Energy Research and Development Division
FINAL PROJECT REPORT

SMART POWER FOR SMART HOME

Inverter Controls, Power Factor Corrections, and Peak Demand Reductions

Prepared for: California Energy Commission
Prepared by: California Plugload Research Center Power Electronics Laboratory, University of California, Irvine

MARCH 2015
CIEE Subaward No. PODR05-V20

CALIFORNIA PLUG LOAD RESEARCH CENTER

PREPARED BY:

Primary Author(s):
Linyi Xia
Prof. Keyue Smedley
Prof. G.P. Li

California Plugload Research Center
4100 Calit2 Building
Irvine, CA 92697
Phone: 949-824-4874)

Contract Number: PODR05-20

Prepared for:

California Energy Commission

Jamie Patterson
Contract Manager

Fernando Pina
Office Manager
Energy Systems Research Office

Laurie ten Hope
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Robert P. Oglesby
Executive Director

ACKNOWLEDGEMENTS

Type here.

PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Energy Research and Development Division conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The Energy Research and Development Division strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

Energy Research and Development Division funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

[Report title in italics] is the [final or interim—select one] report for the [project name] project (contract number XXX-XX-XXX, work authorization number [insert #] or grant number [insert #]) conducted by [research entity]. The information from this project contributes to Energy Research and Development Division's [insert RD&D program area from bulleted list above] Program.

For more information about the Energy Research and Development Division, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

ABSTRACT

Typical American households have a dynamic power quality factor varying from 0.8 to 0.95 depending on the signature of loads and their use at the time. (Appliances such as HVAC, motors, and lighting generate reactive and harmonic power, which is typically about 20% of the power consumption.) While PV via inverter provides mostly real power to home loads, the reactive power consumed by the loads would need to come from the electric grid and thus lowering the energy efficiency of the total system. Surging demand on reactive power at peak hours further induces instability to the grid.

We propose a grid tied inverter (GTI) integrated with APF that harnesses power from the renewables and cancels the reactive Q and harmonics H in the meantime. The power flow to or from the grid is thus purely sinusoidal and active. The proposed concept can be realized by using the one-cycle control (OCC) technology, featuring fast and stable dynamics and precise harmonic and reactive cancellation.

Another long term solution we proposed is to promote behavioral adaptive changes. This starts with a deep understanding of energy related human behaviors. Advances in the knowledge of power measurement and appliance recognition would benefit both the utilities and consumers. The proposed power monitoring system will measure the performance of the APF/inverter, report the overall load, and recognize the consumer usage patterns.

The load signature analysis will help both users and utilities understand how energy is consumed regarding human beings as the focal point. With this information available, we can further study and discover means to save energy either by providing guidance to the users or implement control systems to help users save energy seamlessly. At the same time, upon the availability of this information, simply simply suggesting the users to conduct some activities after peak hours may shift peak demand. This load disaggregation system can tailor towards individual users' preferences and provides suggestions on how energy saving and peak shifting can both be achieved for the benefit of the environment.

In this report, we have listed methods and developments of both active power filter and load signature analysis devices. The systems have been fully implemented, tested and demonstrated for effectiveness during the in house testing at UC Davis' "smart home" location.

Keywords: APFC, Power factor correction, One-cycle control, Load Disaggregation, Algorithm, Load Signature Analysis.

Please use the following citation for this report:

Xia, Linyi; Smedley, Keyue; Li, G.P. (University of California, Irvine, California Plugload Research Center). 2015. ***Smart Power for Smart Home: Active Power Factor Correction and Load Signature Analysis.*** California Energy Commission. Publication number: CEC-500-YYYY-XXX.

TABLE OF CONTENTS

Acknowledgements .... **i**

PREFACE .... **ii**

ABSTRACT .... **iii**

TABLE OF CONTENTS .... **iv**

LIST OF FIGURES .... **v**

EXECUTIVE SUMMARY **1**

Introduction 1

Project Purpose 1

Project Results 1

Project Benefits 1

CHAPTER 1: Implementation of OCC-APF for smart home **3**

CHAPTER 3: Load Signature Analysis and Wireless Monitoring System **8**

3.1 Electrical Characteristics Capture 8

3.1.1 Methodologies 8

3.1.2 Hardware design 8

3.1.3 Firmware Design 10

3.2: Disaggregation 13

3.2.1 Backward learning 13

3.3: Communications 15

3.3.1 PCB to Gateway Communication Protocol 15

3.3.2 Gateway to Server Communication Protocol 15

3.4: User Interface and Usage Modes 16

3.4.1 Normal Operational mode 16

3.4.2 Training mode 17

3.5: Industrial Design 19

GLOSSARY **23**

Works Cited **24**

APPENDIX A: Title of Appendix..Error! Bookmark not defined.

LIST OF FIGURES

Figure 1 One line diagram of the APF connection circuit 4
Figure 2 OCC-APF circuit diagram 5
Figure 3 Printed circuit board for OCC-APF 5
Figure 4 The OCC-APF Prototype, Left-Front view, Right-rear view 6
Figure 5 Modularized PCB design diagram 8
Figure 6 PCB Schematics 9
Figure 7 PCB Layout 10
Figure 8 Implemented System Level Firmware Flowchart for ARM Processor on PCB 11
Figure 9 KNN algorithm diagram two dimensional projection representation 13
Figure 10 Data package definition between PCB and Gateway 15
Figure 11 Gateway to Server Communication data package definition 15
Figure 12 User Interface for Load Monitoring System (Home) 17
Figure 13 Training Mode User Interface 18
Figure 14 Enclosure Interior 19
Figure 15 Enclosure with lid on 20
Figure 16 Finished Product pictures 21

EXECUTIVE SUMMARY

Introduction

To better understand the demand response is to gain more knowledge directly from the user end. Where the energy is drawn from the grid will provide extremely useful information once we understand how people are interacting with devices at home and find patterns in that pool of information.

One way to gain such knowledge is to understand the load signature of devices that are grid connected and their effects on the grid. Hereby, an investigation in a systematic approach of development is conducted.

Project Purpose

To benefit consumers and utilities, a prototype device is developed to capture load signatures of multiple devices which could be extend to monitor the entire the house to monitor, record, and disaggregate devices' power consumption. At the same time, this will provide the user with a simplified viewing feature by displaying their devices energy consumption information at their fingertips.

Project Results

Develop PCB and algorithms to capture and disaggregate plug load devices. Define server end protocol to establish a communicational channel between PCB and a mobile friendly interface.

Project Benefits

Technological advancements are produced in algorithmic approaches in load disaggregation. Simplifications on measuring devices are made to be more compatible at household levels. Establish a foundation for the utilities and stakeholders to incentivize energy monitoring and managing.

A blank page is inserted to insure Chapter 1 starts on an odd number page. Blank pages are not labeled.

CHAPTER 1:
Implementation of OCC-APF for smart home

For a typical American household, the power quality factor varying from 0.8 to 0.95 is observed depending on the loads and their use at the time. While PV via inverter provides mostly real power to home loads, the reactive power consumed by the loads would need to come from electric grid and thus lower the energy efficiency of the total system and reduce the system power delivery capability. Surging demand on reactive power at peak hours further induce instability to the grid. In this project period, we focused on implementing a one-cycle controlled active power filter (APF) for home that can dynamically adjust the power quality factor of the electric circuit of the home to near unity.

Household appliances such as HVAC, motors, and lighting generate reactive and harmonic power, which is typically about 20% of the power consumption. Conventional inverters do not absorb it, thus, the reactive and harmonic will flow to the power grid. In the extreme case when zero power is flowing between the grid and the home, the reactive and harmonic draw counts 100%, which causes power losses in the line, disturbance to the system, distortion to the voltage, and possible system instability.

Article (Smedley, Zhou and Qiao, Unified constant-frequency integration control of single phase active power filter 2001) introduced a simple, fast and precise control solution based on one-cycle control (Smedley and Cuk, One-cycle control of switching converter 1991) for a single-phase APF, with excellent harmonic and reactive cancellation result. In 2006, a GTI/APF was proposed in (G. Smedley n.d.) that demonstrated active power processing with reactive and harmonic cancellation capability for three-phase systems. This technology is adopted for the home power application in this project.

The one line diagram of the APF is shown in Figure 1, where i_s is the grid current, i_{load} is the combined home appliance and PV inverter current, while i_{APF} is the APF current.

$$i_s = i_{APF} + i_{load}$$

Without APF, we have

$$P_s + Q_s = P_{load} + Q_{load}$$

When the load reactive current is high, the power grid will suffer from more loss, more congestion, and instability.

With APF, we have

$$P_s + Q_s = P_{APF} + Q_{APF} + P_{load} + Q_{load}$$

Where P_s is the grid power, Q_s is the grid reactive power, P_{APF} is the power consumed by the APF, Q_{APF} is the reactive power generated by the APF to cancel the load reactive power, P_{load} is the load power, and Q_{load} is the load reactive power.

The function of APF is to eliminate the reactive current of the home, i.e.

$Q_{APF} = - Q_{load}$

As the result, we achieve:

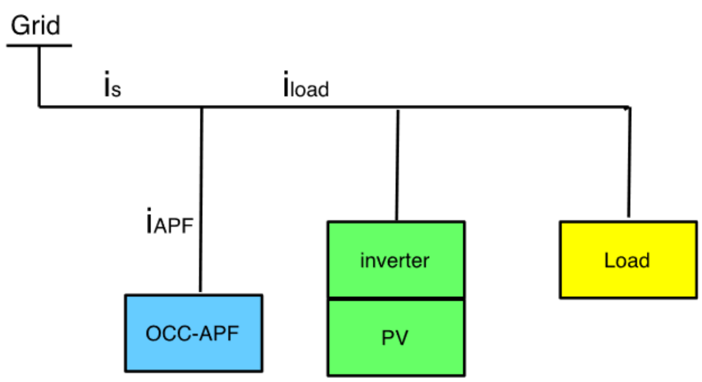
$P_s = P_{APF} + P_{load}$

$Q_s = Q_{APF} + Q_{load} = 0$

If we define the system efficiency as $\eta = \frac{P_{load}}{P_s}$, it is expected that the efficiency is at its maximum at full load, while the efficiency will drop at light load. In the extreme case at NZE condition, P_{load} will zero. Without APF, the reactive power Q_{load} from the load will flow back to the grid, which is very undesirable. This phenomenon has been a real concern for utility companies, because they will need to generate reactive current and delivery it to customers while the customers are not buying the power.

In order to promote renewable power generation and ZNE, it is necessary to eliminate the reactive power flow to the grid. The OCC-APF is an effective solution for that.

Figure 1 One line diagram of the APF connection circuit



The circuit diagram of the proposed grid tied APF inverter is shown in Figure 2. An H-bridge inverter is used as the power processing stage. The OCC control core shown in the dashed box controls the H-bridge to perform reactive and harmonic cancellation. The OCC control core is comprised of a clock, an integrator with reset, a comparator, a flip, flop, and a compensator, AV(s), as well as protection circuit. When the home pulls harmonic current as shown in Figure 3 as i_{load}, the OCC-APF will produce and reactive/harmonic current that cancels the one in the load and ensures the current draw from the grid, i_s, is pure sinusoidal and PF~0.99. The OCC method is simple, fast, and precise, yielding a cost effective, reliable, and versatile solution. Due to limited funding available in this phase, we built a 1.5kVA APF inverter to demonstrate the concept with a smart home. It can be used standalone or be placed next to a PV inverter for retrofit.

A printed circuit board layout was developed as shown in Figure 3 to connect the circuit components. Mechanical enclosure and thermal management system were designed and built. The final prototype is shown in Figure 4 for the front and rear view of the prototype. The front panel features circuit breaker, LED light status indicator, and air vent. The rear panel shows current sensor, power connectors, and fan guards.

Figure 2 OCC-APF circuit diagram

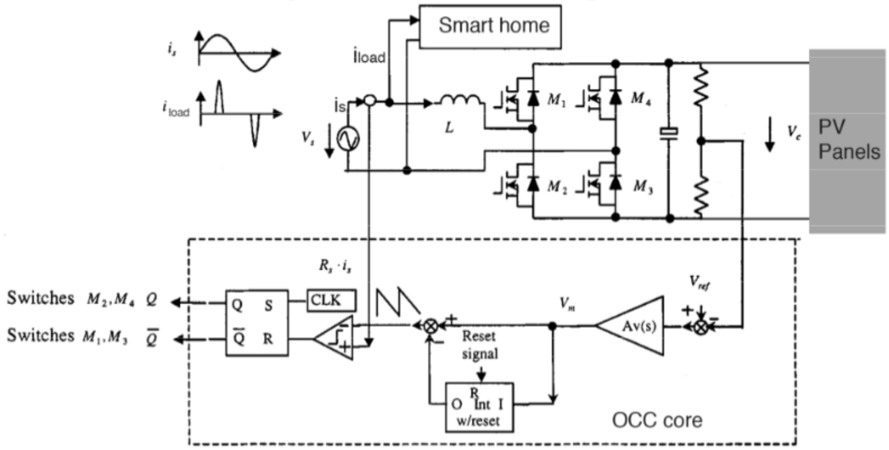


Figure 3 Printed circuit board for OCC-APF

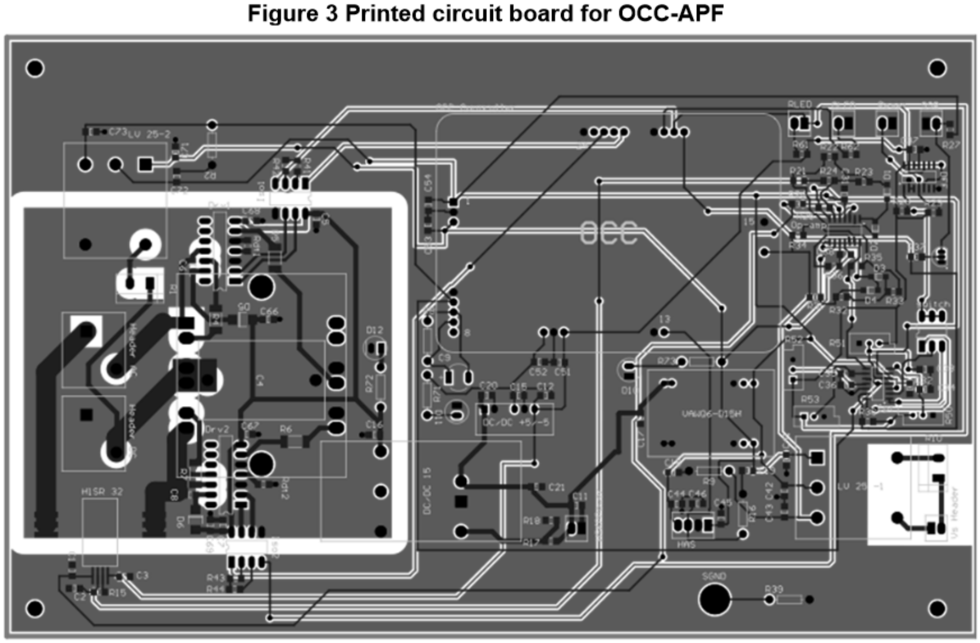
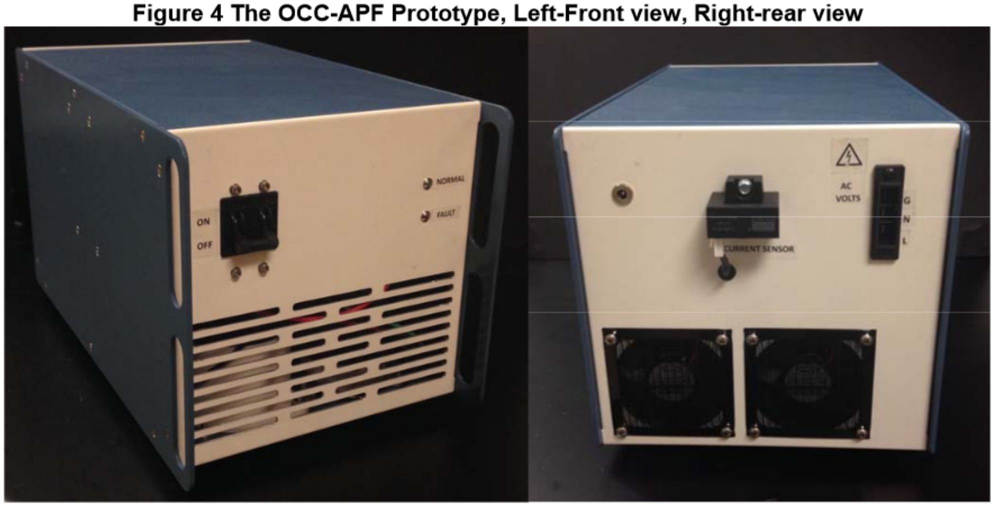


Figure 4 The OCC-APF Prototype, Left-Front view, Right-rear view



The OCC-APF prototype was first debugged and tested at laboratory. It was then delivered to UCD and was tested at a real world environment of test home. It went through a set of planned test procedures including eight scenarios:

- Lights
- Lights & Electronics
- Electronics
- Vehicle Charging
- Kitchen Appliances
- Vacuum & Air Compressor
- Whole House Fan, Water Heater & Vacuum
- Washer & Dryer

Following points were observations from the real world test.

- The APFC consistently adjusts power factor to very near unity, as predicted from our analysis.
- Reactive power is reduced by more than 80%, as predicted.
- The APFC reduces electric current drawn by the load, as predicted.
- Real power consumption increases – by 2-10%, as predicted. When the load is heavy, the real power consumption increases should be about 1-2%, when the load is near zero, the real power consumption increases should be about 100%.
- Current and real power consumption tends to be more stable when the APFC is enabled, as predicted.

The project has provided an excellent opportunity for my students to practice the knowledge they learned from classes and also experience many real world challenges that were not in any textbooks. My students Roozebeh Naderi, Weijian Jin, Yiming Ma, and Shijie Yu have worked closely on the circuit design, mechanical and thermal design, component selection, PCB layout, machine tool operation, circuit assembly, testing, and debugging. Dr. Taotao Jin, expert of

One-Cycle Control, Inc. has provided valuable assistance in the controller design and system debugging and testing.

Our team is ready to undertake the challenge to implement grid-tied inverter/APF combo as smart inverter for field demonstration.

CHAPTER 3:
Load Signature Analysis and Wireless Monitoring System

3.1 Electrical Characteristics Capture

3.1.1 Methodologies

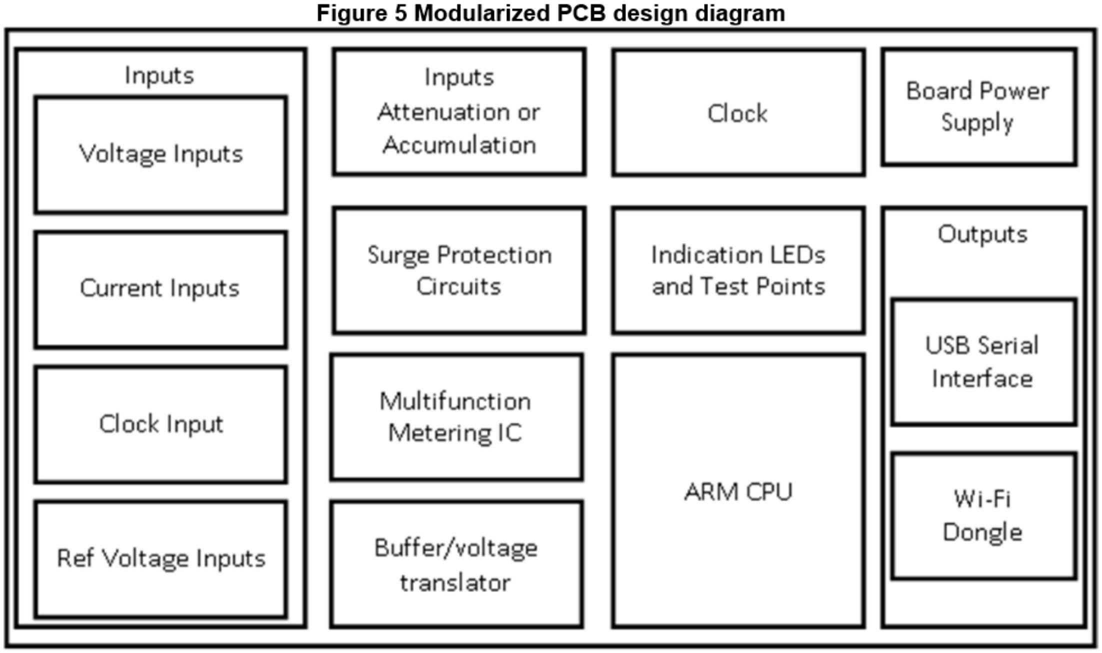
The load signature is captured by a printed circuit board (PCB) then passes the data to the gateway. The circuit design is consisted of two parts: passive sensing and analog to digital (ADC) conversion, and microcontroller level communications.

The board features fast sampling and ADC frequency capabilities given its compacted form factor. In order to obtain an accurate power measurement, voltage is measured periodically to calculate the power consumption overall. To measure the power factor (PF), the apparent, real and reactive currents are recorded for calculation.

3.1.2 Hardware design

The prototype is designed in a compact form factor with capabilities to be fit into the breaker box. For this demonstration purpose, the PCB is enclosed in a hard enclosure and directly plugged into an electric outlet to monitor a section of the house.

Figure 5 Modularized PCB design diagram



Voltage is directly fed to the PCB after attenuation circuits, whereas the current is probed with a coil and an integrator to obtain a current waveform by measuring the current with an inductor. Available methods of measuring current flow are: Rogowski coil and shunt resistor.

The shunt resistor will require a biasing point for system to measure current correctly. The system will require additional amplification either by op-amp or a voltage translator in order for the power meter IC to be able to read the current. By implementing this, it is very likely to be sensitive to noises from supply side, which can potentially be amplified with the actual current.

The current sensor determines the system's sensitivity. In our application, we used both an internal and external sensors. For enclosed current sensor (Rogowski coil part number: PA3202NL), is rated for 200A. This allows the system to measure the entire household including electrical vehicle charging at the same time, but the limitation remains for smaller devices, for example, idle phone chargers. These smaller power adapters usually draw a small amount of energy while plugged in but not used (also known as phantom loads). The current coil is not sensitive enough for picking up signals from such small loads. On the other hand, the system was also implemented for use with current probes. Tests have been conducted with Fluke current probes where the current probes are usually rated for 20A max with external battery power. The accuracy increased dramatically. System is sensitive for small loads down to approximately 1 watt. Therefore, more of smaller devices can be identified with more accurate current measurements. The drawback of the current probe design is such that the system requires multiple probing points in order to monitor the house as a whole. The accuracy comes at a price, where the coil's price is at a few dollars and the current probe can range from a few hundred dollars each.

Figure 6 PCB Schematics

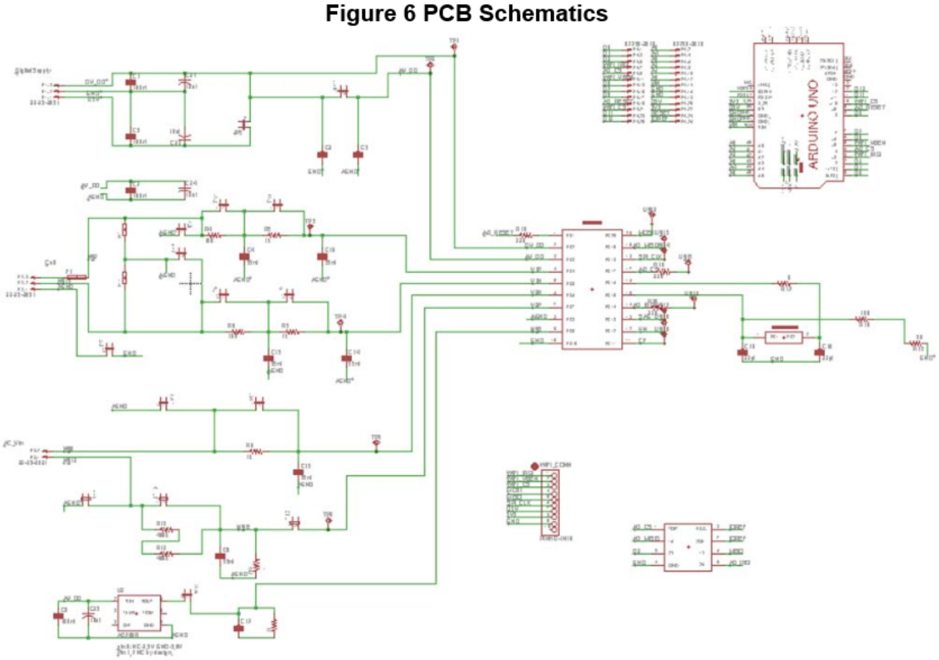
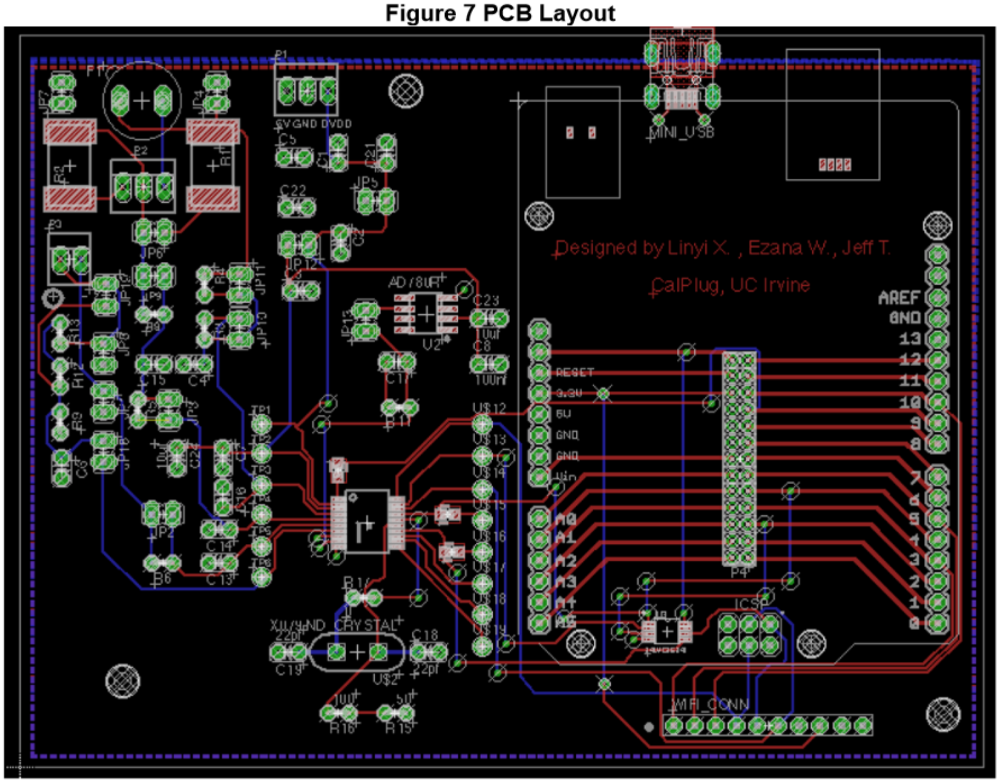


Figure 7 PCB Layout

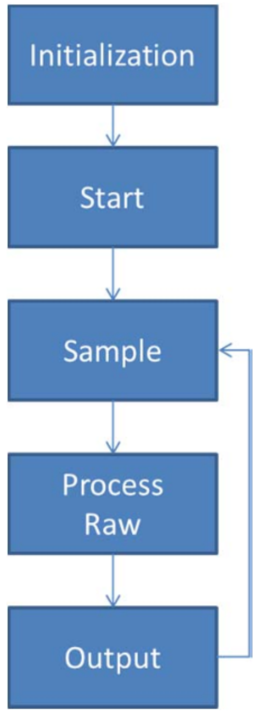


3.1.3 Firmware Design

The firmware is loaded on microcontroller level. The goal of the design is to have a quick response time from the physical device plugged into the grid to the device recognition completes. The system is designed in such a style with five main subroutines: Initialization, start, sample, process raw and output, illustrated as the figure below.

In order to accurately acquire the information needed for load disaggregation, steady–states data are taken in both power and power factor changes. This is the preliminary information needed to reaffirm the accuracy of disaggregation. The harmonic analysis is added on top of the steady state information. The steady-states analysis benefits simpler appliances better, which are more resistive. The harmonic analysis works better to identify non-linear loads. Other researches are also using transient state information to perform load disaggregation, which is the least effective of all three major approaches here. The greatest drawback of transient state analysis is its requirement for high sampling frequency, often beyond 500 kHz to 1 MHz. At the same time, the transient response requires the devices to have similar or almost identical transient responses in each test case. The limitation will be that this method can easily be inapplicable once expended to more devices of the same kind. For example, if a device is monitored under different ambient temperature, the results can also be different and hard to identify. Lastly, transient measurements will require a greater space of storage for device characteristics. In this design, we applied both steady state analysis and harmonic analysis in combination. Therefore, the capture device should be able to measure voltages; power and power factor in a timely manner and perform basic data processing on the firmware level instead of relying on the gateway to process the raw data.

Figure 8 Implemented System Level Firmware Flowchart for ARM Processor on PCB



3.1.3.1 Initialization:

As the system starts up, it will run a self-check for Wi-Fi availability and attempt to connect over Wi-Fi. The system then initializes all variables and registers on the power meter IC, via 8-bit serial peripheral interface (SPI) communications. The system will initially report its IP address once connected to the Wi-Fi successfully. The disaggregation algorithm later uses this information to distinguish different zones of the house. The initialization will only run upon startup and reset button events.

3.1.3.2 Start

The system then starts sampling voltage and set the nominal voltages for the rest of the measurement then changes mode to measure current. The steady state voltage information will be stored as a baseline for power calculations.

3.1.3.3 Sample

The system samples up to 57samples per cycle, given that the grid supplies a 60Hz alternating current. Therefore, the sampling frequency can be adjusted up to 3420Hz. The system samples both real current and apparent current, voltage and reports power factor. Note, the system is capable of sampling at a higher frequency, but the development here aimed for real time ADC and processing. Therefore, the higher sampling frequency will require the system to process at a faster speed, with more rigorous computing resources. We found that 3 to 3.5 KHz sampling frequency is sufficient to disaggregate devices and also process with an energy efficient Linux single board computer, as our gateway.

3.1.3.4 Processes Raw

The sample will be passed to the ARM processor via SPI. SPI ensures the high-speed communication between two embedded devices. The system processes the samples collected from the previous stage. Upon completion of analog digital conversion (ADC), the system then performs frequency domain analysis. The harmonic frequencies are: 60, 180, 300, and 420(Hz). Both phase and amplitude are evaluated.

3.1.3.5 Output

If the Wi-Fi connection was successfully established in the setup stage, the data will be communicated to the gateway via Wi-Fi. The Wi-Fi connection and data path are discusses in the next chapter. If Wi-Fi connection failed and serial cable is detected by the system, the system will send the data via serial communication at BAUD rate of 115200. Then the gateway will send the data to the server upon internet availability. Data can also be stored locally and uploaded at a later time.

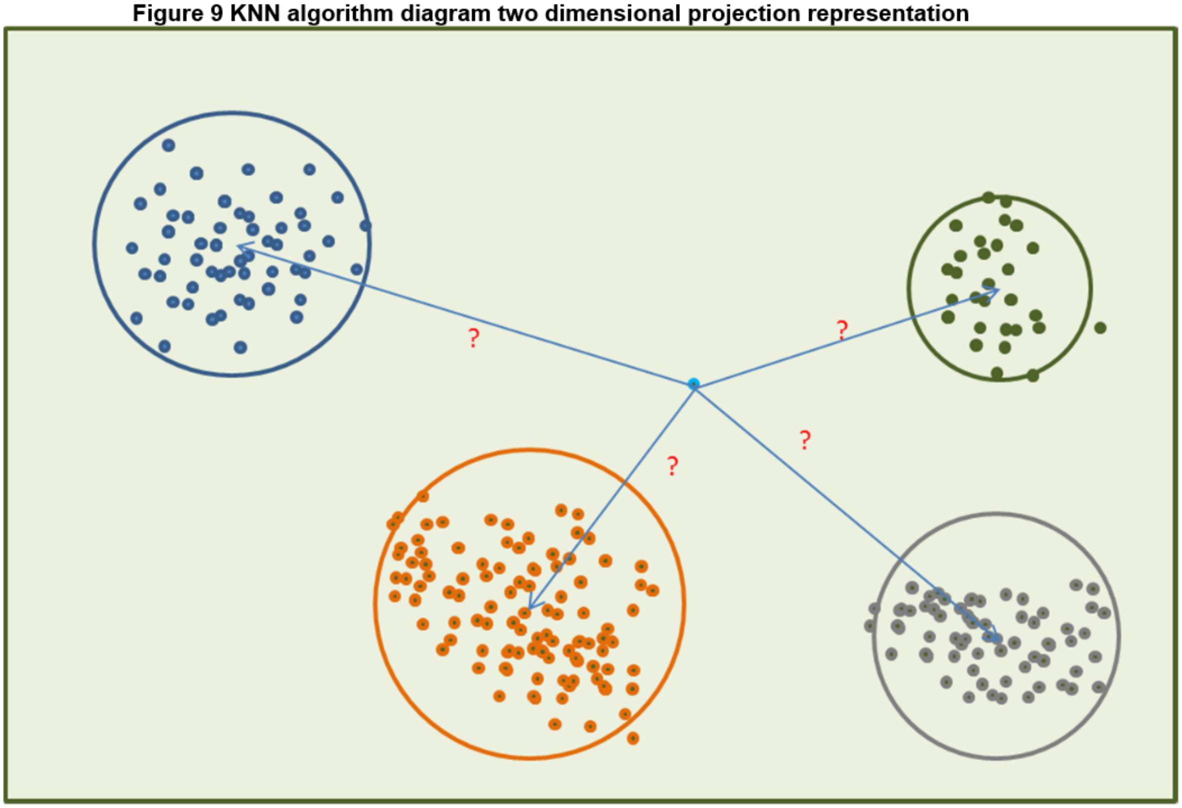
3.2: Disaggregation

Load disaggregation is a machine learning process, which requires a training period to first obtain data and targets. In this application, a supervised learning is chosen for more accurate classification. In order to have accurate and rapid responses, the system expands itself upon new entries into the database. Hereby, K-nearest-neighbor (KNN) method is chosen and modified and combined with a voting process instead of simple perceptron neuron network learning model.

3.2.1 Backward learning

The module will start with backwards learning. It will learn on the previous data if available. Hereby we use modified k-nearest-neighbor algorithm as a baseline algorithm to determine the most suitable device or category. From previously recorded data, the key features are extracted. Once key features are identified, heavier weights are assigned to these features.

Figure 9 KNN algorithm diagram two dimensional projection representation



The figure above demonstrates a basic version of KNN. Different data points are plotted on a 2D plane. Different data entries will form a cluster denoted by the color differences. Therefore, these entries forms a circular with a radius regards to the center of the circle. Upon new entries entering the dataset, distance is measured to all centers of clusters. The distances are ranked from shortest to longest, d_1; d_2... d_n. K denotes the number of nearest neighbor the algorithm is supposed to evaluate. Once K is given, the first K results are taken, from the cluster that provides d_1, to d_k. The likelihood of new entry to be classified into each circle decreases as the distance increases. (Söder 2008)

In real life, the data can never be presented in 2D domain. For this project, each data entry is consisted of 11 features, therefore, to the 11^{th} dimensions. Some features are less valuable comparing to the others. The importance is taken into consideration when calculating the distance between the new entries to their neighbors. Most appliances will appear to have a dominant feature in one of the odd multiples of the base frequency, 60Hz. In this case, the harmonic values in this particular frequency are given a heavier weight in calculating the distance to neighbors.

3.2.2 Forward Prediction

Once training completes, the program runs forward as new data comes in. The program will classify the data into appliances. There is also a committee voting process on the criteria for KNN's consideration. For example, if the harmonic feature in one frequency domain appears to be dominant, this feature is assigned with a heavier weight when computing distance. The more dominant the feature is the heavier weight it becomes. Once the top features are identified, the distance between each entry is measure to the center of the clusters. The total weight is then ranked to find the closest clusters, which will be the identifier of the classification.

Once the system is trained, steady state data will be better to identify devices that have definitive power states or frequent usage patterns, such as light bulbs. This detects the sudden incremental or decline in power, in both active and reactive. KNN will identify the closest cluster to the device with its characteristics. Since power can be simply added together to verify the accuracy of the prediction, this can easily identify appliances with significant energy consumptions.

On the other hand, the non-linear loads are more difficult to identify. With the harmonic features, the data collection dataset size and time are both reduced. This allows the system to capture and perform raw process at the same time.

During forward prediction classification process, the K-fold cross-validation committee voting ensemble learning adds weight to different dimensions. The feature with greater correlation will be placed with a heavier weight comparing to the other ones. For example, table lamps will have a greater magnitude in 60Hz harmonic value whereas TV will also have a relatively significant harmonic value in 180Hz along with 60Hz harmonic values. Therefore, the 180Hz harmonic value is more meaningful comparing to 300Hz and 420Hz values. The weight of each committee member is pre-defined in the backward training stage, but only referenced by k-fold cross validation.

3.3: Communications

In order to achieve real time monitoring, devices have to be identified dynamically followed by display on the mobile interface dynamically as well. Hereby we define the communicational protocols between devices in this system.

3.3.1 PCB to Gateway Communication Protocol

The PCB is synced with the gateway every 2 seconds. Each message contains the power consumption in total, power factor, odd multiples of 60Hz harmonic features' magnitudes in digital counts and phase values in degrees. The KNN based algorithm later performs classification to processes these values.

Figure 10 Data package definition between PCB and Gateway

Power	Power Factor	Odd Harmonic Magnitudes	Odd Harmonic Phase

3.3.2 Gateway to Server Communication Protocol

From the gateway, this data package is sent out upon availability. The server is capable to handle data insertions significantly faster than the physical devices sensing and classification speed. The time stamp is referencing the time the gateway received the input from the PCB, instead of the time of the server receiving the input from the gateway. By doing this, the timestamp will not need further correction upon internet unavailability. Whenever the internet becomes available, the data will be sent over the internet and inserted to the database.

Figure 11 Gateway to Server Communication data package definition

Power	Power Factor	Device ID	Time Stamp

3.4: User Interface and Usage Modes

The interface provides the users with a simplified and unified overview of different areas of the house regarding its energy consumptions and power status. Data is stored on the server end for later analysis to understand the bigger picture for future usages. Once the time domain data is acquired, the system can also expand to evaluate time domain events as a signature in addition to devices' electric characteristics. This will even help to identify some devices which are normally hard to tell. At the same time, this will help to establish a baseline consumption model for the household. In the long run, this data can also be taken into consideration to set the stage for more accurate disaggregation.

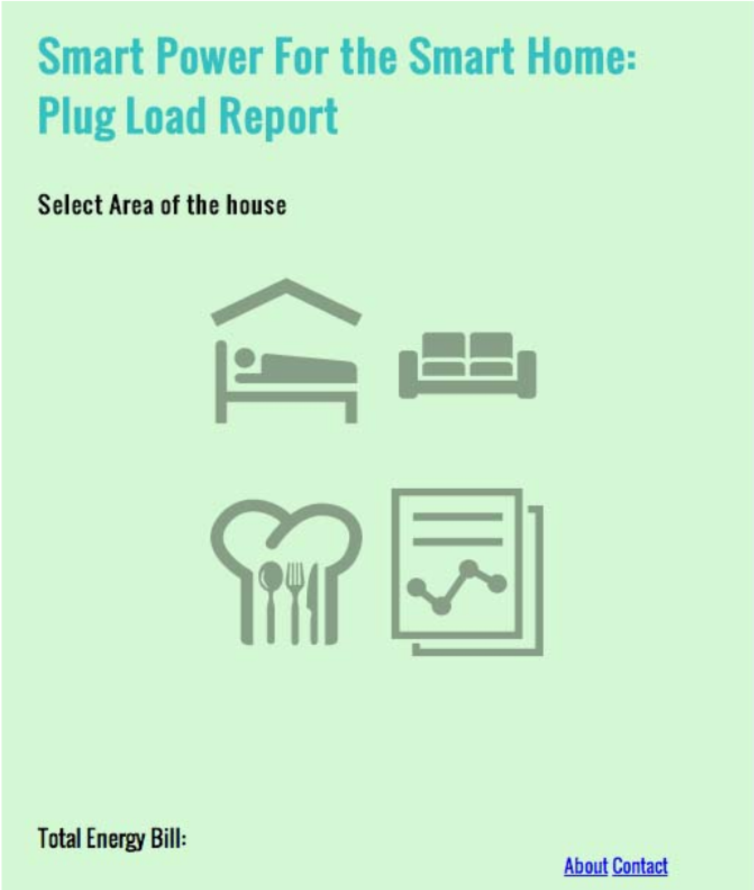
The user interface is designed with the elegance to provide a relaxing sensation to viewers where the general public may find data to be overwhelming and lose their interest in the monitoring system. Also, since data is hosted on a server, it allows future implementations to integrate an alert feature, where users can receive notification from abnormal energy related activities such as fire or outage.

3.4.1 Normal Operational mode

In normal operational mode, the system operates under forward prediction part of the algorithm. The system will continuously identify devices upon new events recognized on the board level. The events and data are displayed under each sub-area of the house. In this demonstration, the data is categorized into bedroom, living room and kitchen. The last icon is for entering the training mode. Users can simply click on a subsection of the house and view device connectivity status and power consumption. The user interface is expandable. The server stores much more information but only displays a small portion for simplicity. It might not be appropriate to display the full set of data for an average user but it has the back end capability to display more than just power consumption and device recognition results.

Another advantage of this design is: that it will feed back to assisting with load disaggregation. If multiple monitoring devices are at present in a household, the can disaggregate plug loads with a higher precision once they are assigned to an area. For example, most households will not have a TV in the kitchen, where living room is a more common place to appear. Or an electric stove will be very unlikely to appear in a bedroom setting. This will help the load disaggregation system to eliminate many possibilities, which may or may not contain a similar load signature.

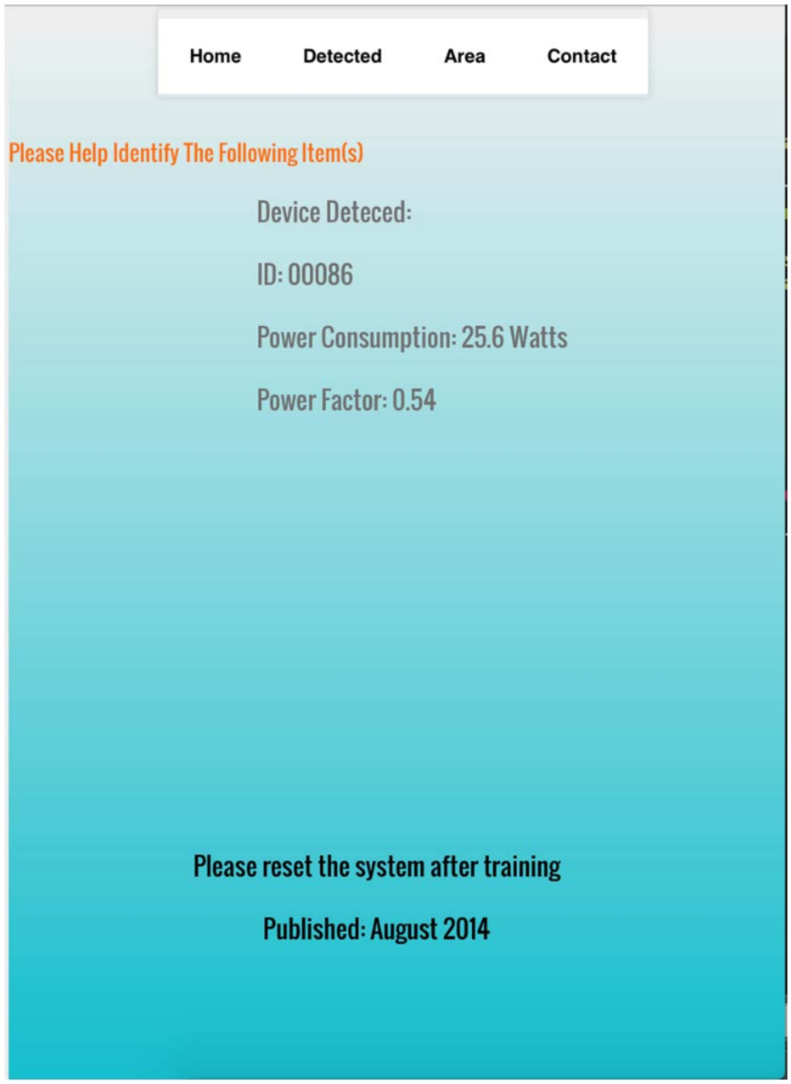
Figure 12 User Interface for Load Monitoring System (Home)



3.4.2 Training mode

When setting up the device, users can select the lower right corner icon to enter training mode shown in figure 7. In training mode, the system will start to detect the devices plugged in. One at a time, the system will record its electrical characteristics, even not displaying every single characteristic used for identification, but to just display the power consumption. Users can use this to roughly estimate whether the capture is accurate or not. Then the user should select one subarea of the house and add the device into that subsection of the house. Once the training is completed, the user can simply press the reset button on the PCB and return to "home" on this interface to normal operational mode, as figure 6 above.

Figure 13 Training Mode User Interface

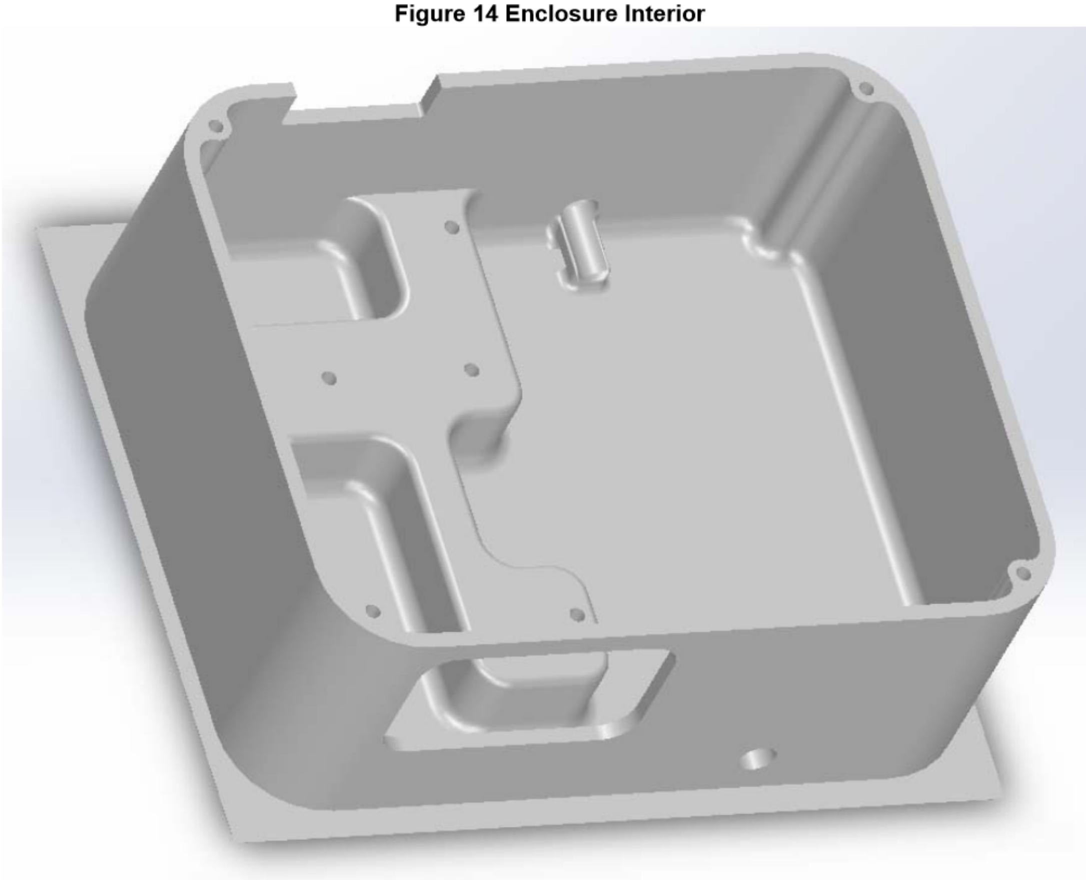


3.5: Industrial Design

In order for conduct in house testing, the PCB requires a few steps to package it to be a more consumer ready product. For both safety and usability, we have designed an enclosure for our electronic devices. The enclosure is designed such that:

- Protects the circuitries enclosed.
- Allows max airflow to keep board at a nominal working temperature without additional fans or heat sinks.
- The cables are placed on wire-guiding slots, which prevent the cables from falling out easily when the device is pulled by the cable.

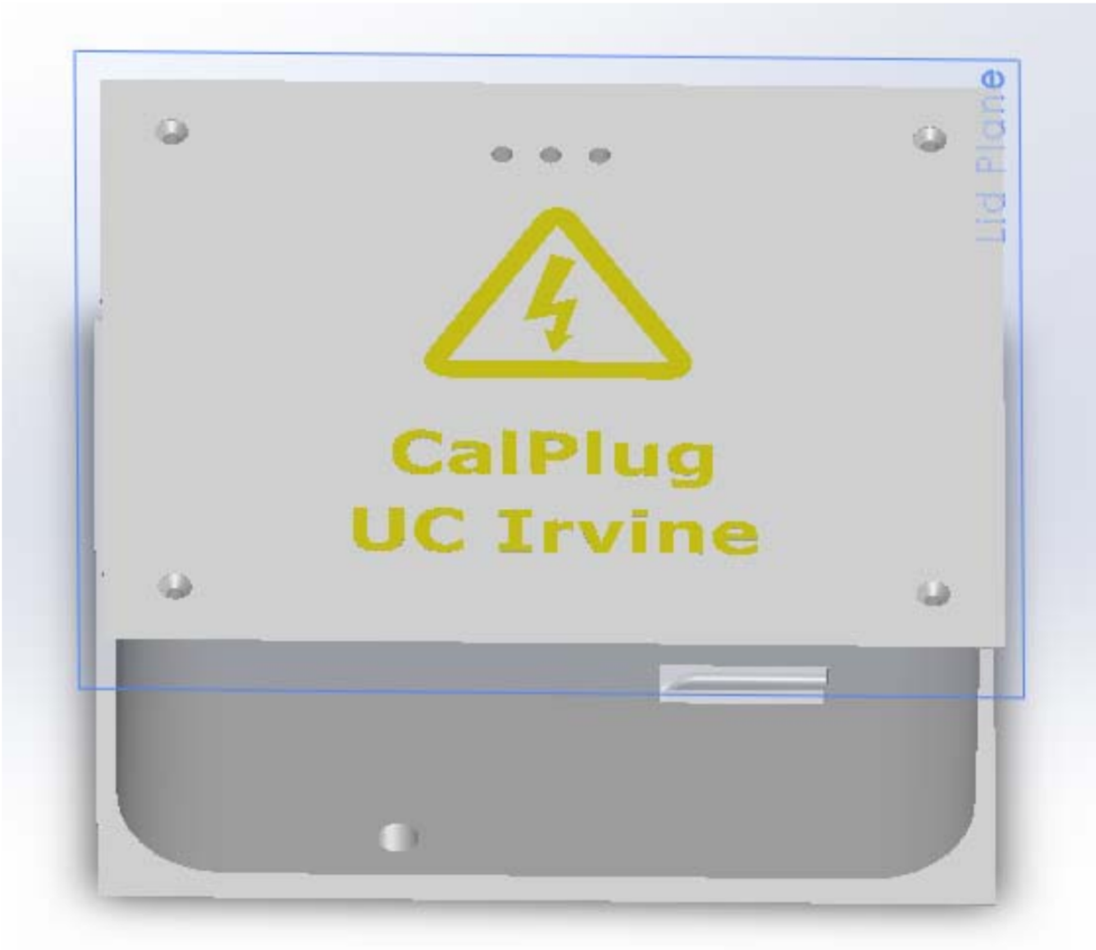
Figure 14 Enclosure Interior



The device is designed in two pieces with the convenience of 3D printing. This eliminates the errors of alignment so that only one part of the box has to be reprinted. The top of the box has three holes for placement of the LED status lights. Once the box is closed, it would be hard to know the states of operation. Since the box will be left at a residential unit, it requires extra caution from the user once out of the lab controlled environment. The larger cutout is for the access to multiple USB cables to both supply power and data communication. The smaller cutout is designed for the USB dongle to extend out of the box. Since the dongle has an onboard chip antenna, this would allow maximum signal strength.

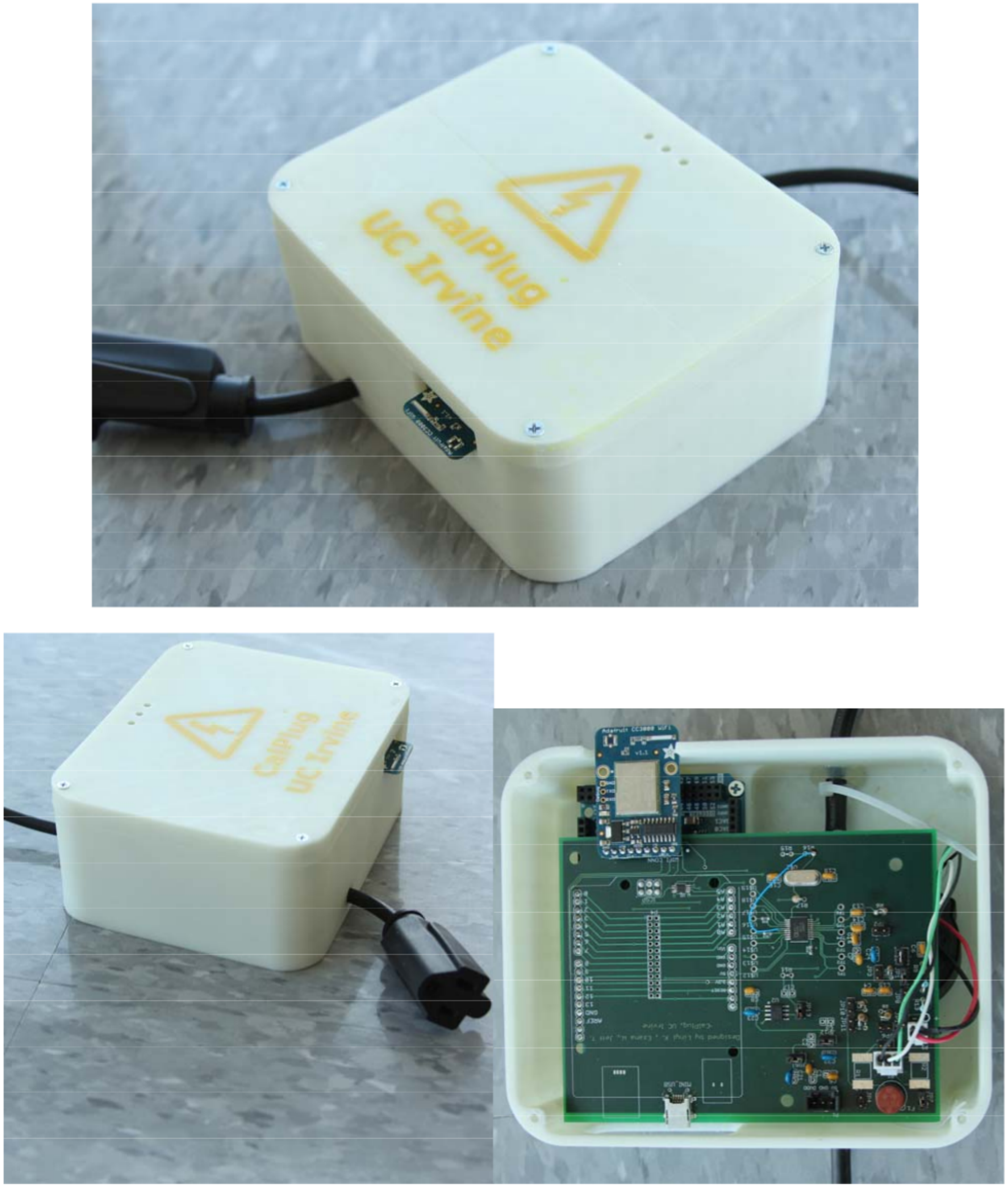
The board is designed with latched cables to allow users to switch out coil to have a current probe installed for more accurate measurements. The user will have to simply unplug the current cable and plugin the current probe. A battery powered current probe is preferable.

Figure 15 Enclosure with lid on



The pictures below show the finished product. The material glows in the dark so that once the users switch off the light, this will remain lit for a short period to ensure safety and visibility for both humans and pets. The Wi-Fi dongle operates on a 3.3V or 5V supply, which is 100% save for both humans and pets to make skin contacts, which is not recommended but is not life threatening if contacted by accident.

Figure 16 Finished Product pictures



The actual printed enclosure is highly durable and elegantly printed. The parts are secured and lose connections are highly eliminated. The housing for cables and coil help keep coil and wire in a fixed position so that the current flow sensitivity will not change due to the angle between the cross section of the coil and the hot wire. This will further help to improve the algorithm effectiveness by providing reliable sensing data at all times.

GLOSSARY

Term	Definition
PCB	Printed circuit board.
KNN	K-nearest neighbor. Classification (generalization) using an instance-based classifier can be a simple matter of locating the nearest neighbor in instance space and labeling the unknown instance with the same class label as that of the located (known) neighbor. This approach is often referred to as a nearest neighbor classifier. The downside of this simple approach is the lack of robustness that characterizes the resulting classifiers. The high degree of local sensitivity makes nearest neighbor classifiers highly susceptible to noise in the training data.
SPI	Serial peripheral interface is a synchronous serial data protocol used by microcontrollers for communicating with one or more peripheral devices quickly over short distances.
APF	Active power filter.
OCC	One Cycle Control
GTI	Grid tied inverter
ZNE	Zero net energy
APFC	Active power factor correction
IC	Integrated circuit
BAUD	Data transfer rate in bits per second

Works Cited

Söder, Ola. *kNN classifiers 1. What is a kNN classifier?* May 29, 2008. http://www.fon.hum.uva.nl/praat/manual/kNN_classifiers_1__What_is_a_kNN_classifier_.html (accessed Jan 20, 2015).

Smedley, G. *A Three-Phase Grid-Tied Inverter That Suppresses Harmonics and Reactives.* PIER EISG grant.

Smedley, Keyue, and S. Cuk. "One-cycle control of switching converter." *Proc. Power Electronics Specialists Conf.* 1991. 888-96.

Smedley, Keyue, L. Zhou, and C. Qiao. "Unified constant-frequency integration control of single phase active power filter." *IEEE Trans. Power Electron* 16 (May 2001): 428-36.