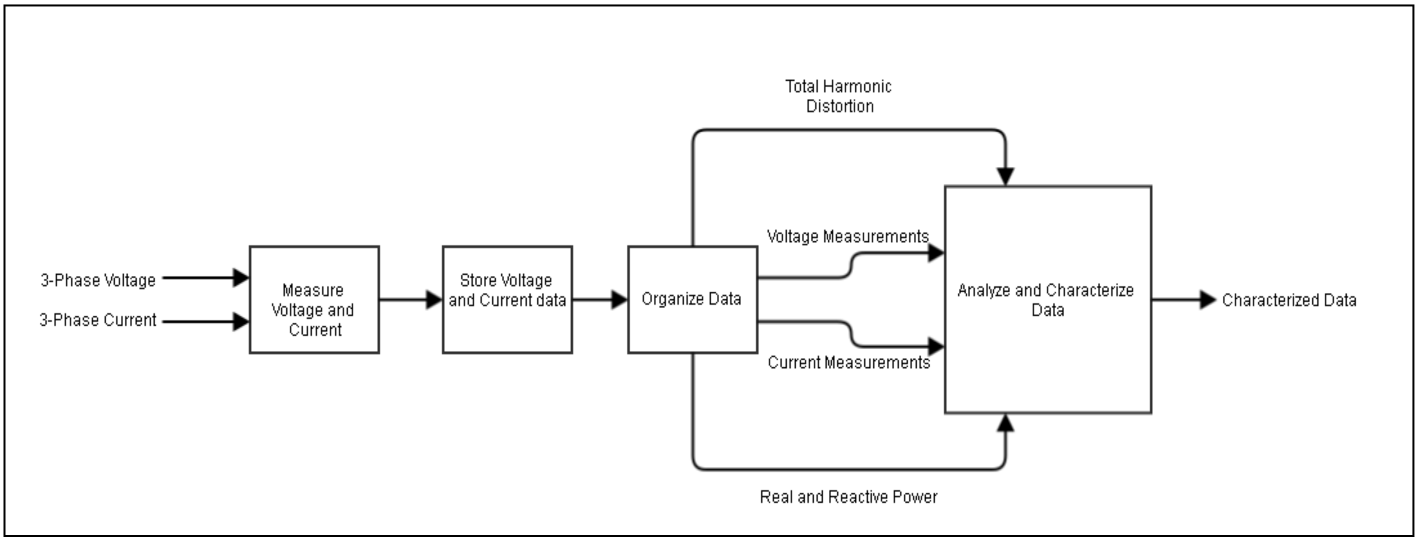
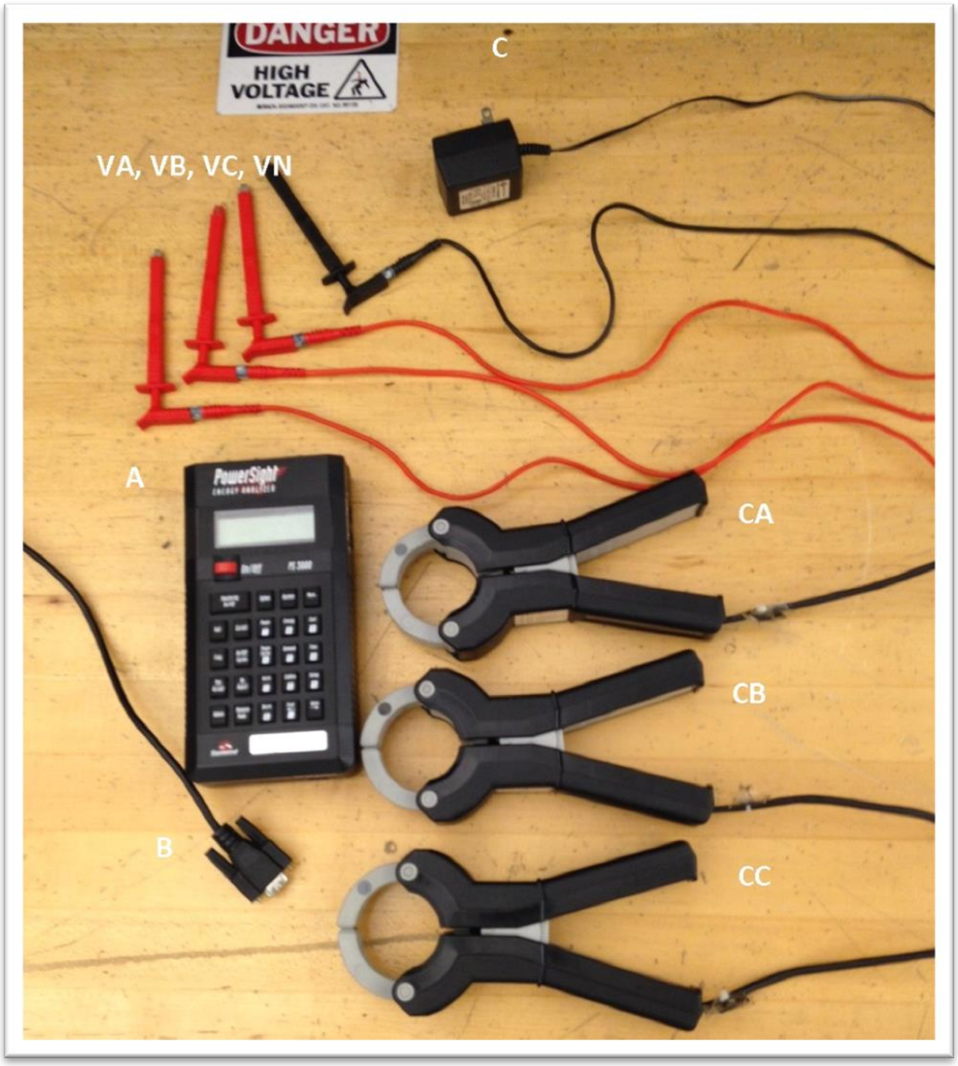


Figure 2: Level One Block Diagram

Chapter 4:PowerSight 3000 Instruction Manual

Equipment List
PowerSight 3000 Module x1 [A]
Voltage Probe x4 [VA, VB, VC, VN]
Current Probe x3 [CA, CB, CC]
Com to Module connector [B]
Module Charger x1 [C]



Picture 1: Equipment List

Step by Step Instructions

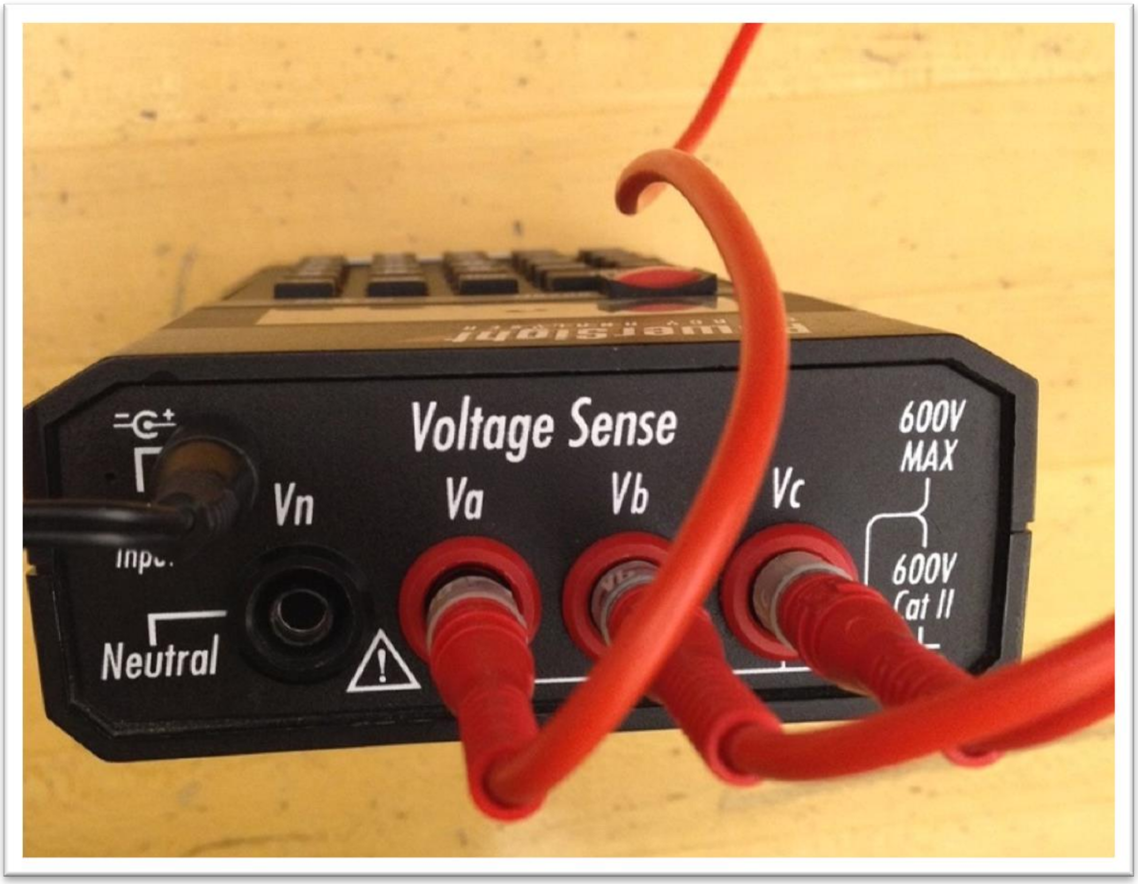
Set up (Hardware)

1) Ensure that you have all pieces of the PowerSight kit as depicted in Picture 1
2) Ensure you have the correct version of PowerSight installed on your computer or laptop. See Setup (Software).
3) Connect the DC Module Charger to the PowerSight outlet marked "Input". Also connect the charger to an available power outlet.

4) Connect the Com to Module connector [B] to an available Serial Port on your computer. Then connect the other end to the PowerSight port marked "Serial Comm" as seen in Picture 2.

Picture 2: Serial Comm

5) Connect each voltage probe [VA, VB, VC, VN] to its corresponding input port on the PowerSight as seen in Picture 3. Each voltage probe should be marked which phase it is designed for.
   Note: it is not necessary to connect VN if you are not utilizing a Y-connected source/load.



Picture 3: Connecting Voltage Probes and DC Charger

6) Connect each current probe [CA, CB, CC] to its corresponding input port located on the left and right sides of the PowerSight as seen in Picture 4 and 5.
   Note: It is not necessary to connect CN if you are not utilizing a Y-connected source/load.

Picture 4 & 5: Connecting Current Probes

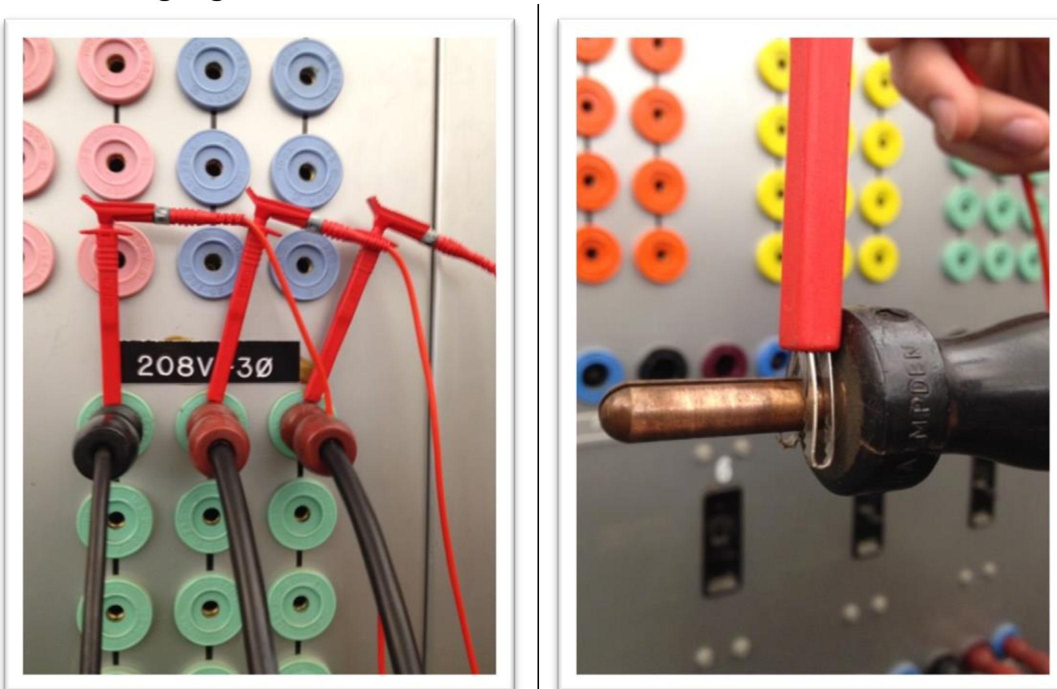
Connecting to the Source or load

1) **Please read these steps carefully** to avoid dangerous shorts. Never perform these steps alone or without qualified supervision.
2) If possible, turn off the source/load.
3) Start by exposing a small segment of the source or load wire so that the voltage probe can get a clean connection as seen in Picture 6.

Do not to touch exposed wires if source/load is live. ⚠

Picture 6: Safely Exposed Segment of Wire (Cal Poly Power Lab)

4) Carefully squeeze and place the voltage probe [VA, VB, VC, VN] on the exposed wire or connecting segment. Refer to Picture 7 and 8 for clarification.



Picture 7 & 8: Connecting Voltage Probes to Source/Load

NOTE: For operations in a Cal Poly Power lab: If the probe does not initially stay connected, squeeze the connector against the probe and wall to force it still (as seen in Picture 9).

Picture 9: Squeeze Exposed Wire Against Probe

5) Next clamp the Current probes [CA, CB, CC] onto the corresponding source/load wire as seen in Picture 10.

Picture 10: Connecting the Current Probes

6) Once all probes are in place and the area is clear of contact, proceed to the Software Setup.

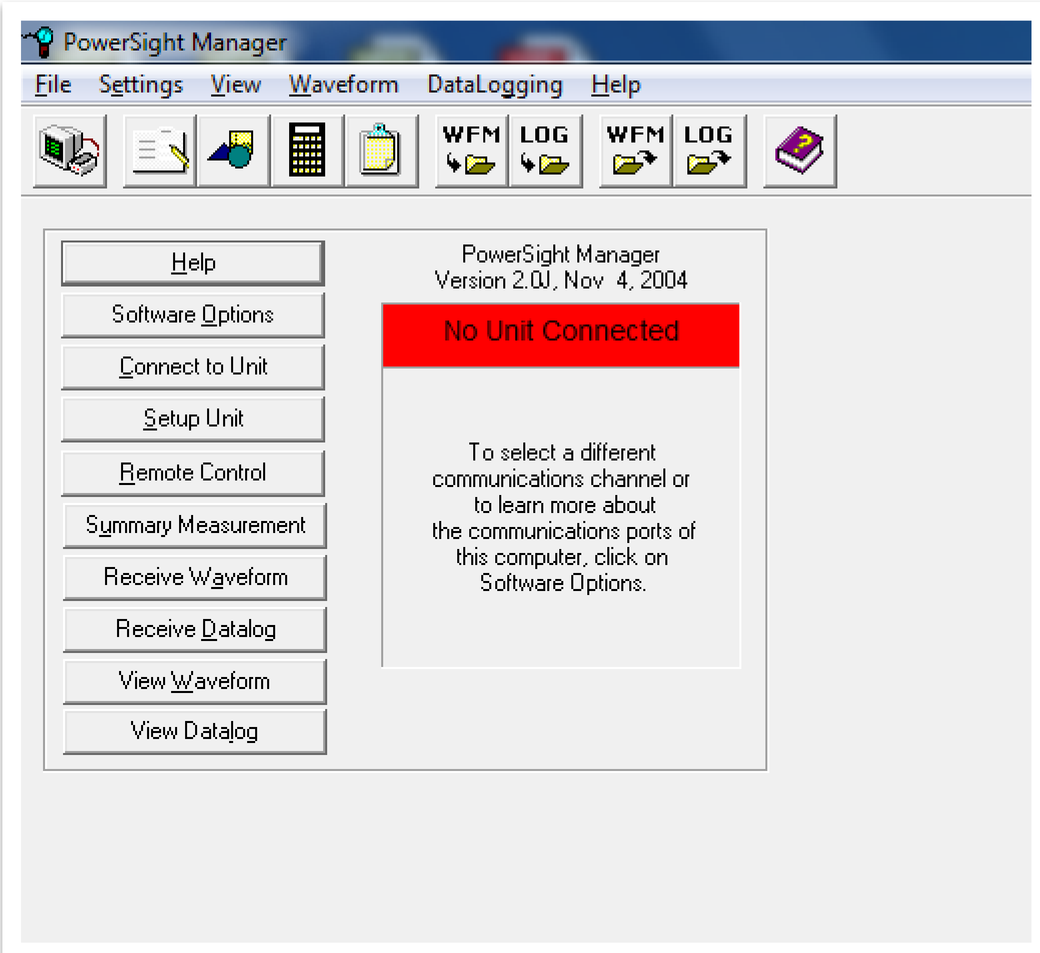
Software Installation and Setup

1) Go to PowerSight.com and download the corresponding version of PowerSight Manager depending on the series of PowerSight you are using. For the PS3000, download version 2.0J.
2) Install the software.
3) After installing, connect the Serial Comm cord to an available Serial Port on your computer as seen in Software Picture 1.

Software Picture 1: Connecting Serial Comm to Computer

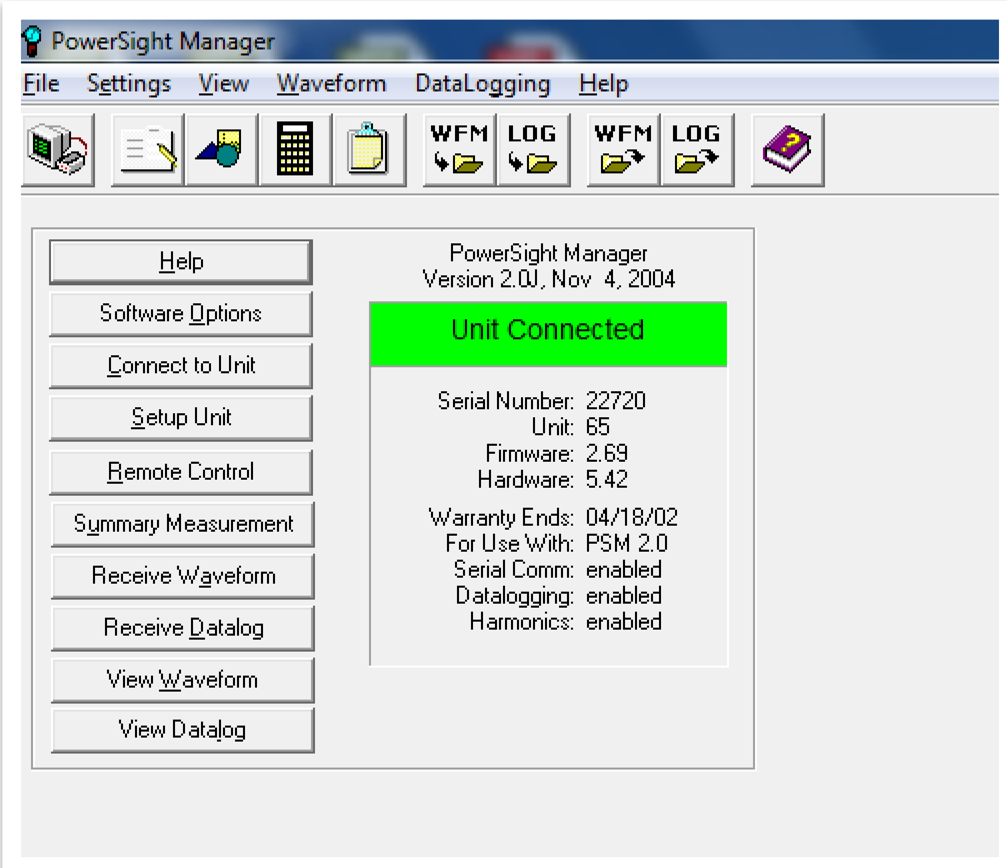
4) Make sure the PowerSight is plugged in to the power outlet as described in the hardware setup.
5) Turn on the PowerSight 3000.
6) Open the PowerSight Manager software.

7) You should see a menu pop up like in Software Picture 2. Click "Connect to Unit".



Software Picture 2: No Unit Connected

8) The menu should now say "Unit Connected" in green as seen in Software Picture 3.



Software Picture 3: Unit Connected

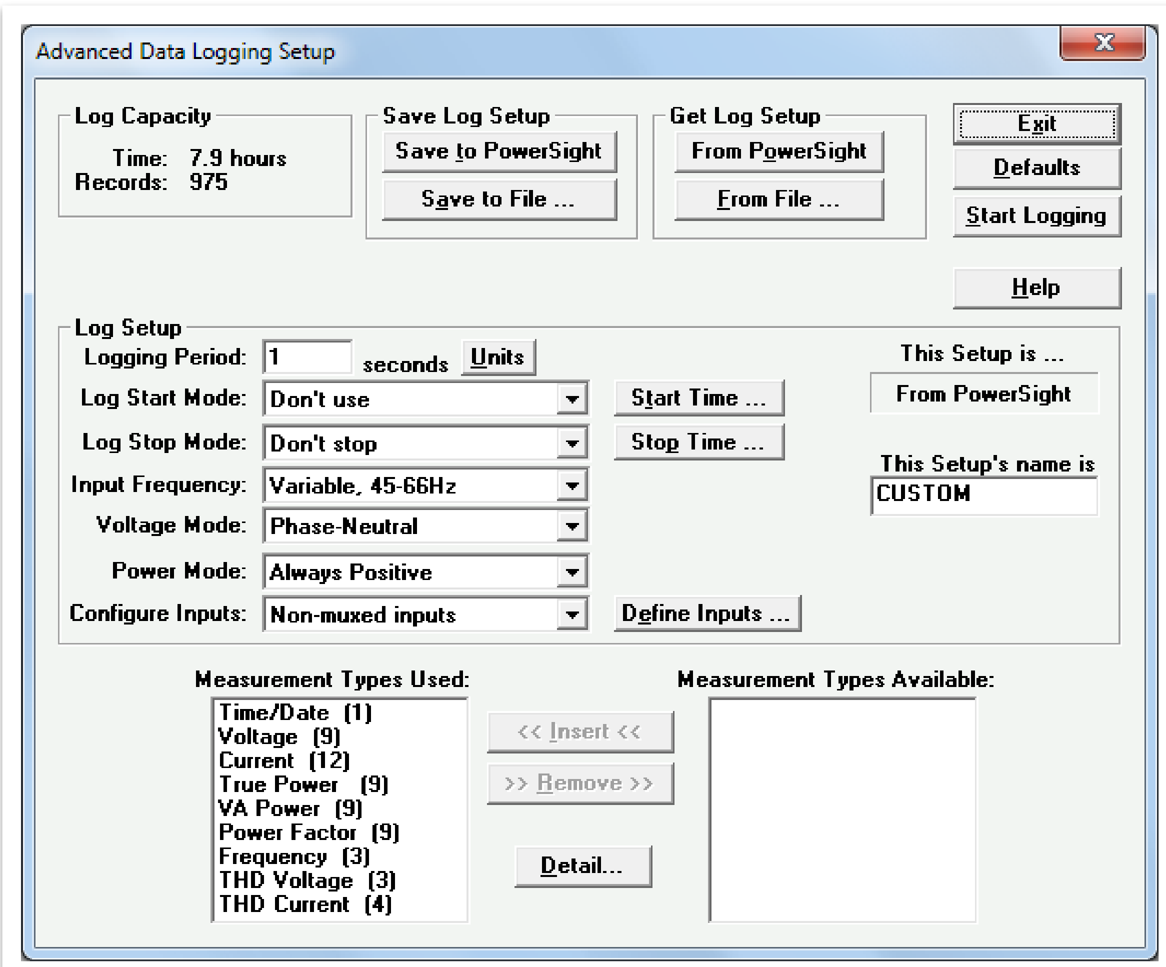
Checking Connections and Setup

9) It's very important that your phase connected wires (Voltage and Current Probes) are accurate. The PowerSight has a simple method for checking connections. Once the hardware setup is complete, press the "Setup" button on the PowerSight and hit "Yes" when the check connection menu pops up on the LCD screen. You can then verify the phase, voltage, frequency, current, etc of your setup.

Logging Data to the PowerSight

10) After the unit is connected to the software you can begin by going to the Datalogging tab at the top of the menu. Click on "Advanced Data Logging Setup".

11) A menu like in Software Picture 4 should pop up. This menu allows you to customize the time interval in which you take data. Edit any or all options you need for your measurements. Notice the maximum data points possible that the PowerSight can hold at any time and the maximum duration you can record before the PowerSight will be at capacity.



Software Picture 4: Advanced DataLogging Menu

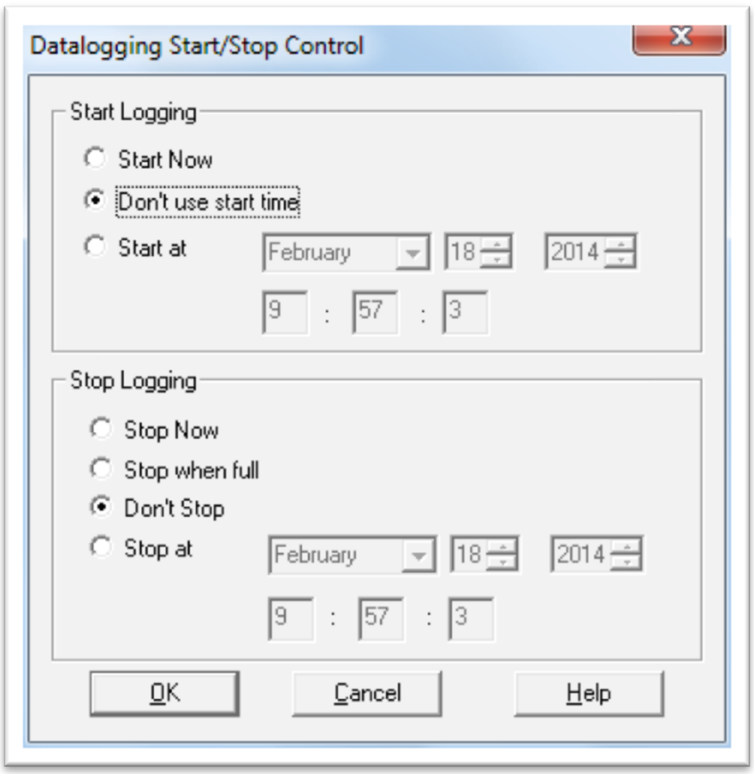
12) After you finish editing your options, click "Save to PowerSight".

NOTE: Doing this will delete all previously recorded data in the PowerSight.

13) After saving your setup to the PowerSight, click "Start Logging."

14) If you set a time to stop logging (Stop Time), simply wait until the PowerSight has finished, indicated by the text "Monitoring has ended" on the PowerSight LCD display.

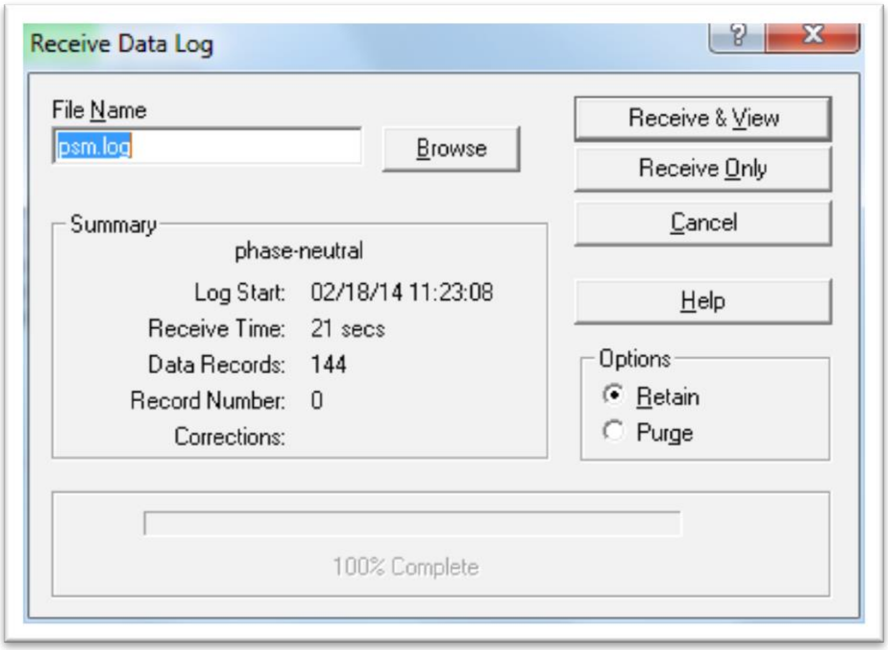
15) If you did not set a specified stop time, when you are finished taking data open the Datalogging tab again and go to "Basic Data Logging Setup." A menu like in Software Picture 5 will pop up. Ignore start time menu and click "Stop Now" and click OK. The PowerSight will finish it's last data point and display "Monitoring has ended."



Software Picture 5: Basic DataLogging Menu

Retrieving Stored Data

16) To retrieve and view your data, at the main menu click "Receive Datalog." A menu like the one in Software Picture 6 will pop up. In the box that has "psm.log" give your new file a name but make sure to give it a ".log" extension.



Software Picture 6: Retrieving Stored data

17) Click either receive and view or receive only to start downloading your data from the PowerSight. NOTE: the PowerSight Manager sometimes comes across strange errors like "BadSum." Ignore these errors and initiate step 15 again. This may take several times depending on your version of PowerSight Manager.

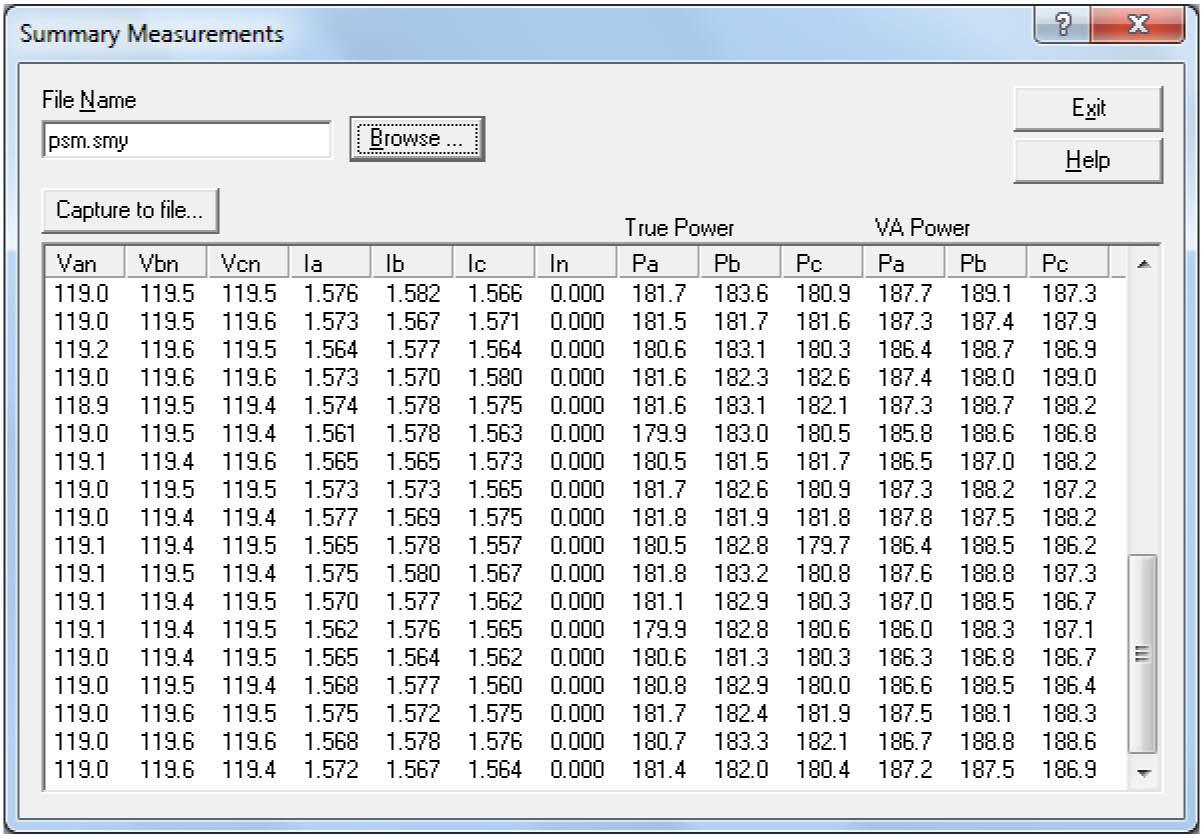
18) After it has reached 100% completion, your new file will appear on either the desktop or the folder you decided to store the file.

Viewing Stored Data

19) To view your data, you can either use the main menu and click View Datalog or right click the file and open with Microsoft Excel to view the physical data points and plot the graph(s) yourself. NOTE: The graphing options in PowerSight Manager are severely limited and only allow basic graphs to be displayed.

Viewing Real-Time data

1) The first method to see the real time voltage, current, real, and apparent power measurements click “Summary Measurement.” You can save and name this file as seen in Software Picture 7 below.



Van	Vbn	Vcn	Ia	Ib	Ic	In	Pa	Pb	Pc	Pa	Pb	Pc
119.0	119.5	119.5	1.576	1.582	1.566	0.000	181.7	183.6	180.9	187.7	189.1	187.3
119.0	119.5	119.6	1.573	1.567	1.571	0.000	181.5	181.7	181.6	187.3	187.4	187.9
119.2	119.6	119.5	1.564	1.577	1.564	0.000	180.6	183.1	180.3	186.4	188.7	186.9
119.0	119.6	119.6	1.573	1.570	1.580	0.000	181.6	182.3	182.6	187.4	188.0	189.0
118.9	119.5	119.4	1.574	1.578	1.575	0.000	181.6	183.1	182.1	187.3	188.7	188.2
119.0	119.5	119.4	1.561	1.578	1.563	0.000	179.9	183.0	180.5	185.8	188.6	186.8
119.1	119.4	119.6	1.565	1.565	1.573	0.000	180.5	181.5	181.7	186.5	187.0	188.2
119.0	119.5	119.5	1.573	1.573	1.565	0.000	181.7	182.6	180.9	187.3	188.2	187.2
119.0	119.4	119.4	1.577	1.569	1.575	0.000	181.8	181.9	181.8	187.8	187.5	188.2
119.1	119.4	119.5	1.565	1.578	1.557	0.000	180.5	182.8	179.7	186.4	188.5	186.2
119.1	119.5	119.4	1.575	1.580	1.567	0.000	181.8	183.2	180.8	187.6	188.8	187.3
119.1	119.4	119.5	1.570	1.577	1.562	0.000	181.1	182.9	180.3	187.0	188.5	186.7
119.1	119.4	119.5	1.562	1.576	1.565	0.000	179.9	182.8	180.6	186.0	188.3	187.1
119.0	119.4	119.5	1.565	1.564	1.562	0.000	180.6	181.3	180.3	186.3	186.8	186.7
119.0	119.5	119.4	1.568	1.577	1.560	0.000	180.8	182.9	180.0	186.6	188.5	186.4
119.0	119.6	119.5	1.575	1.572	1.575	0.000	181.7	182.4	181.9	187.5	188.1	188.3
119.0	119.6	119.6	1.568	1.578	1.576	0.000	180.7	183.3	182.1	186.7	188.8	188.6
119.0	119.6	119.4	1.572	1.567	1.564	0.000	181.4	182.0	180.4	187.2	187.5	186.9

Software Picture 7: Summary Measurement

NOTE: PowerSight Manager does not save every single point that has been recorded.

2) The second method to viewing the real-time measurements is by using either the buttons on the PowerSight or by using "Remote Control Mode," as seen on the main menu and in Software Picture 8.

Software Picture 8: Remote Control Mode

Chapter 5: Testing

RL-Load Test:

The Resistor-Inductor Load test circuit shown in Figure 3 was constructed. The test setup is shown in Figure 4.

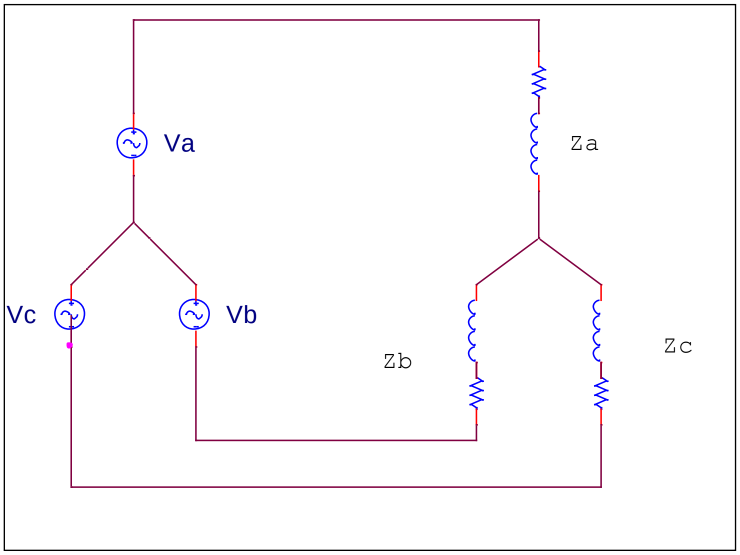


Figure 3: RL load Test Circuit

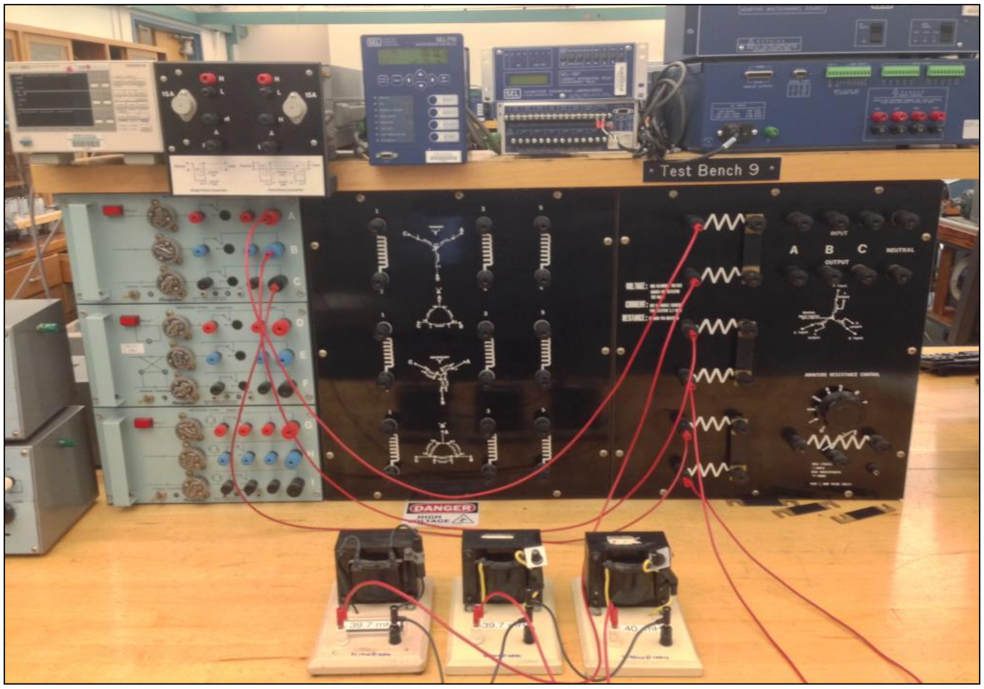


Figure 4: RL load Test Setup

Figure 5 depicts the 3-ϕ Voltage vs. Time data retrieved from the PS3000. The load in the power lab was not strong enough to significantly affect the voltage; therefore, no power quality factors could be determined.

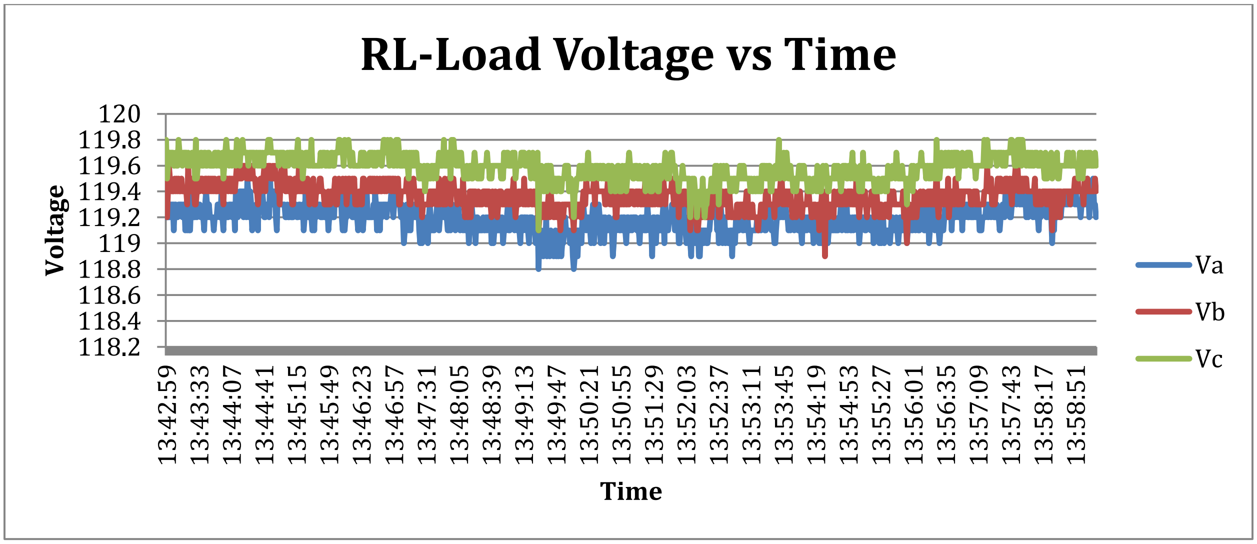


Figure 5: 3-ϕ Voltage vs. Time

Induction Motor Test:

The Induction Motor test circuit shown below in Figure 6 was constructed. The test setup is shown in Figure 7. The induction motor is rated at 1/3 HP, 1725 RPM and 2.4 AMPS.

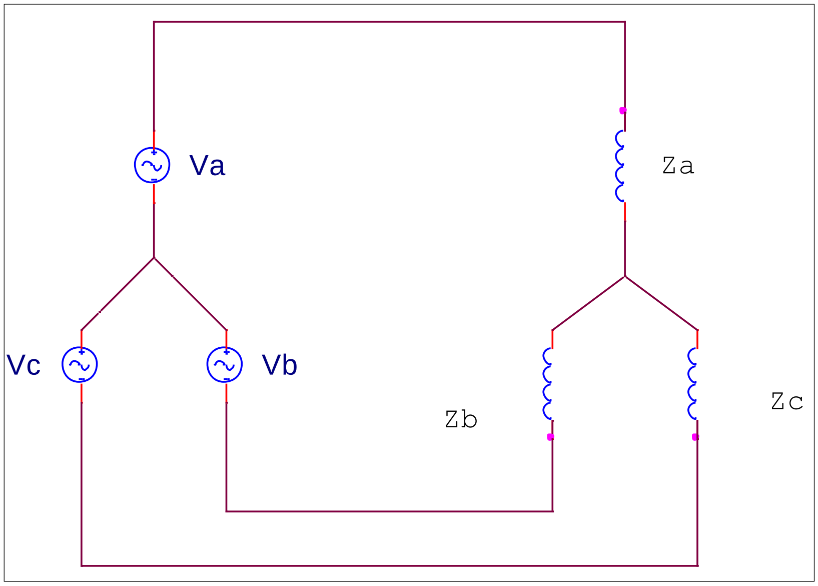


Figure 6: Induction Motor Test Circuit

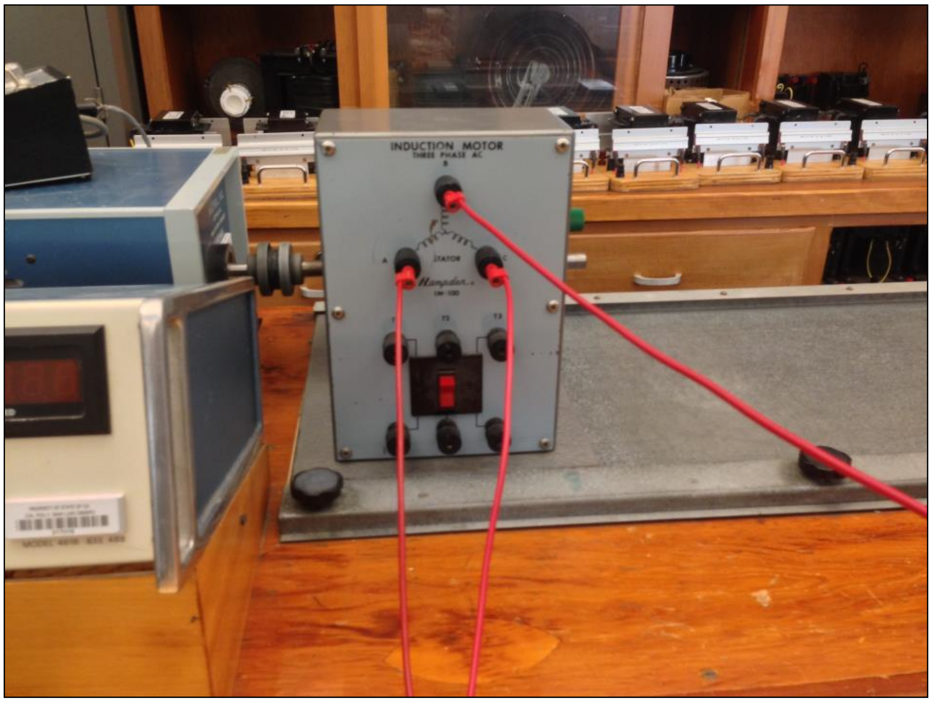


Figure 7: Induction Motor Test Setup

Figure 8 depicts the 3-ϕ Current vs. Time data retrieved from the PS3000. The data shows the load current increasing as the induction motor torque is increased. This test was performed to show the PS3000's measurement capability for a variable load.

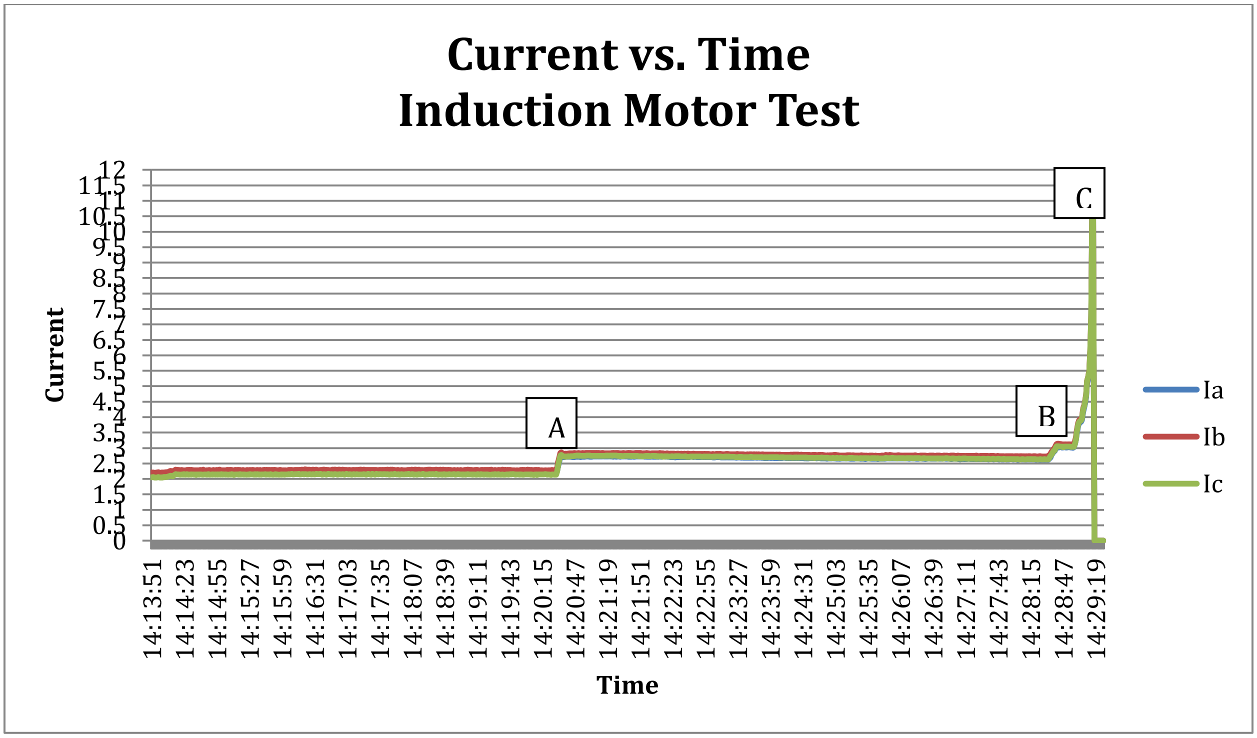


Figure 8: Current vs. Time for a variable load**.**

This test was performed in a few stages. The first step was to give the motor time to reach a steady state current setting (while we set up another test nearby). At Point A we increased the motor torque slightly to decrease the rotor speed, thus increasing the current. After finishing another test setup we increased the torque again at Point B then quickly increased the torque to the point of motor shut off at Point C. We can see that the PowerSight quickly responds to this rapid change in current. It should be noted that the PowerSight also monitored voltage and frequency during this test; however, a single inductive motor was not enough to significantly cause any voltage sag, spike, or variance in frequency.

24 Hour Resistor-Inductor Load Test:

Figure 9 shows Voltage data vs. time for a duration of approximately 24 hours, thus demonstrating the monitoring capabilities of the PS3000. The purpose of this test was simply to show how the PS3000 can capture sudden changes in load voltage. It should be noted that the load itself was not strong enough to present any significant power quality problems; as such, the current and power factor of each phase was relatively constant.

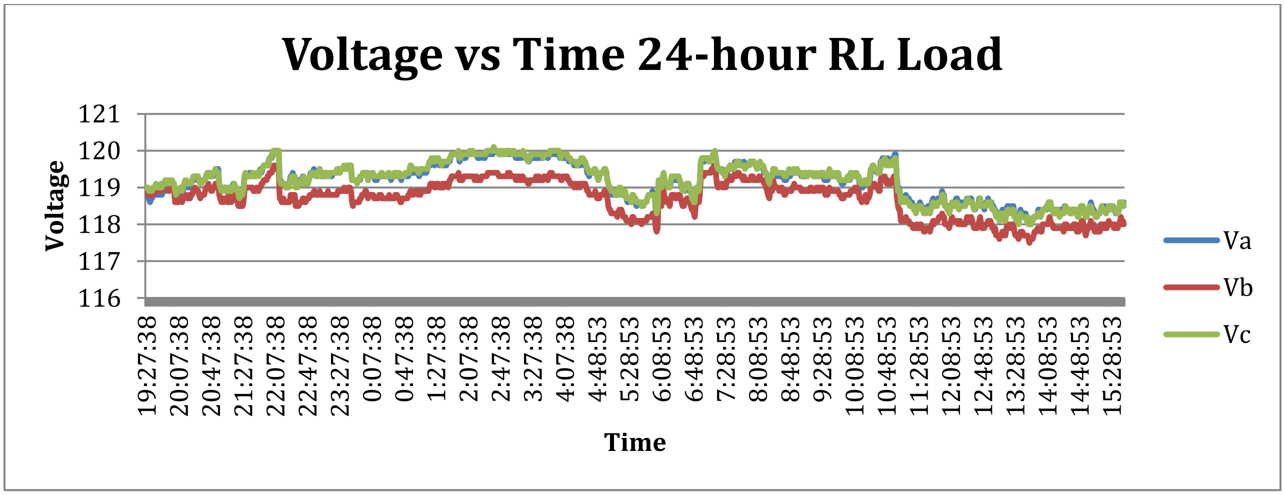
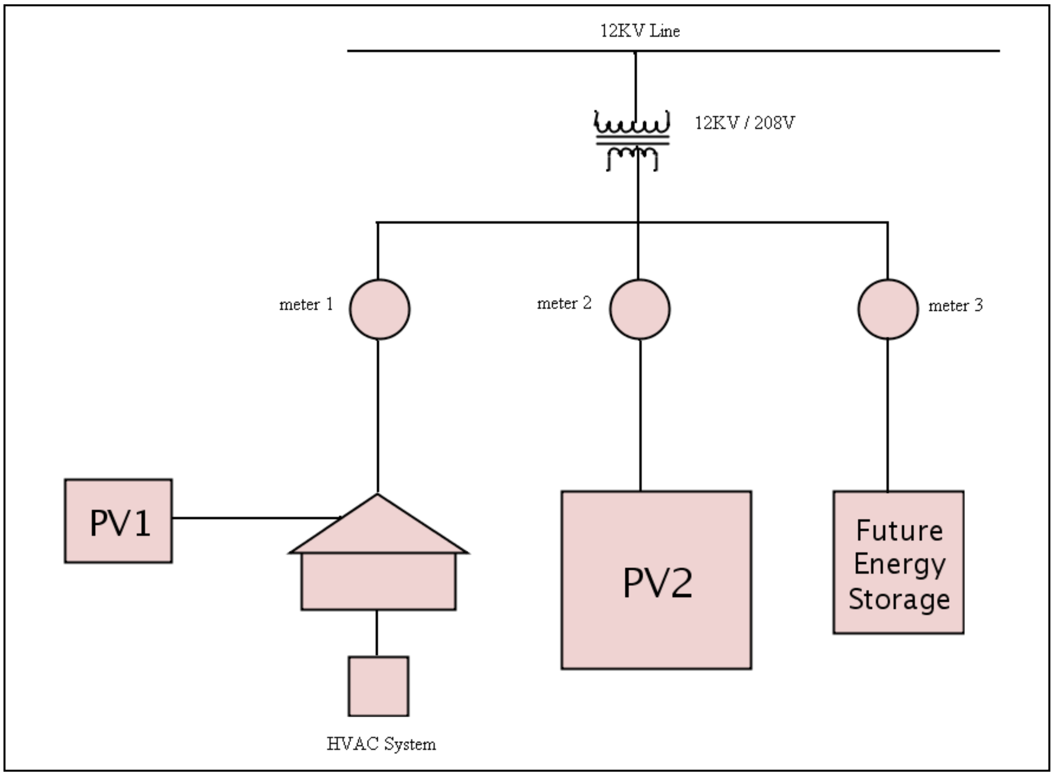


Figure 9: 24 hour PS3000 data

Chapter 6: Client Data



Schematic 1: Power System schematic

Schematic 1 shows a schematic of a power system being monitored. The circles labeled meter 1, meter 2, and meter 3 are smart meters used to retrieve Electrical data (Voltage, Current, Power). Data retrieved from meter 1 consists of rooftop PV data (PV 1) and HVAC load data.
The proceeding figures and graphs are from data retrieved by meter 1. Power Quality analysis is needed to ensure successful microgrid operation.

Figure 10 shows the power data of the building depicted in Schematic 1. This data doesn't reflect the power delivered from the rooftop photovoltaic system (PV 1). Therefore the power factor shown in figure _ is lower than it actually is. This is due to a decrease in real power (kW) without a decrease to reactive power (kVAR).

$$\text{EQ (1): } Power\ Factor = \frac{Real\ Power}{Apparent\ Power} = \frac{kW}{\sqrt{kW^2 + kVAR^2}}$$

EQ (1) shows that if real power (kW) decreases while reactive power remains constant (kVAR) then power factor decreases.

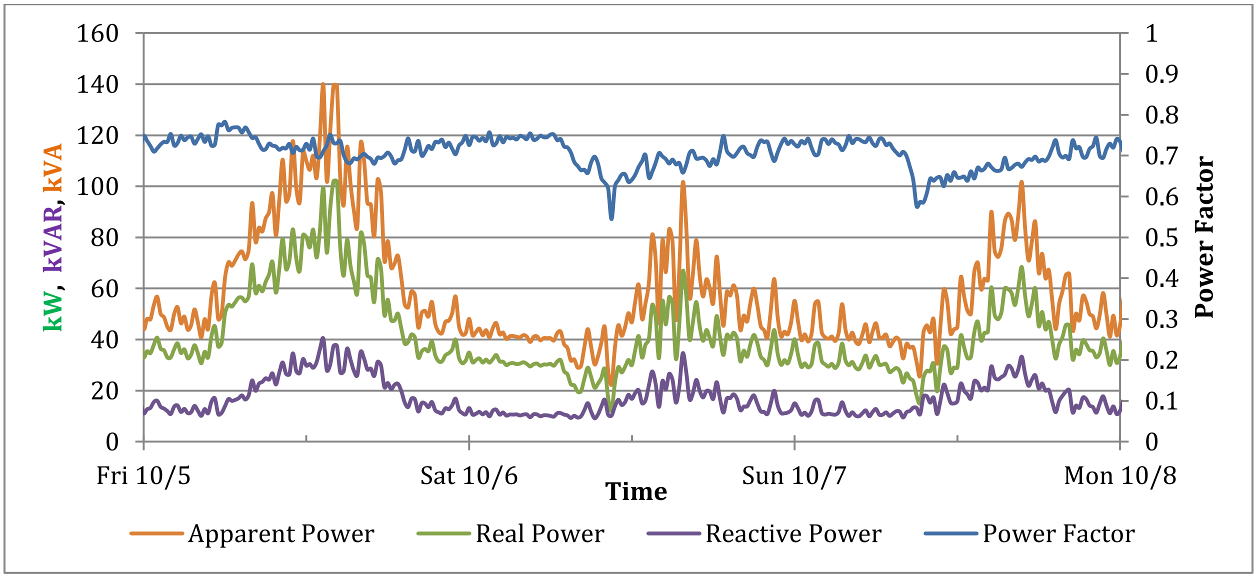


Figure 10: Power Data from Raytheon

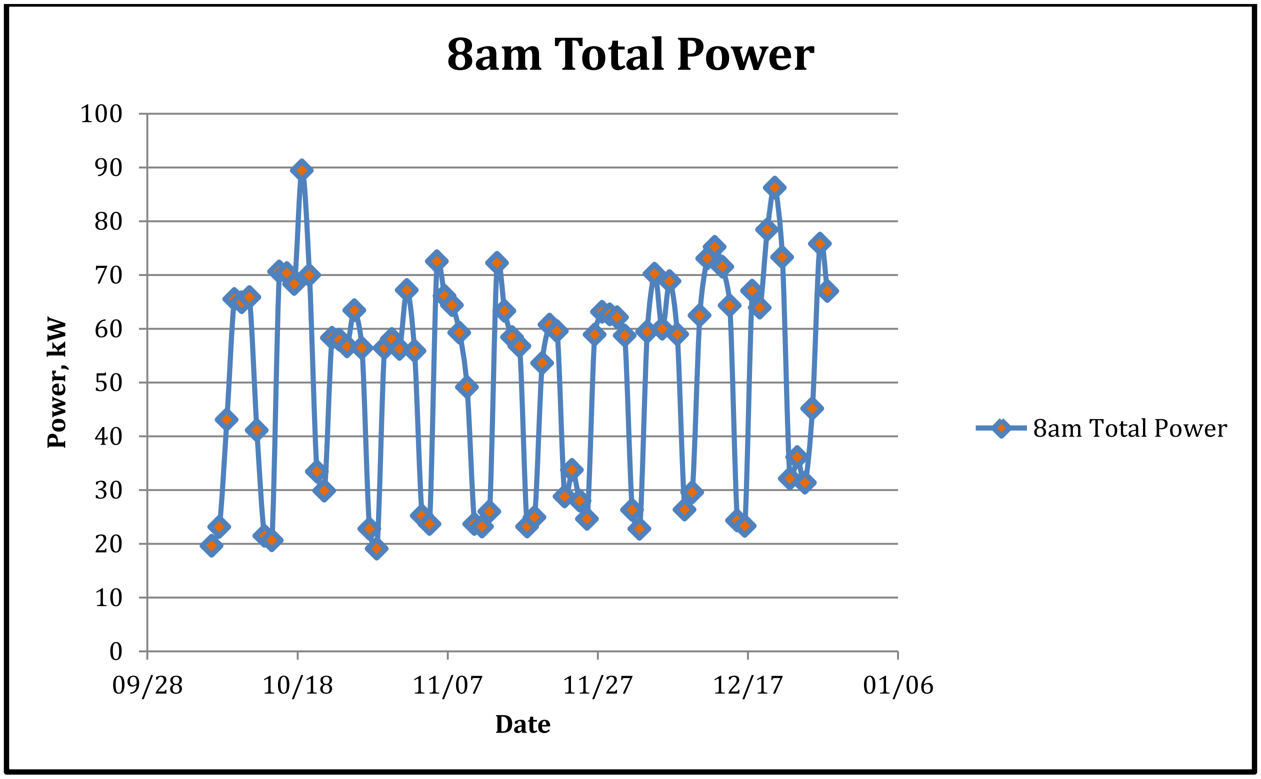


Figure 11: 8AM Total Power Data

Figure 11 shows the total power each day at 8am, the time when most employees get to work and begin using significant power loads. No power quality issues can be determined from this graph; however, we can determine that level of power consumption on weekdays vs. weekend. Each maximum peak was verified as a weekday and each minimum was verified as a weekend day.

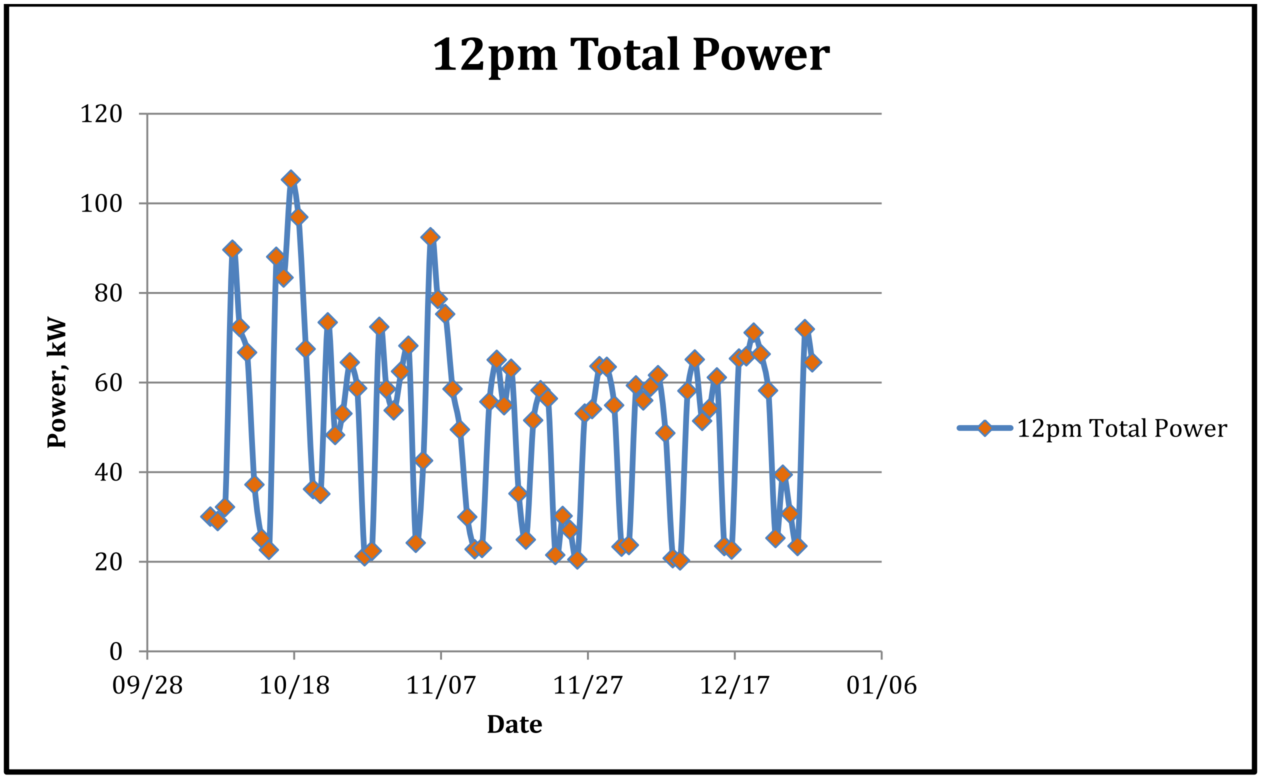


Figure 12: 12PM Total Power Data

Figure 12 shows the total power each day at noon, the time when most employees are generally using the most power in the facility due to specific loads and also AC units. We can see a dramatic difference in consumption during the end of summer (October and early November). Again, no power quality issues can be determined from this graph.

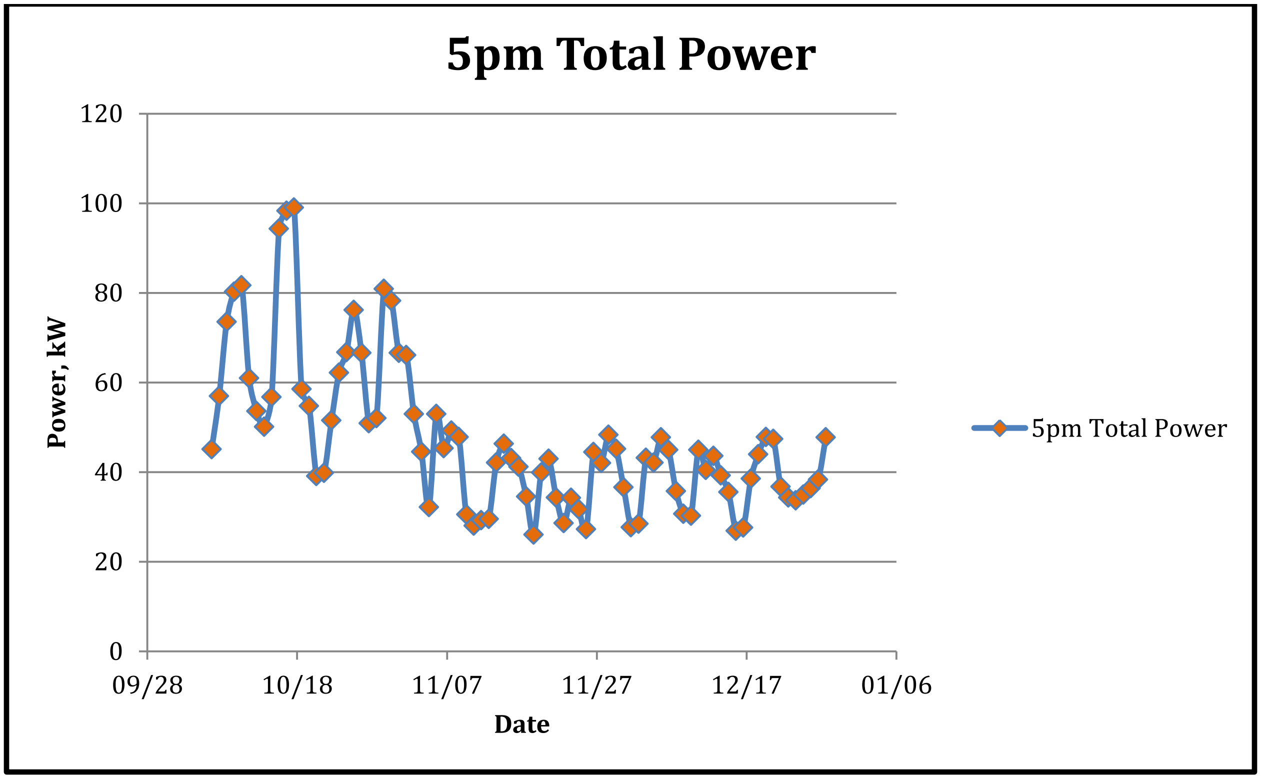


Figure 13: 5PM Total Power Data

Figure 13 shows the total power each day at 5pm, the time when most employees are ending their workday. During the warmer months of October we can see a larger power consumption compared to the winter months of late November through December. No power quality issues can be determined from this graph.

Line to Line Voltage Summary (Per Month)

One of the most important characteristics in power quality analysis is voltage imbalance. The equation for voltage imbalance is seen here.

$$\%\,Voltage\ Imbalance = \frac{\Delta V_{max}}{\tilde{V}_{avg}}\ x\ 100\%$$

For our analysis, we characterized the voltage imbalances by month below in Table 3.

Table 3: LL Voltage Summary

	Max Line Voltage	Min Line Voltage	Max % Voltage Imbalance
March	212.7	201.9	0.771084
April	215.5	201.5	0.782778865
May	213.8	200.8	0.781631656
June	213.2	200.1	1.154401154
July	213.6	199.6	1.028403526
August	214.5	197.7	0.737825873
November	212.7	202.2	1.094196004

As long as the voltage imbalance remains below 3% the system can be characterized as stable. The maximum voltage imbalance for any given month was well below that limit, varying only as high as 1.15% in June. Also, the maximum and minimum line voltages were within typical norms for most months but did vary as high as 215.5 volts in April and as low as 197.7 in August. The voltage swing is usually caused by the sudden or frequent turn on or turn off of a reactive load, in this case, the HVAC unit. The hot summer months require greater air conditioning; as such, June, July, and August saw more variation in voltage imbalance. We also noticed that AC unit #8 consistently saw a higher average voltage imbalance than all the other loads each month which suggests that it is used more often.

It should be noted that there was insufficient data during September and October.

Appendix B contains the full voltage imbalance and max & min voltage data.

Step Load Data by Month

Figures 15 and 16 show a comparison of summer and winter current vs. time plots for AC unit 1 and 3. From the variations in load you can see that the HVAC system is controlled by a set temperature value. When the room reaches a certain temperature the HVAC unit turns on and off. This explains the periodical cycle that appears. This cycle can be seen more clearly in Figure 14. Figure 14 shows the 15 minute current vs. Time intervals for 6th of August.

From the plots you can see the HVAC units are more loaded during the warmer month of July and less loaded during the colder month of November. The max spikes of current are the result of inrush currents or starting current from the AC turning on. Normally, the initial turn on of the AC would cause a noticeable voltage sag; however, the data given to us was only in 15 minute intervals which is incapable of capturing the transient voltage sags that would occur.

Appendix B contains more current vs. time plots per month.

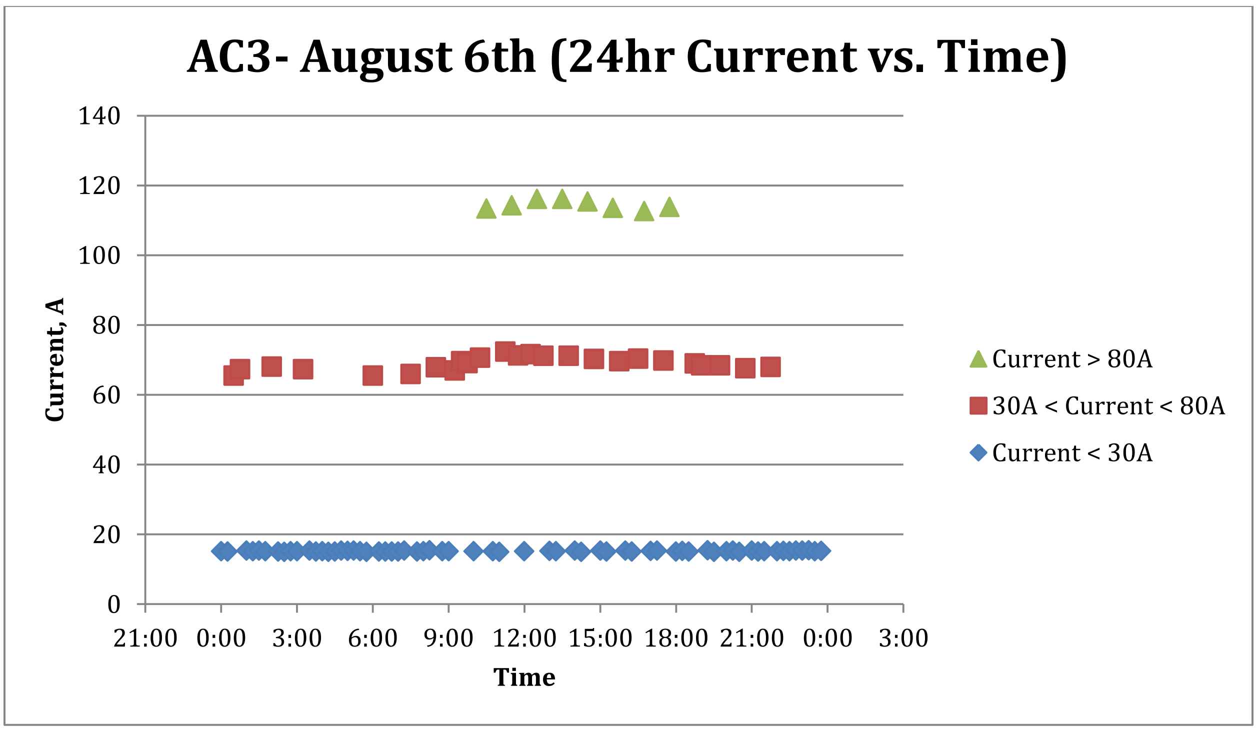
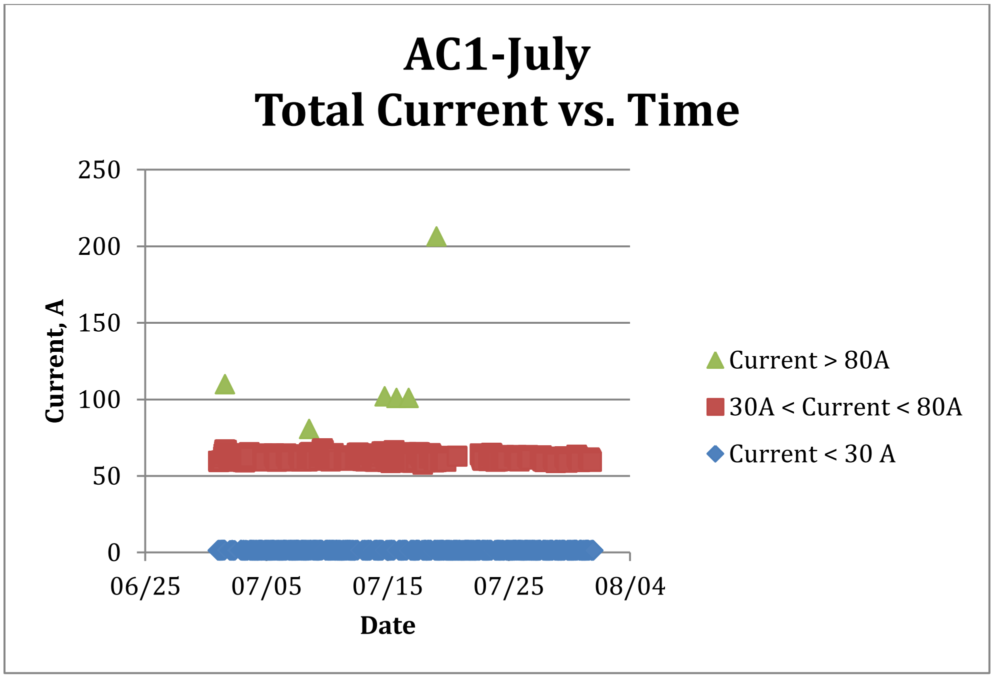


Figure 14: Current vs. Time 24hr data in August



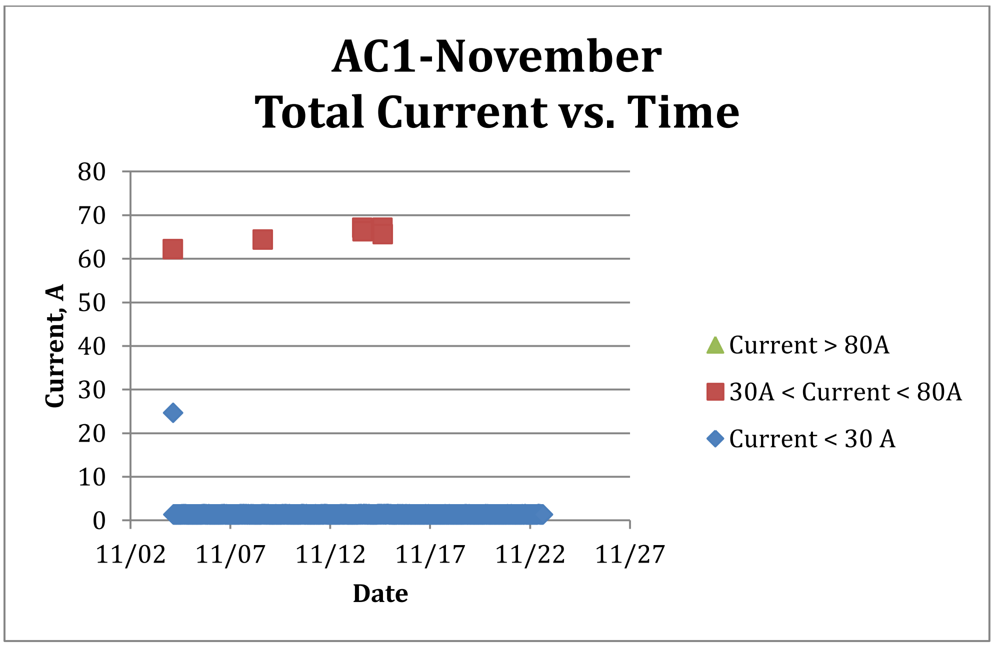
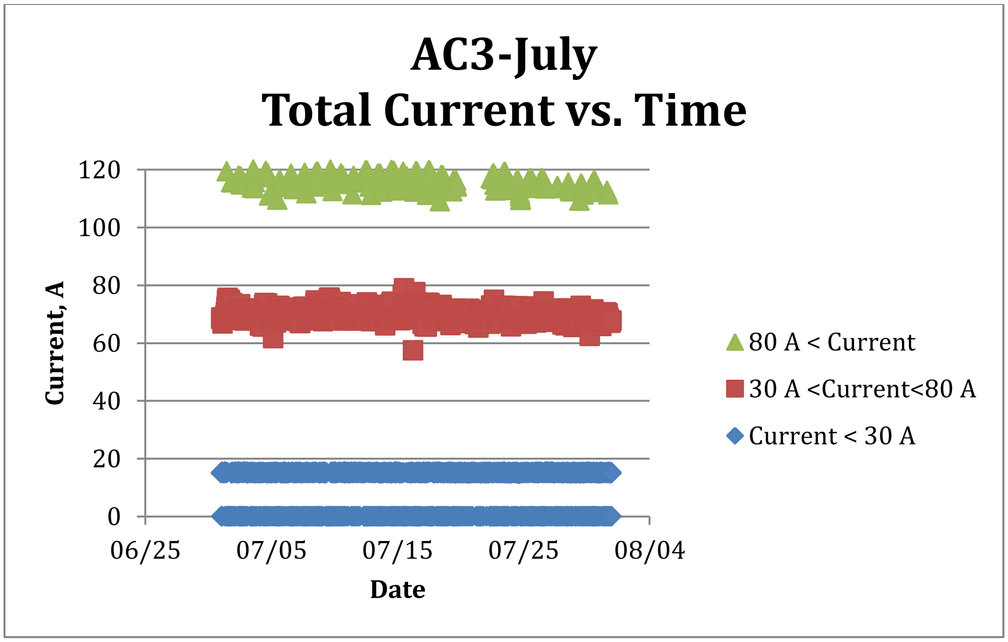


Figure 15: AC1 Summer and Winter Current vs. Time Comparison

Figure 15 shows the vast difference just within a single HVAC unit for different seasons. AC1 shows frequent usage during July as the total current often fell between 30 and 80 Amps, with occasional readings (most likely inrush current readings) of greater than 80A. As expected of a colder month, November saw a much lower and infrequent use of the AC unit, never reaching above 70A.



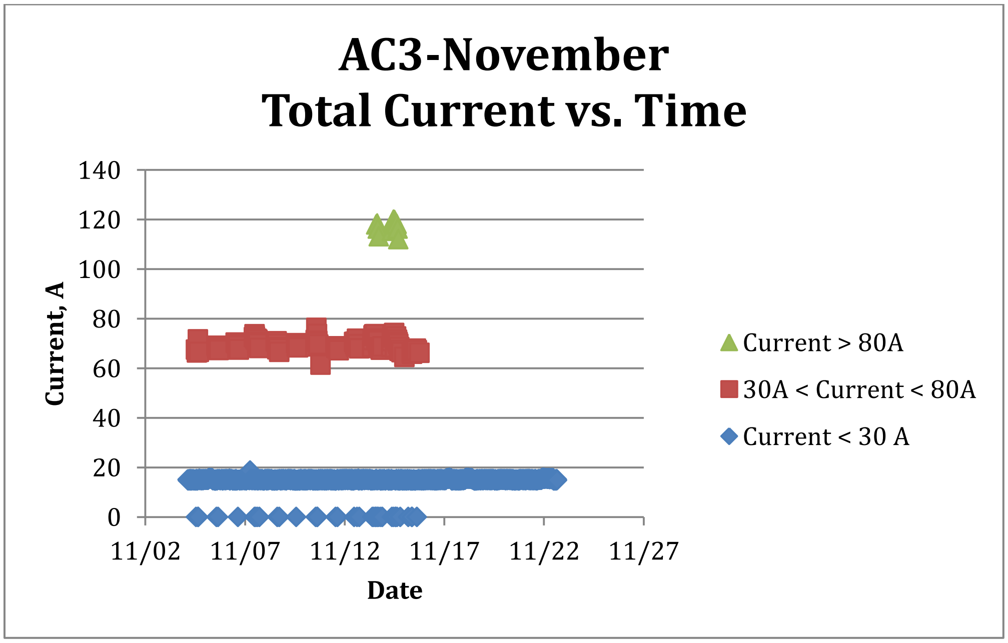


Figure 16: AC3 Summer and Winter Current vs. Time Comparison

Figure 16 shows the same seasonal comparison but for AC3, which we found is used more frequently than most other HVAC units. We can see during July that the AC unit is used several times a day and draws a very high and consistent inrush current. November on the other hand only sees occasional use during the first few weeks. The important fact to take away from this comparison is that AC3 is used far more than other AC units and thus the PV system should be designed to handle this load first during the summer months.

References

[1] *Title of Standard*, Standard number, date.

[1] *IEEE Guide for Self-Commutated Converters,* IEEE Standard 936, 1987

[2] *IEEE Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems*, IEEE Standard 1547.4, 2011

[3] Taufik and D. Dolan, “Advanced Power Electronics,” unpublished

APPENDIX A – POWER QUALITY

Voltage Imbalance:

Voltage Imbalance is defined as (referring to IEEE Std 936-1987 *): The difference between the highest and the lowest fundamental rms values in a three-phase system, referred to the average of the three fundamental rms values of current or voltages, respectively* [1].
Voltage imbalance can then be calculated as follows:

$$Voltage\ \%Imbalance = \frac{\Delta V_{max}}{\tilde{V}_{avg}}$$

ΔV_{max} is defined as the maximum deviation between line or phase voltages.

$\tilde{V}_{avg} = \frac{\tilde{V}_{ab} + \tilde{V}_{bc} + \tilde{V}_{ca}}{3}$ (Average line voltage)

$\tilde{V}_{avg} = \frac{\tilde{V}_{a\phi} + \tilde{V}_{b\phi} + \tilde{V}_{c\phi}}{3}$ (Average phase voltage)

Voltage imbalance occurs in a system when the RMS line/phase voltages are unequal. Three phase voltage is rarely equal but when the voltage difference becomes excessive problems can arise. One of the main effects of voltage imbalance is damaging motors and creating unwanted harmonics. When dealing with three-phase inverter based Distributed Resources, harmonics can affect inverter operation. According to IEEE Std 1547, a voltage imbalance of greater than 3% can cause problems to three-phase inverter based distributed resources [2].

Overvoltage: An increase in the rms of ac voltage greater than 110% at the power frequency for a duration longer than 1 minute [3]. Overvoltages are usually the result of Load Switching.

Undervoltage: A decrease in the rms of ac voltage lower than 90% at the power frequency for a duration longer than 1 minute [3].

Voltage Sag: A decrease to between 0.1 and 0.9 pu in rms voltage or current at the power frequency for durations from 0.5 cycles to 1 minute [3].

Voltage Swell: An increase to between 1.1 and 1.8 pu in rms voltage or current at the power frequency for durations from 0.5 cycles to 1 minute [3].

APPENDIX B – CHARACTERIZED DATA

Table 4: LL Voltage March Data

March	Line to Line Voltage Data								
Voltage / Load	AC1	AC2	AC3	AC4	AC5	AC6	AC7	AC8	Max & Min per line
Max Voltage L12	210.6	212.2	210	210.8	210.9	211	210.6	210.2	212.2
Max Voltage L23	210.7	212.7	209.8	210.7	211.3	211.3	211.1	210.2	212.7
Max Voltage L13	209.8	212.2	209.8	210.6	210.4	210.6	210.2	209.6	212.2
Min Voltage L12	202.9	204.6	203	202.8	202.9	202.9	203	201.9	201.9
Min Voltage L23	203.1	205.2	203	203	203.1	202.4	203.3	202.3	202.3
Min Voltage L13	202.7	205.2	202.8	202.5	202.8	202.7	203	201.9	201.9
Max % Voltage Imbalance Per Load	0.771084	0.384431	0.675024	0.436258	0.389674	0.442913	0.434573	0.733855	
Max % Voltage Imbalance Per Month	0.771084								
Average % Voltage Imbalance Per Load	0.122875	0.181326	0.123459	0.107409	0.110113	0.134511	0.11149	0.249589	

Table 5: LL Voltage April Data

April	Line to Line Voltage Data								
Voltage / Load	AC1	AC2	AC3	AC4	AC5	AC6	AC7	AC8	Max & Min per line
Max Voltage L12	211.2	214.9	213.1	214.6	213.9	212.7	212.4	213.6	214.9
Max Voltage L23	211.4	215.4	212.7	214.4	213.5	212.2	212.3	212.6	215.4
Max Voltage L13	211	215.5	212.4	214.3	213.2	212	212.1	212.4	215.5
Min Voltage L12	202.9	203.6	203.4	202.3	202.8	202.9	201.6	202.9	201.6
Min Voltage L23	202.6	204.3	203.5	202.2	202.7	202.7	201.6	201.5	201.5
Min Voltage L13	202.2	204.2	203.1	201.9	202.4	202.3	201.6	201.5	201.5
Max % Voltage Imbalance Per Load	0.768492	0.580552	0.531144	0.440313	0.437743	0.438596	0.437743	0.782779	
Max % Voltage Imbalance Per Month								0.782779	
Average % Voltage Imbalance Per Load	0.13824	0.177598	0.137292	0.117577	0.122177	0.15627	0.121473	0.299278	

Table 6: LL Voltage May Data

May	Line to Line Voltage Data								
Voltage / Load	AC1	AC2	AC3	AC4	AC5	AC6	AC7	AC8	Max & Min Per Line
Max Voltage L12	211.1	213.3	209.9	211.8	212.2	212.1	212.5	210.3	213.3
Max Voltage L23	211.1	213.6	210	211.9	212.2	211.9	212.6	209.8	213.6
Max Voltage L13	210.8	213.8	209.8	211.5	211.9	211.5	212.1	209.8	213.8
Min Voltage L12	203.6	203.6	203.5	202.7	202.8	203.2	202.3	201.3	201.3
Min Voltage L23	203	204	203.1	202.7	202.8	203.1	202.4	200.8	200.8
Min Voltage L13	202.9	204.5	203.2	202.3	202.3	202.6	202	201	201
Max % Voltage Imbalance Per Load	0.769231	0.529865	0.628019	0.728155	0.339147	0.38835	0.388727	0.781632	
Max % Voltage Imbalance Per Month								0.781632	
Average % Voltage Imbalance Per Load	0.130777	0.183447	0.137707	0.109375	0.110264	0.156417	0.115945	0.245764	

Table 7: LL Voltage June Data

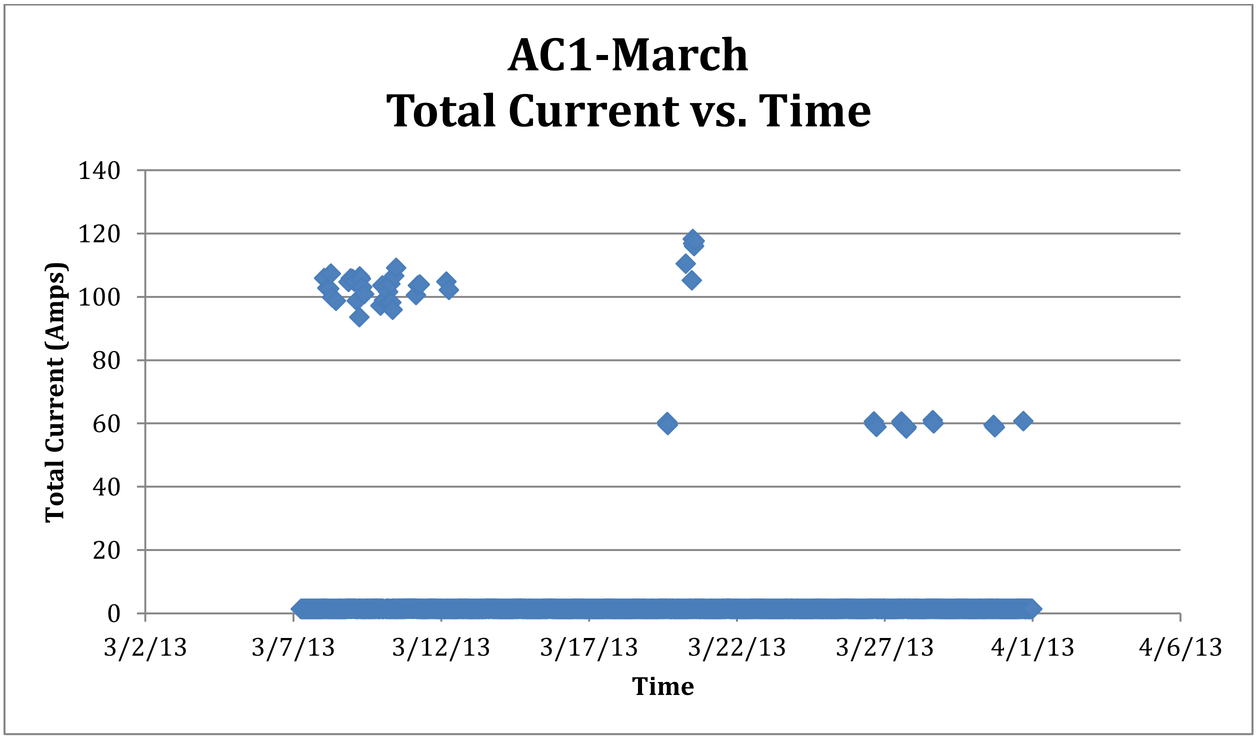
June	Line to Line Voltage Data								
Voltage / Load	AC1	AC2	AC3	AC4	AC5	AC6	AC7	AC8	Max & Min Per Line
Max Voltage L12	210.6	212.3	209.1	210.5	211.7	211.4	210.7	209	212.3
Max Voltage L23	211.2	213.2	209.5	211.1	212	211.5	211	208.4	213.2
Max Voltage L13	208.7	213.1	208.6	210.6	211.6	210.8	210.4	207.8	213.1
Min Voltage L12	202.7	202.4	202.9	200.9	200.8	201.8	201.8	200.9	200.8
Min Voltage L23	202.6	203.2	202.6	201	201	201.9	201.9	200.5	200.5
Min Voltage L13	202.4	203.1	202.5	200.8	200.6	201.1	201.3	200.1	200.1
Max % Voltage Imbalance Per Load	0.962001	0.722543	1.154401	0.484966	0.386847	0.436469	0.392542	0.68326	
Max % Voltage Imbalance Per Month			1.154401						
Average % Voltage Imbalance Per Load	0.150829	0.182385	0.148282	0.124039	0.130153	0.176591	0.129219	0.29135	

Table 8: LL Voltage July Data

July				Line to Line Voltage Data					
Voltage / Load	AC1	AC2	AC3	AC4	AC5	AC6	AC7	AC8	Max & Min Per Line
Max Voltage L12	208.5	213.2	209.9	211.8	212.2	212.1	211.6	210.9	213.2
Max Voltage L23	209.1	213.6	210.1	211.9	212.2	212.1	211.8	209.9	213.6
Max Voltage L13	208.4	213.3	209	211.4	211.6	211.4	211.1	208.9	213.3
Min Voltage L12	202.7	204.7	201.7	203.1	201.8	201.3	200.5	201.4	200.5
Min Voltage L23	202.5	204.7	201.4	202.9	201.7	201.2	200.6	199.6	199.6
Min Voltage L13	202.2	204.7	201.1	202.5	201.3	200.6	200.5	200.1	200.1
Max % Voltage Imbalance Per Load	0.723938	0.481464	0.5345	0.393507	0.437743	0.437956	0.489716	1.028404	
Max % Voltage Imbalance Per Month								1.028404	
Average % Voltage Imbalance Per Load	0.158864	0.184912	0.153633	0.138451	0.137259	0.193447	0.142803	0.290326	

Table 9: LL Voltage August Data

August				Line to Line Voltage Data					
Voltage / Load	AC1	AC2	AC3	AC4	AC5	AC6	AC7	AC8	Max & Min Per Line
Max Voltage L12	211.2	211.4	211.5	210.8	211.4	212.4	214	211	214
Max Voltage L23	211	212.4	210.9	210.9	210.9	211.7	214.5	210.5	214.5
Max Voltage L13	210.4	212.2	210.8	210.4	210.8	211.5	213.7	210.3	213.7
Min Voltage L12	200.8	202.5	200.7	202.9	201.4	201	202.4	198.9	198.9
Min Voltage L23	201.1	203.2	200.6	203.4	201.2	200.8	202.4	197.7	197.7
Min Voltage L13	200.6	202.9	200.5	202.6	200.9	200.2	202	198	198
Max % Voltage Imbalance Per Load	0.676002	0.531658	0.678952	0.485201	0.44096	0.38835	0.440744	0.737826	
Max % Voltage Imbalance Per Month								0.737826	
Average % Voltage Imbalance Per Load	0.153915	0.211125	0.147223	0.141247	0.131425	0.175928	0.138828	0.24178	



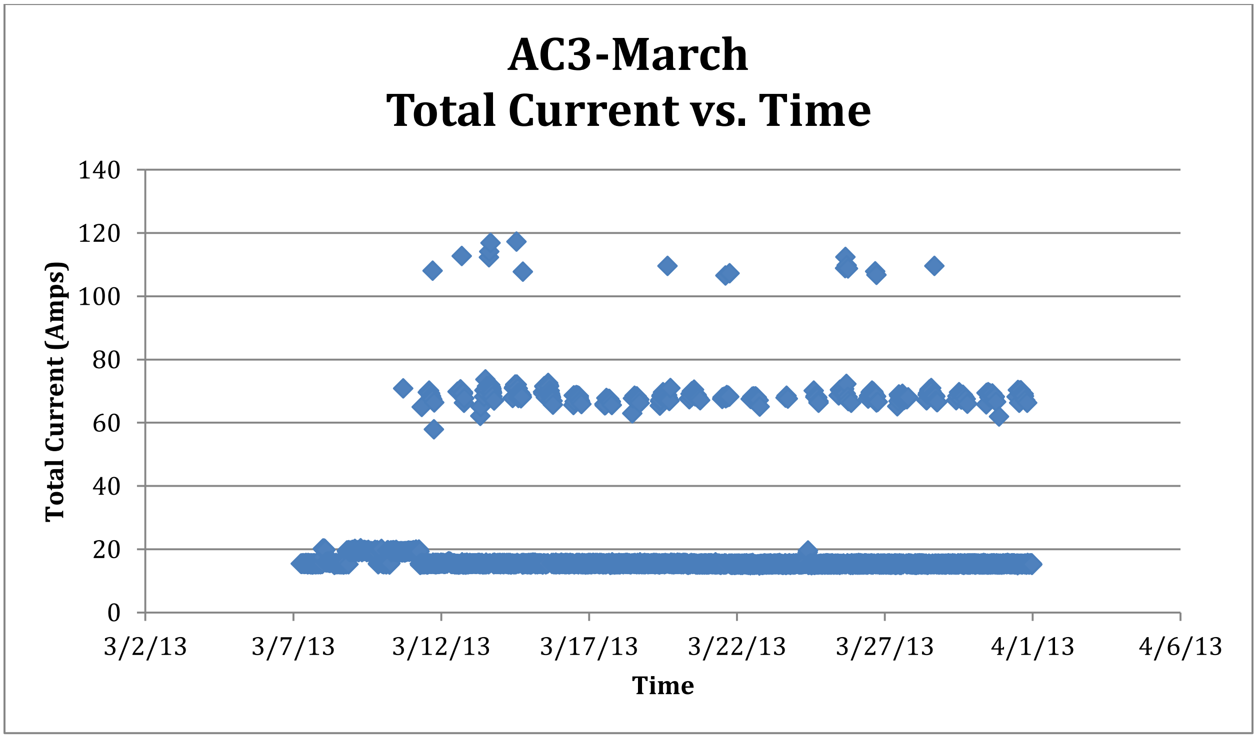
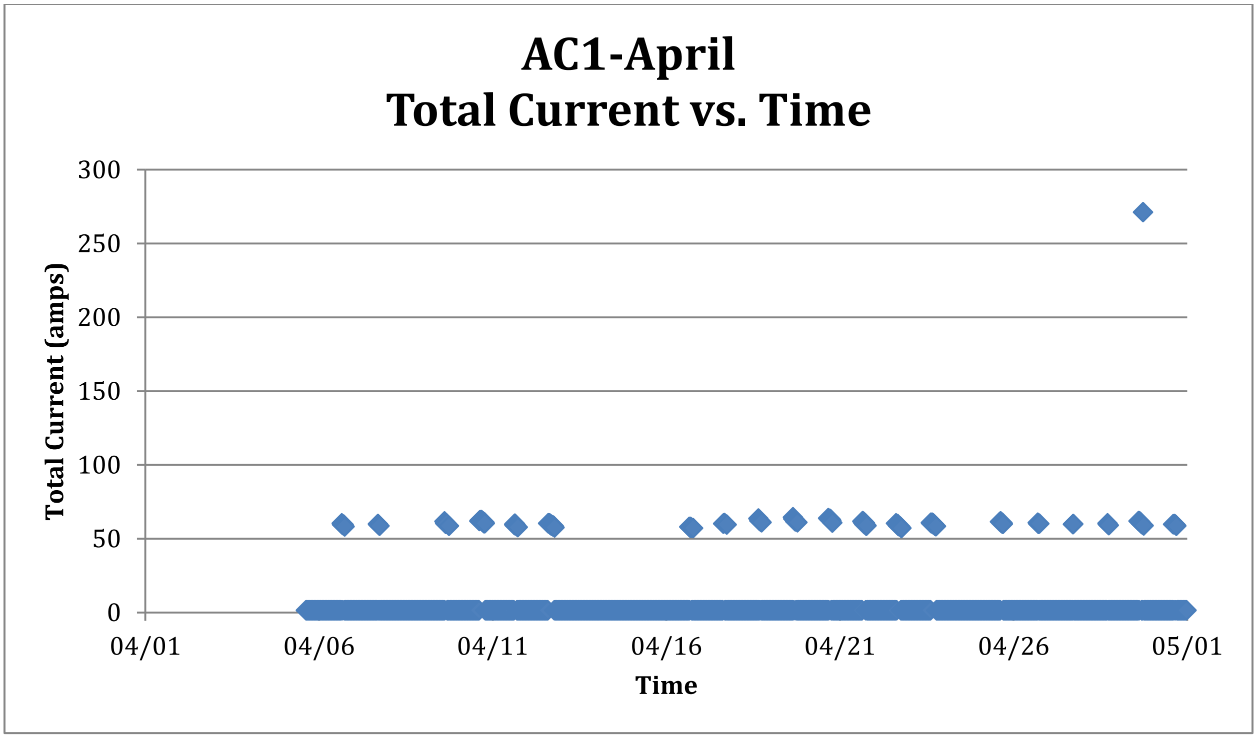


Figure 17: Total Current vs. Time data for AC1 and AC2 in the month of March



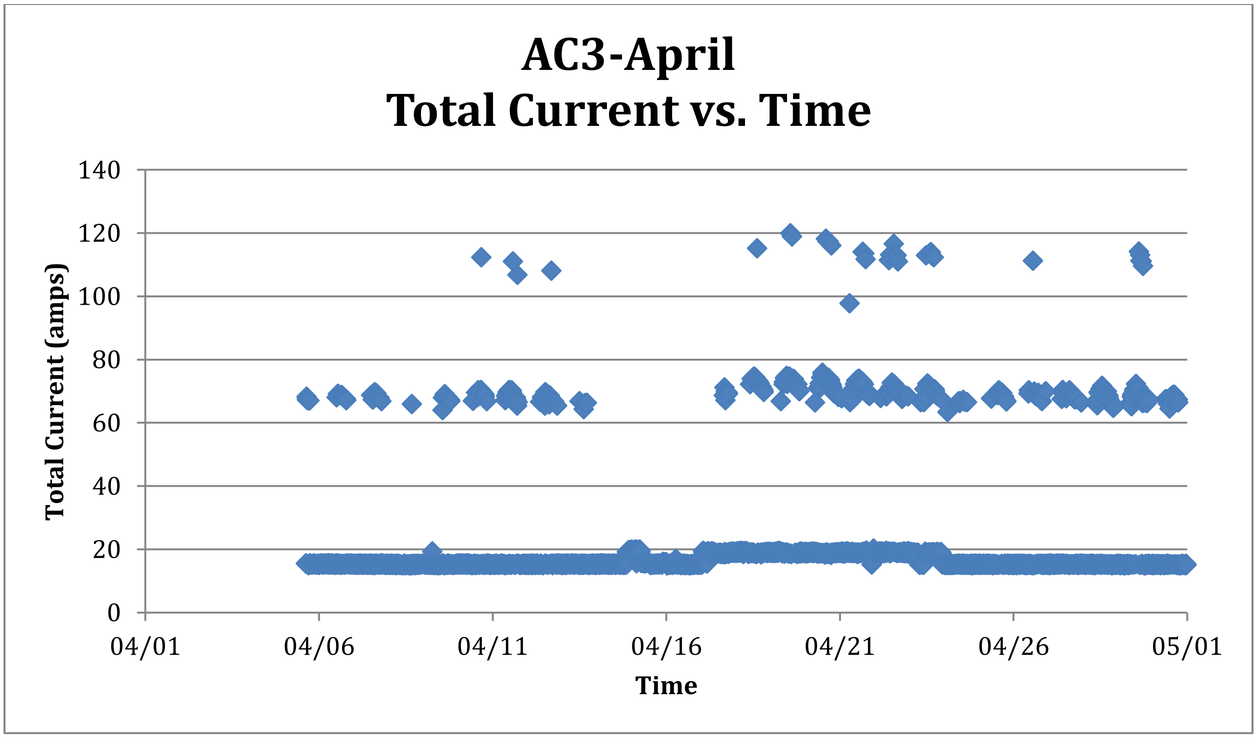
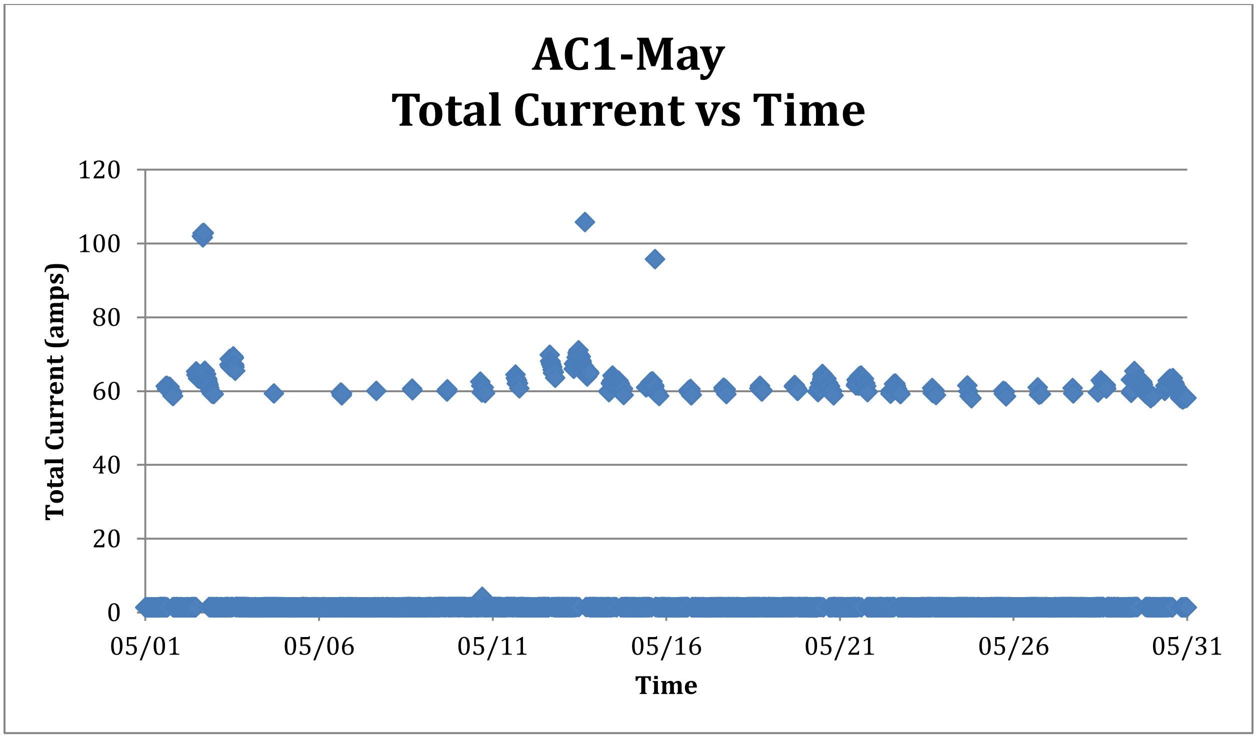


Figure 18: Total Current vs. Time data for AC1 and AC2 in the month of April



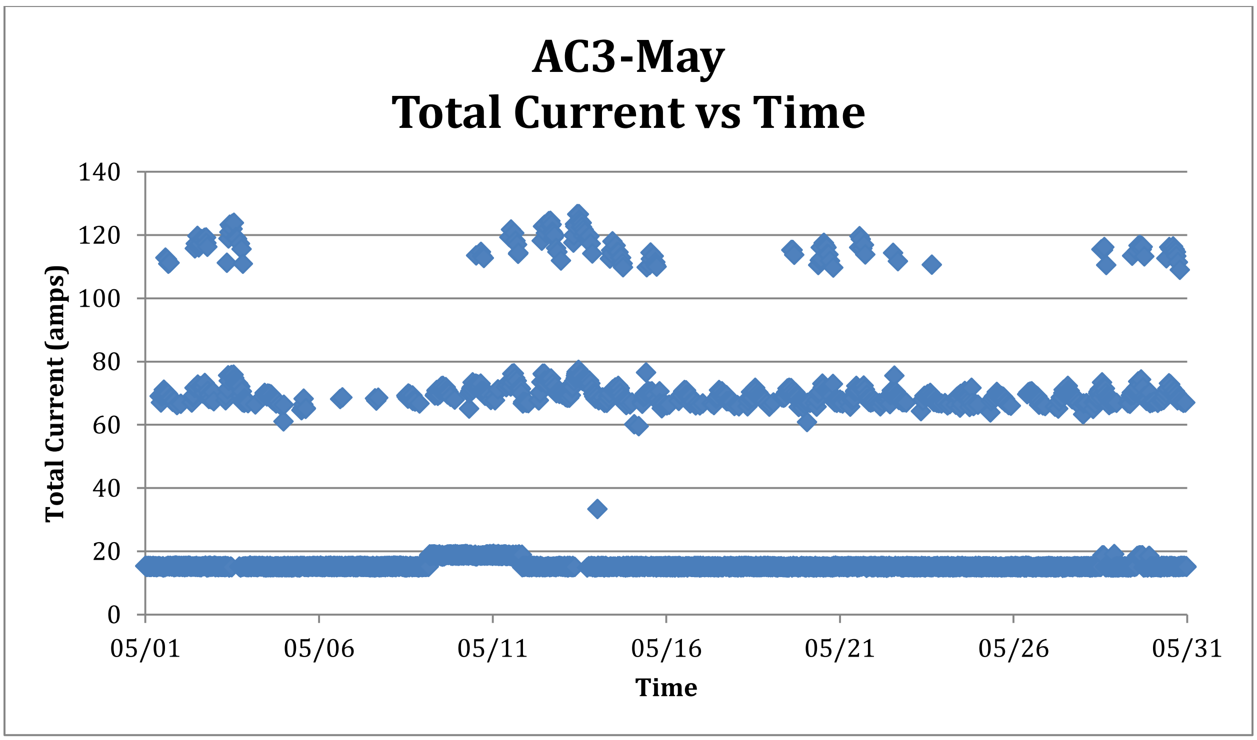
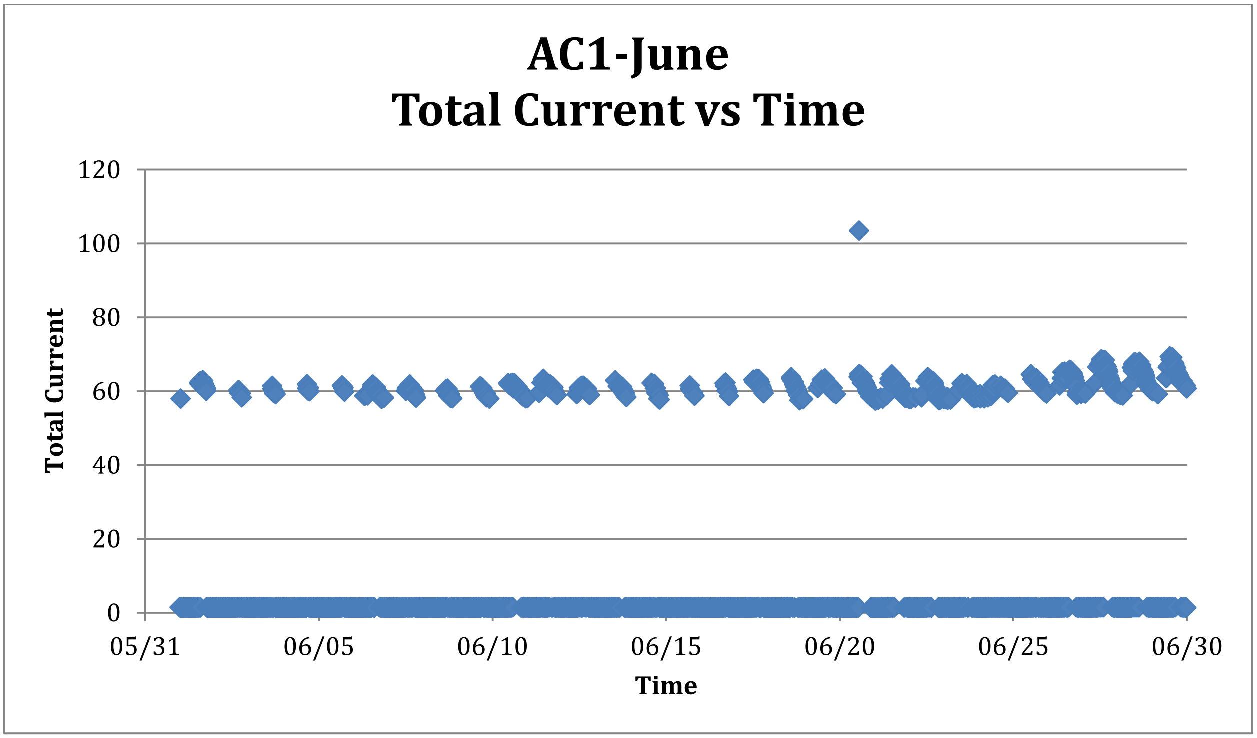


Figure 19: Total Current vs. Time data for AC1 and AC2 in the month of May



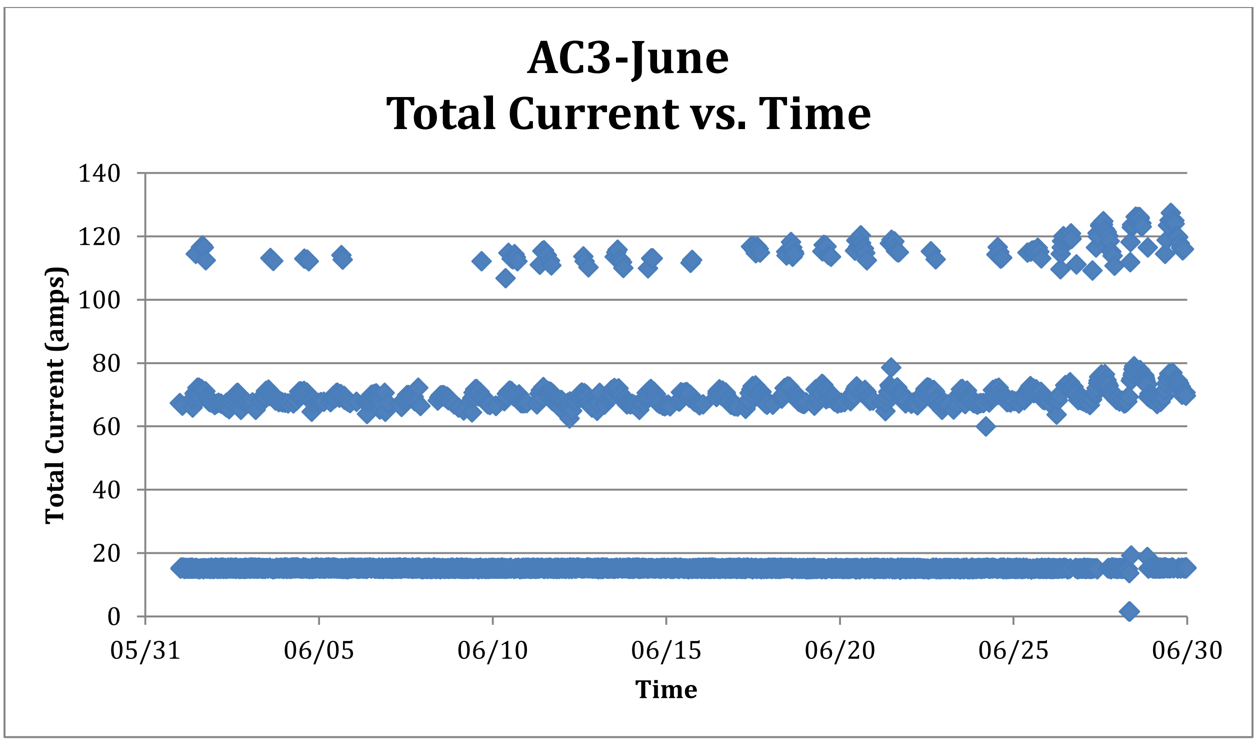
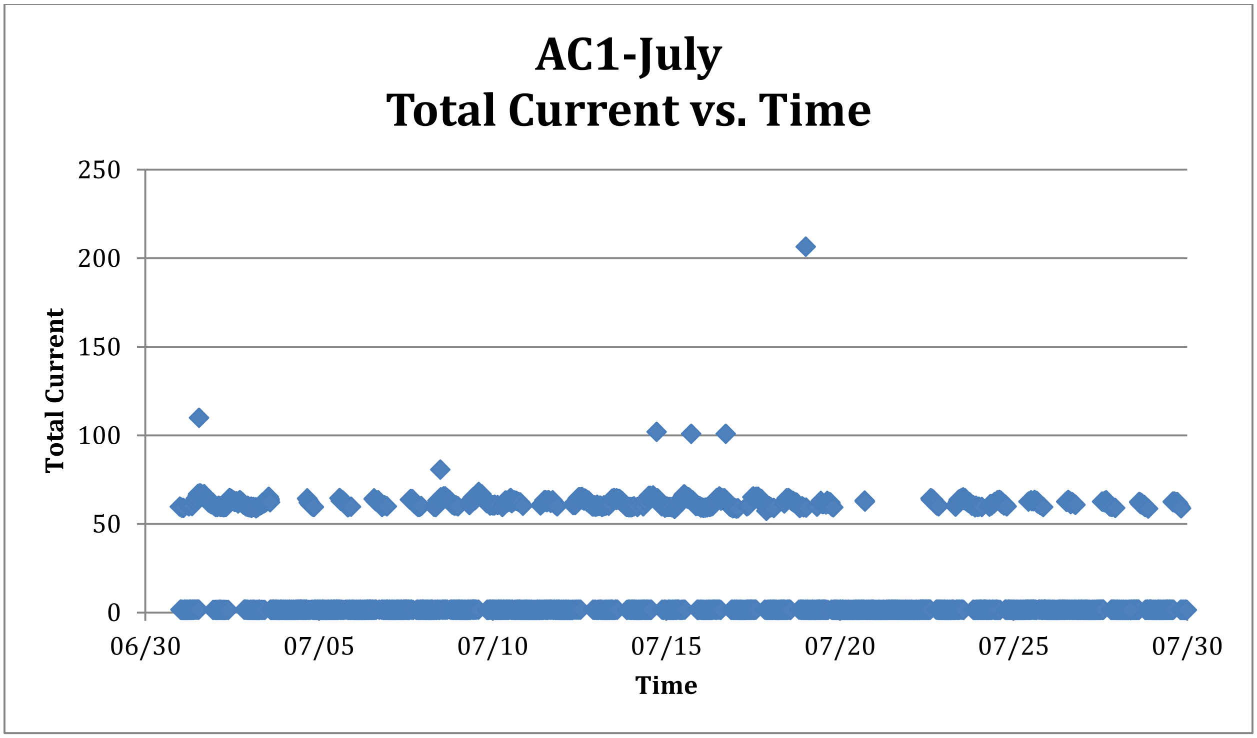


Figure 20: Total Current vs. Time data for AC1 and AC2 in the month of June



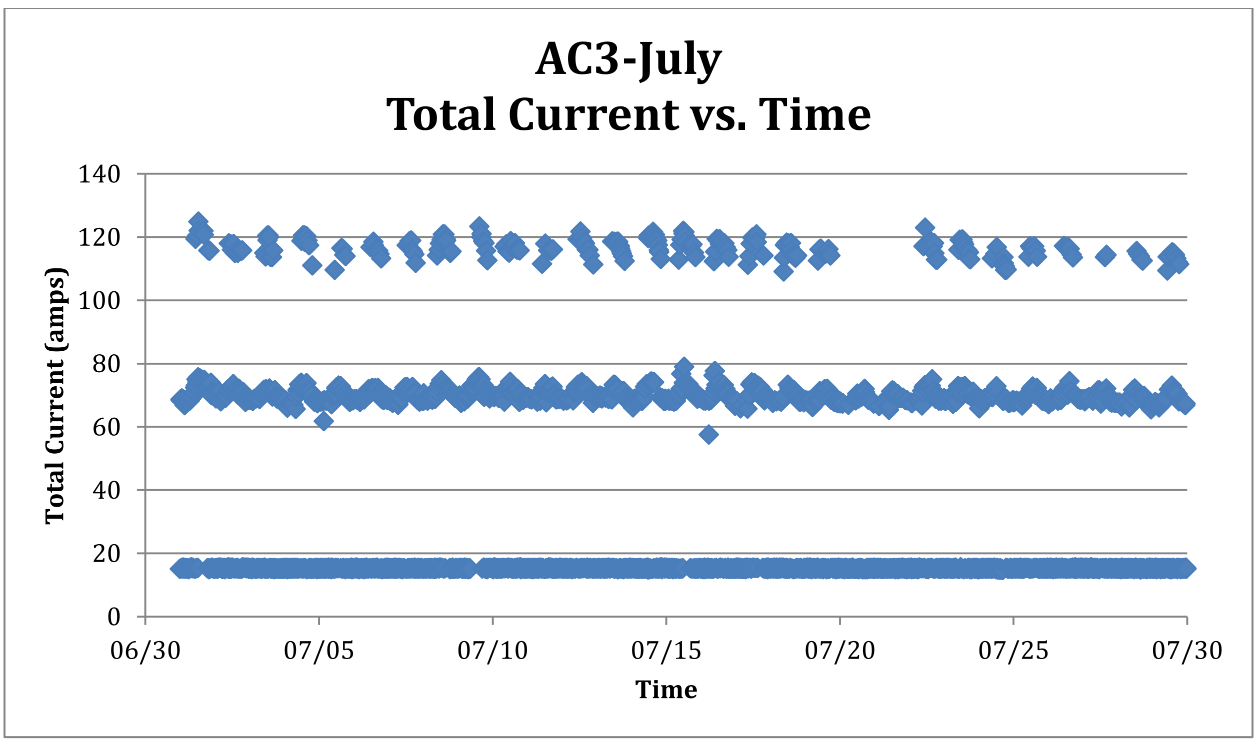
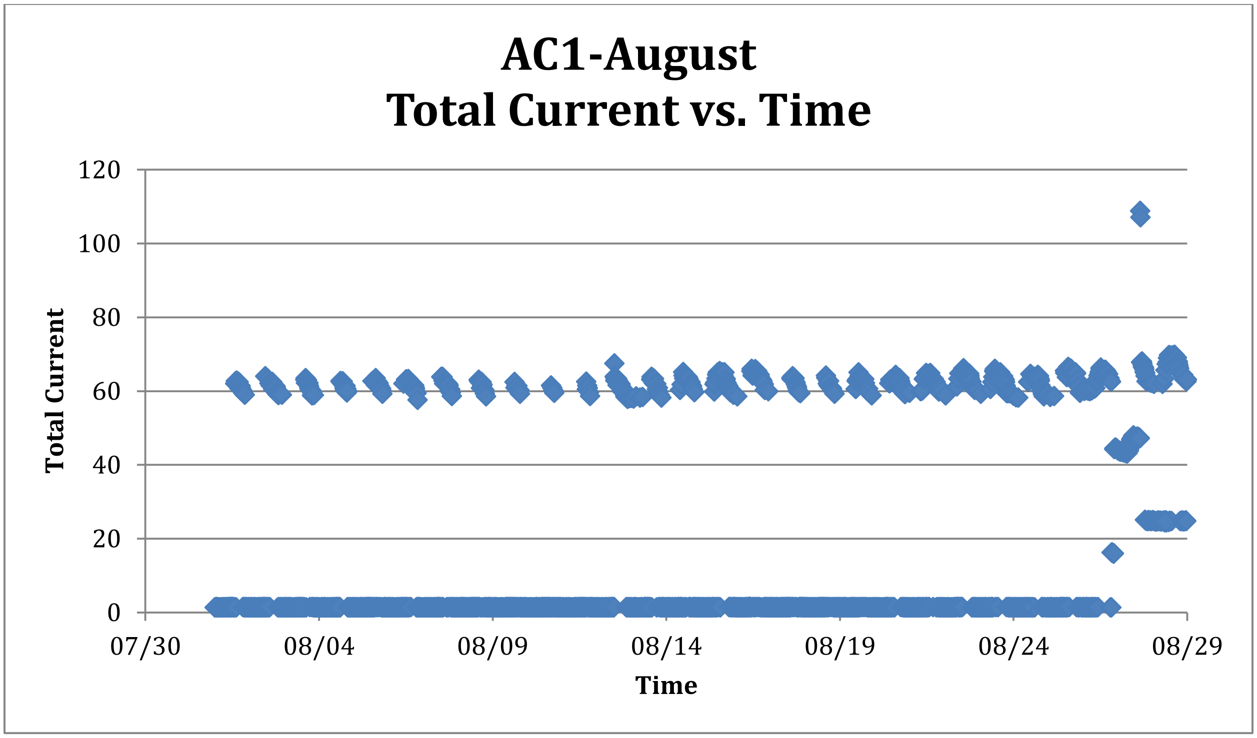


Figure 21: Total Current vs. Time data for AC1 and AC2 in the month of July



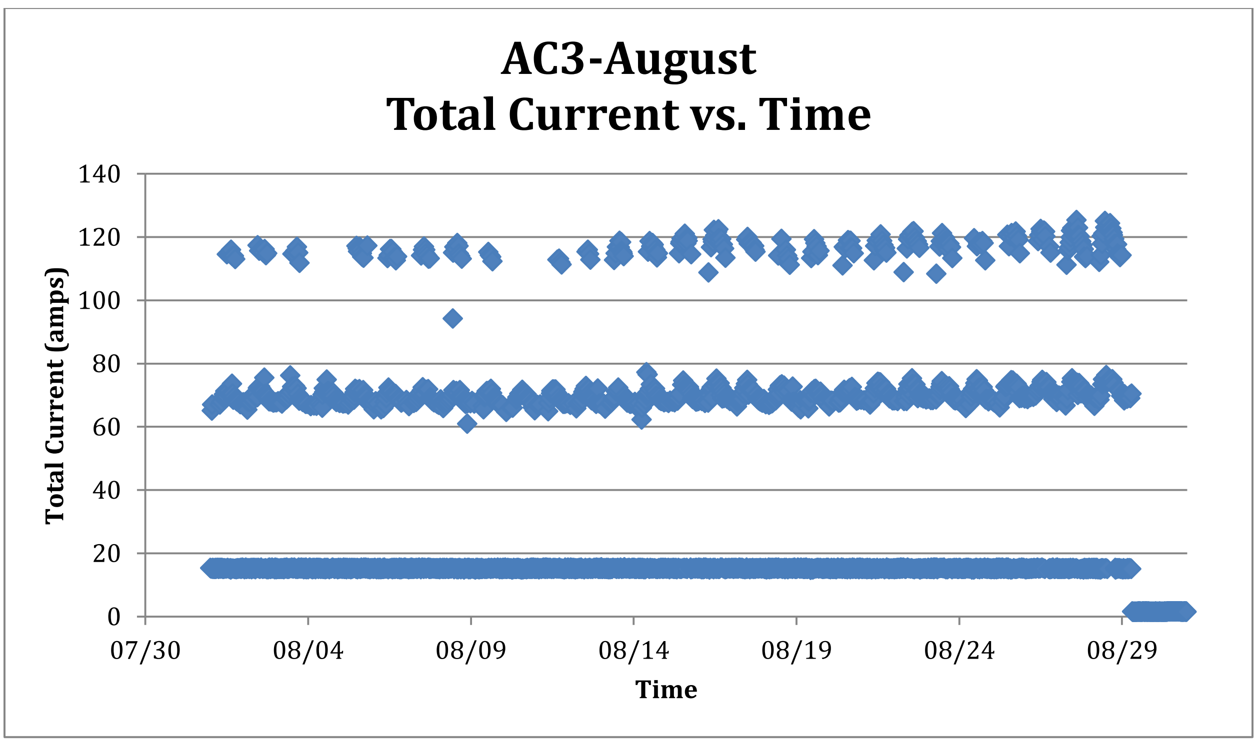
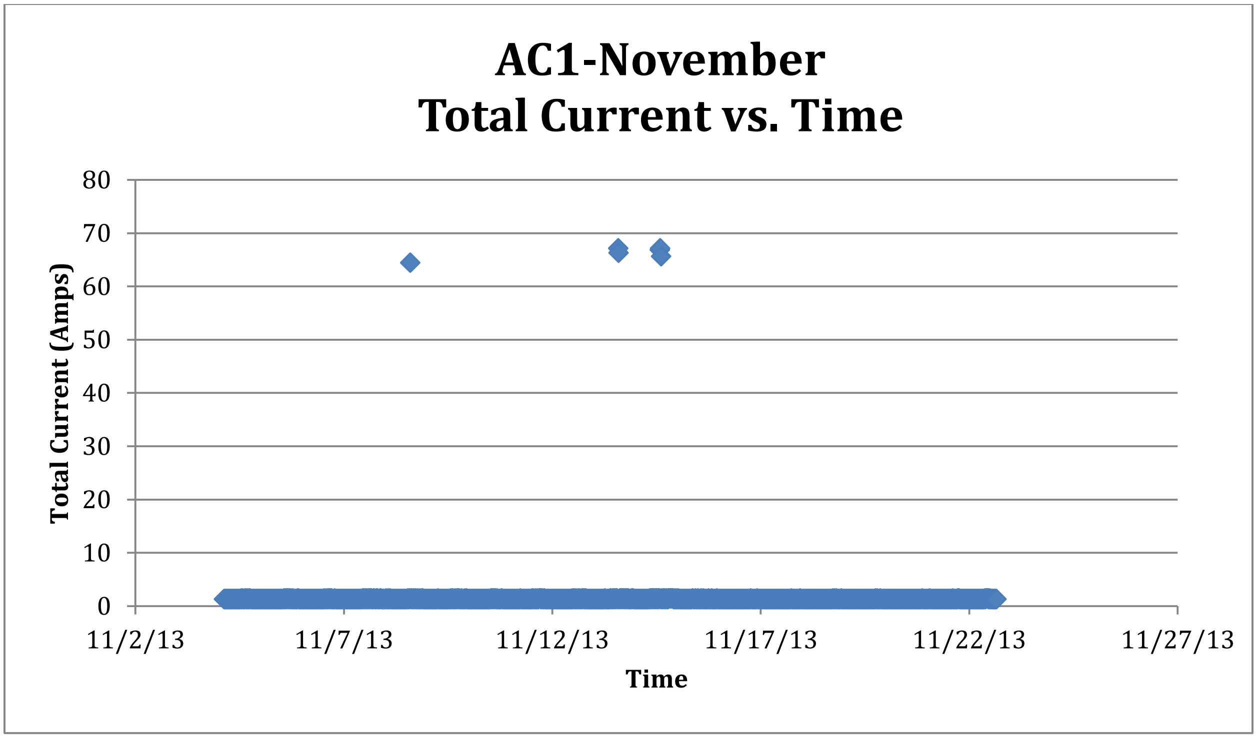


Figure 22: Total Current vs. Time data for AC1 and AC2 in the month of August



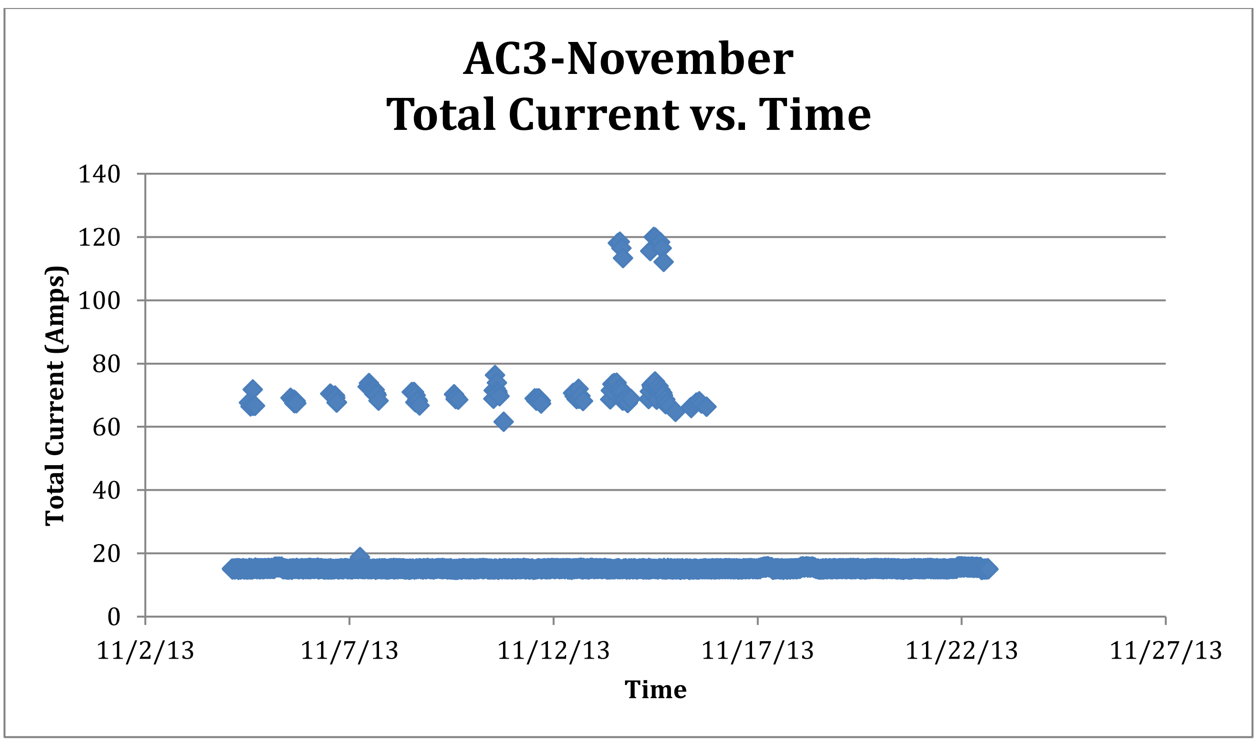


Figure 23: Total Current vs. Time data for AC1 and AC2 in the month of November

APPENDIX C - ANALYSIS OF SENIOR PROJECT DESIGN

- Summary of Functional Requirements:

  Our project involves monitoring issues that can cause economic or environmental distress due to power inefficiency. Our project will analyze issues that result from switching from the utility grid to a smart grid run on primarily photovoltaic "components".

  The primary Functional Requirements are as follows:

  1. Able to measure and analyze power quality continuously and accurately
  2. Able to setup, measure, and analyze the power system safely
  3. Setup should not interfere with client workplace for extended durations of time
  4. Sampling of less than 5 second intervals attainable
  5. Measured and characterized power quality data should be presented in a way that clearly and accurately identifies problems in the power quality of the system

- Primary Constraints:

  Our project involves using the PS3000 power measurement tool to perform data analysis on a power system. Therefore the first challenge involved was getting accustomed to using the PS3000. Multiple tests were performed to become proficient in both using the hardware and software associated with the PS3000.

  Another challenge and limiting factor to our project is gaining access to a power system. Since our project involves monitoring and characterizing data from a power system, a power system must be located and permission must be attained to perform measurements. We have plans to perform power system analysis at a Navy base through Raytheon. Thus gaining access to Raytheon's site is the primary limiting factor so far.

- Economic:

  Based on our readings, companies can lose large amounts of money due to power inefficiency. for example some companies have reported losing hundreds of thousands of dollars from less than a tenth of a second momentary power interruption. From these findings we can conclude that the power quality analysis of a system can result in economic growth.

Our project makes use of a faculty owned instrument (PS3000), therefore the costs required to successfully complete this project include the following: Shipping, Calibration, Gas, Hotel and Misc. A cost estimate, **Figure 3**, and explanation for costs can be seen below.

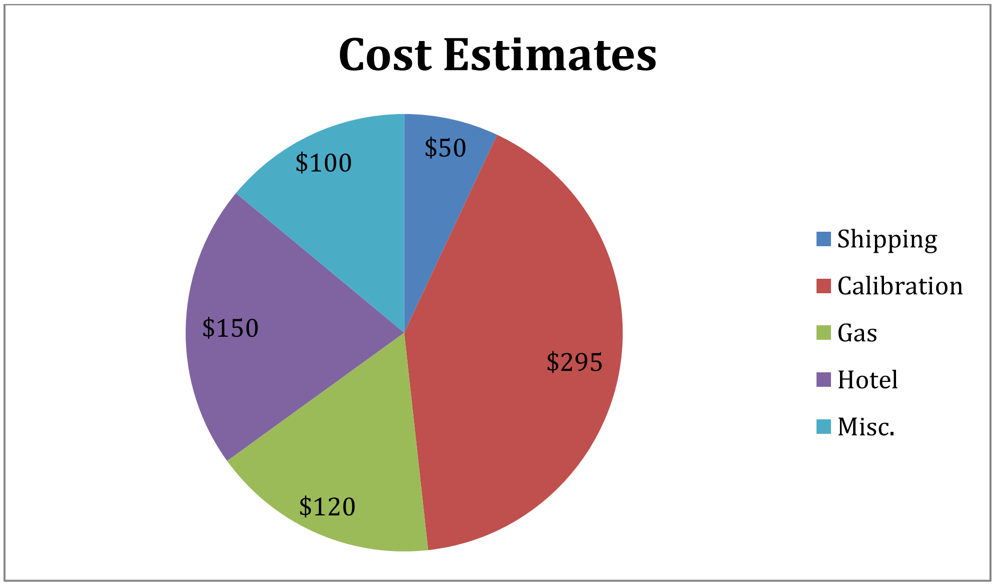


Figure 24: Cost Estimate Pie Chart

Shipping: The PS3000 needs to be shipped to the manufacturer in Walnut Creek, CA to be calibrated. Due to the device's large and heavy nature, a $50 shipping estimate is reasonable.

Calibration: The PS3000 needs to be calibrated to function accurately. The labor and other charges needed are priced at $295.

Gas: Expected to drive 360 miles to Miramar, CA to visit the facility and perform measurements. $120 for gas expenses is a rough but reasonable estimate.

Hotel: will be required to stay one to two nights in San Diego. Average prices range from $80-$150 a night.

Misc: Food and other expenses necessary to complete the measurements and return to San Luis Obispo.

Gantt Chart:

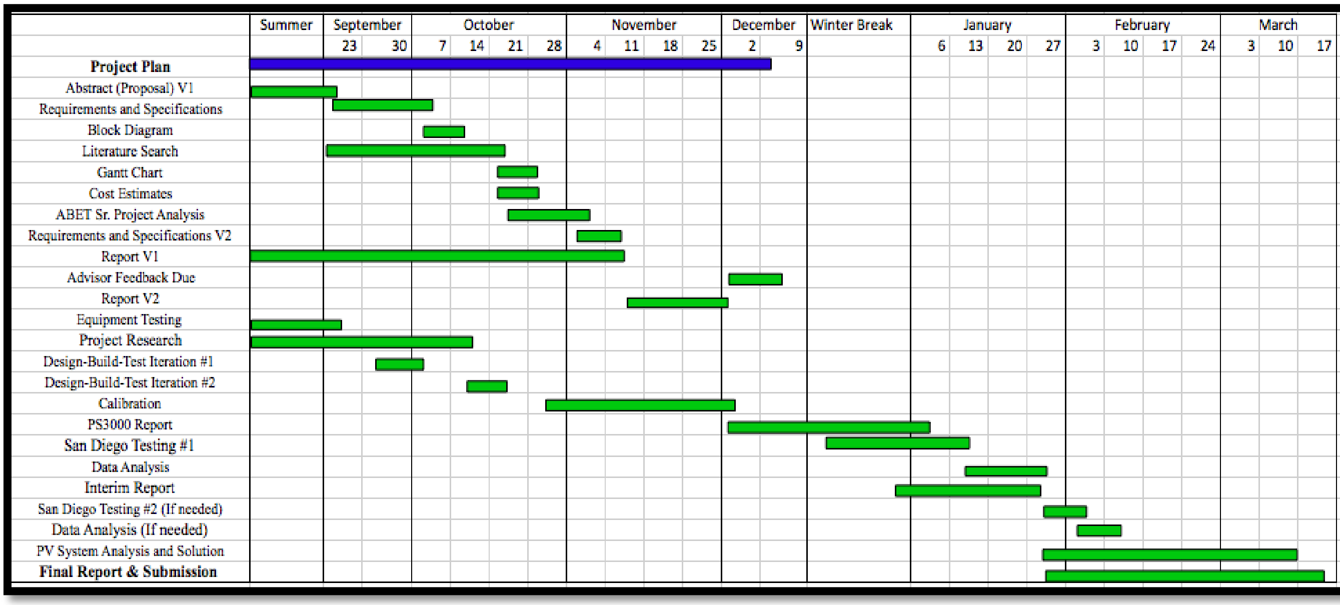


Figure 25: Cost Estimate Pie Chart

The primary inputs required are human input to setup the instrument and to characterize the data accurately. Another input required is the Voltage and Current of the system.

The total cost of the project is estimated at $715.

The fees will be partially paid by the department and the remaining fees will be paid by the students involved in the project.

The projects earnings are based off of the power systems improved efficiency. Therefore the earnings are to be determined.

The entity profiting from the project would be the establishment benefitting from an improved power system.

- This project does not require manufacturing.
- Environmental:

Project doesn’t involve manufacturing. Use of power monitoring equipment does not have environmental impact.

This project does not use any natural resources directly; however, natural resources are indirectly consumed to produce the power that the system consumes. As

stated earlier, our project aims to reduce the overall power consumption and inefficiencies.

This project aims to improve a system's power efficiency by identifying power quality problems. Increasing power efficiency will decrease a system's overall power consumption and thus decrease the use of natural resources needed to create power.

The project has the potential to enhance a systems overall power efficiency. This can impact species in a positive way by creating more efficient power systems and thus reducing our ecological footprint on Earth.

- This project does not require manufacturing

- Sustainability:

Several issues that could arise from maintaining the system include: ensuring the PowerSight remains untouched while performing measurements, the PowerSight configuration does not reset from lack of battery charge, and not allowing unauthorized personnel to access the project.

The project aims to improve the sustainability of power resources by monitoring power consumption in the system and identifying potential issues that can cause overconsumption or irregularities in efficiency.

The project could be improved by using updated power technology like the PowerSight PS4500 that measures power characteristics more accurately and quantifies data in a more presentable format.

The major challenge in upgrading the technology is that the newer versions of the PowerSight meter cost upwards of $5,000. New software and expertise would also be required.

- Ethical:

For our project we are dealing with smart-grids and their efficiency on a large scale. Since we are dealing with the efficiency of the power/energy, the analysis of data we obtain will allow us to find suggestions that will help out with the lowering of use of energy which helps out the environment; not running these analysis' are detrimental to the environment because there is wasted energy in most systems. This is directly related to the first part of IEEE's Code of Ethics: the responsibility of the well-being of the public.

Other parts of this project that deal with ethics is the use of the PowerSight. The PowerSight needs to be calibrated, and if the person that is using doesn't keep it calibrated, the values that are measured can be inaccurate, which will result in bad data, resulting in an incorrect analysis. Not calibrating the PowerSight could cause false readings on a system; these false readings could cause injury to individuals or even property damage. The IEEE's Code of Ethics talks about how we need to take actions to avoid these situations.

- Health and Safety:

Several safety concerns arise while setting up the PowerSight meter and while the meter is operating. The PowerSight requires a live connection which presents a danger due to the high voltage. While the PowerSight is operating, the setup must be isolated from unauthorized personnel to prevent potentially fatal injuries.

- Social and Political:

As the state of California's population continues to increase the necessity of efficient energy systems is needed. Large energy companies, like PG&E, have lobbying groups that try and pass laws that will benefit them. These laws change the ways we are able to acquire energy for our houses as well as how much we have to pay.

The project will directly impact Ratheon because that is the company we are working with. The indirect stakeholders could be the individuals that work under the smart-grid (employees that have desk jobs using the power from the walls).

The project would benefit all stakeholders because of the efficiency increase in their system. Less dips in power, as well as less power loss which equals to money saved.

This project has no inequities. All stakeholders receive benefit in ways that can only benefit them.

- Development:

During the course of the project we have learned how to effectively use the PowerSight software and hardware when attached to high voltage systems. We also independently researched power quality and how it impacts power systems. We are currently researching how to characterize the resulting data from the PowerSight to give an accurate and effective report on the system.

- <u>Two Supporting Development Literature Resources</u>

PS3000 Energy Analyzer "The Tool of First Resort", Summit Technology Inc., Walnut Creek, CA.

The source was chosen because it's the datasheet of the measurement tool were using to retrieve data from a power system. The datasheet can be useful by supplying more information about how the PS3000 operates.

The source has authority because it's the manufacturer of the measurement tool being used in our senior project.

"IEEE Recommended Practice for Utility Interface of Photovoltaic (PV) Systems," IEEE Std 929-2000, vol., no., pp.-, 2000.

The source was chosen because it covers a wide variety of topics necessary for our project including utility fault conditions for PV systems.

The source was published in a yearly IEEE journal, therefore the source has been peer reviewed.