Team PICA Project Proposal and Feasibility Study

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1 Project Introduction

1.1 Overview of the Problem

Standard electric meters were developed decades ago and are still used today, despite many technological advances in the last several years. Along with these technological advances, Americans have become accustomed to having access to large amounts of data, but due to the nature of the standard electric meter, data regarding the usage of power is severely limited. For the power companies, data from the meters is minimal and grid control is limited to manual operation, costing them time and money.

As the cost of electricity becomes higher and higher, electricity use in buildings is becoming a bigger concern and people have few [illegible] or simple ways to monitor this. Of the options available, most only address part of the whole problem, giving some information to the consumer and none to the power company or vice-versa. While there are devices such as breakers and fuses that provide electrical safety for buildings, advances in technology have made it possible to further improve safety but have not been implemented in a cost-effective way or made easily available.

1.2 Why the Project was Chosen

Our team chose the project for several reasons; as future homeowners, the team has an interest in knowing more about power usage within a home. There are also many more people who would benefit from more accurate and useful data about power usage.

As good stewards of Earth we want to make sure the natural resources available are not wasted, and we believe that if there is access to more and better information, people will have a better opportunity to manage those resources more effectively. In addition, providing better information and control to the power companies can lead to less wasting of electricity on the provider's end, further contributing towards better use of Earth's resources.

Electrical related deaths and injuries have been reduced due to devices such as fuses and breakers, but many still happen every year. As fellow human beings, we care and would like to minimize these incidents further. The technology is available and will benefit many people when implemented.

1.3 Team Information

Team 01: Team PICA consists of four electrical engineers: Amy Ball, Nathan Jen, Avery Sterk, and Kendrick Wiersma.

Amy works as an intern at Johnson Controls, where she is part of the Systems Engineering Team. She brings good communication skills, circuit-building experience, and presentation skills to the project. Her section of the project is the solid-state breakers, especially working closely with much of the hardware involved with the project.

Nathan has worked at Amway on the production floor and has gained involvement with club leadership at Calvin College. He brings leadership experience and a good understanding of how smaller elements of a system fit together as a whole. His section of the project is the monitoring of individual circuits and some of the control logic for the breakers.

Avery worked as an intern at the SLAC National Accelerator Laboratory doing CAD design. He brings lots of experience with software to the project. His section of the project is the base station, especially providing the primary user interface and designing a lot of software.

Kendrick works as an intern at Raytheon, where he performs embedded system design and verification. He brings real-world project experience and good experience working with both software and hardware to the team. His section of the project is the E-meter, which measures whole-building power consumption and reporting to the power company.

2 Requirements

2.1 Base Station Requirements

All requirements are to be assumed to be of the base station ("the system") unless explicitly stated otherwise.

2.1.1 Functional Requirements

1. Shall be capable of upgrading its software and firmware upon administrator demand.
2. Shall be capable of connecting with other PICA sub-systems.
3. Shall receive and store power usage measurements from connected PICA systems.
4. Shall function as a Network Time Protocol (NTP)server for connected PICA systems.
5. Shall receive and record event log information from connected PICA systems.
6. Shall be capable of connecting to a Local Area Network (LAN).
7. Shall be configurable by the user.
8. Shall be capable of displaying status information for connected PICA systems.
9. Shall be capable of authenticating administrative access to connected PICA systems.
10. Shall be capable of distributing system updates for connected PICA systems.
11. Shall be capable of giving debugging and troubleshooting output.
12. Shall be capable of actively notifying the power-company and consumer.

2.1.2 Behavioral Requirements

1. Shall store user-defined configuration in non-volatile media.
2. Shall include a backup firmware in the event of a failed firmware upgrade.
3. Shall store critical event logs from connected PICA systems in a non-volatile media.
4. Shall host a webpage to display system information when browsed over LAN

5. Shall store its software in non-volatile media.

6. Shall run an operating system to manage hardware, device drivers, and connections to connected PICA systems.

7. Shall use ZigBee to communicate with connected PICA systems.

2.1.3 Software Requirements

1. Shall include and run an upgradable operating system (OS).
   (a) The OS shall include the drivers necessary to operate the system hardware.
   (b) The OS shall include the protocols necessary to connect to PICA sub-systems.
   (c) The OS shall be able to detect and identify connected PICA systems
2. The OS shall maintain a list or database of PICA systems which the user has allowed.
3. The OS shall control its connectivity hardware to prevent unwanted systems, such as those owned by other customers, from being connected to the system.
4. The OS shall have an administrator-privileged user who may change the configuration of the system and of connected PICA systems.
5. The OS shall give administrator privileges to the power-company and customer as specified by the system application.
6. The OS shall include the protocols necessary to connect to the LAN.
   (a) The OS shall include a DHCP client.
   (b) The OS shall support both IPv4 and IPv6.
7. Shall include and run a web server to provide the web interface.
8. Shall include the necessary tools to download and apply software and firmware updates.

2.1.4 Hardware Requirements

1. Shall include an external power source.

2. Shall be tolerant of fluctuations in input voltage.
3. Shall have a central processor to execute software.
4. Shall have adequate random-access memory (RAM) to execute software.
5. Shall have an Ethernet controller for connecting over LAN.
6. Shall have an RS-232 controller for debugging and troubleshooting the system.
7. Shall have ZigBee connectivity hardware for communication with connected PICA systems.
8. Shall have non-volatile storage dedicated to storing system firmware.
9. Shall have non-volatile storage sufficient to store system software.
10. Shall have non-volatile storage sufficient to store recorded events and short-term consumption history for up to a period of 3 years.

2.1.5 User Interface Requirements

1. Shall provide a web interface for viewing collected data over LAN.
2. Shall provide a web interface for system administration to an authenticated administrator.
   (a) Shall include an interface for managing connections to connected PICA systems.
   (b) Shall include an interface for administration of connected PICA systems.
      i. Shall include interfaces for managing configurations of connected PICA systems.
      ii. Shall include an interface for deploying software/firmware upgrades to connected PICA systems.
3. Shall provide a debugging interface over an RS-232 serial connection.

2.1.6 Power Requirements

1. Shall be powered from a standard 120V wall outlet.
2. Shall have a DC power supply to power internal components.
3. Shall have a backup power supply.

4. Shall require less than 10W to operate.

2.1.7 Codes and Compliances

1. Shall be UL certifiable, including all power supply hardware.
2. Shall have a polarized electrical plug if the power supply is controlled with a switch.
3. Shall restrict electromagnetic (EM) radiation to comply with FCC Title 47 Part 15.

2.2 Solid State Breakers and Monitoring Requirements

All requirements are to be assumed to be of the solid state breakers ("the system") unless explicitly stated otherwise.

2.2.1 Functional Requirements

1. Shall be capable of completely interrupting power delivery on the connected circuit.
2. Shall provide two-way communications to the Master Control Unit (MCU).
3. Shall be capable of detecting brownout conditions.
4. Shall temporarily store gathered information for transmission.
5. Shall package the stored information for transmission over an ethernet link to MCU.
6. Shall be capable of turning off circuits individually.
7. Shall interrupt service to a circuit when current flow exceeds a specified threshold.

2.2.2 Behavioral Requirements

1. Shall be powered by line-voltage.
2. Shall initialize all components when brought out of standby.
3. Shall report all events to the critical event log.
4. Shall monitor voltage levels in the connected circuit.

5. Shall monitor current flow in the connected circuit.
6. Shall monitor the number of kilowatt-hours used.
7. Shall monitor the status of the power supply.

2.2.3 Hardware Requirements

1. Shall use non-volatile storage to store data when the system is without power.
2. Shall have a microcontroller for managing internal and external data and functions.
3. Shall have a control panel external to the breaker box.
4. Shall provide clocks for all synchronous components.

2.2.4 User Interface Requirements

1. Shall have a self-explanatory external interface.
2. Shall have the ability to lockout the control panel.

2.2.5 Power Requirements

1. Shall not restrict the flow of power to a circuit, except when a fault is detected.
2. Shall be powered from before the breakers.

2.2.6 Mechanical Requirements

1. Shall fit into a standard, unmodified electric panel.

2.2.7 Safety Requirements

1. Shall provide circuit interrupter protection.
2. Shall have safety hazards clearly marked and visible from outside the system.
3. Shall safely isolate high-voltage areas.

2.2.8 Codes and Compliances

1. Shall be compliant with ANSI C12.19.
2. Shall be compliant with ANSI C12.21
3. Shall be compliant with FCC Title 47 Part 15.

2.3 Electric Panel Meter Requirements

All requirements are to be assumed to be of the electric panel meter (“the system”) unless explicitly stated otherwise.

2.3.1 Functional Requirements

1. Shall continuously monitor the power used from either a single-phase or a multi-phase installation.
2. Shall store power usage data locally, to be transmitted back to the base station at regular intervals.
3. Shall display power usage data on an LCD display module integrated into the electric panel.
4. Shall provide two-way communication with the Master Control Unit (MCU) to report usage data.
5. Shall be capable of establishing a wireless link with a PICA base station.
6. Shall be capable of detecting a brownout condition and storing critical data before shutting down.
7. Shall be capable of restoring its last state after a brownout condition.
8. Shall be capable of detecting any tampering and alerting both the power-company and the consumer.
9. Shall monitor current flow through the main service lines.
10. Shall monitor voltage levels on the main service lines.
11. Shall control the service shutoff switch by receiving and validating a service shutoff message from the power-company.
12. Shall provide a method for controlling the service shutoff switch from a local interface.
13. Shall provide an interface for 3rd party meters, such as gas, water, or other utility meters to report data over the PICA network.

14. Shall support on-demand reports of power usage, energy consumption, demand, power quality and system status.
15. Shall support bi-directional metering and calculation of net power usage.
16. Shall support automatic meter reads.
17. Shall monitor the voltage flicker.
18. Shall monitor the reactive power.

2.3.2 Behavioral Requirements

1. Shall, in the event of wireless link loss; attempt to re-establish the wireless link.
2. Shall, in the event of a wireless link loss, revert to stand-alone mode, storing data internally until internal storage is full, at which point the system will begin overwriting the oldest data with the newest data.
3. Shall, in the event of a wireless link loss, notify the user via the LCD display.
4. Shall perform a built-in self-test upon system boot up.
5. Shall, in the event of a brownout, save all volatile information to non-volatile storage space.
6. Shall be capable of detecting corrupted data when brought out of a brownout condition.
7. Shall log all events processed in the following 4 categories: critical, error, warning, and note.
8. Shall report all events to the PICA base station.
9. Shall report to the power-company as specified by event criticality.
10. Shall have dedicated non-volatile storage for all critical settings and configuration data.
11. Shall compute the total power used in kilowatt-hours.
12. Shall be capable of receiving messages from the power-company, providing the user with the current cost of a kilowatt-hour.
13. Shall use 128-bit AES encryption for all messages transmitted outside of the device.
14. Shall report the total amount of outage time.

15. Shall date-stamp all detected outages with the date and time of the outage.

2.3.3 Software Requirements

1. Shall have enough onboard EEPROM for boot.
2. Shall verify system firmware on boot up.
3. Shall periodically perform a system check to verify the health and status of the system.
4. Shall perform an on-demand system health and status check as demanded by the PICA base station or the power-company.
5. Shall contain sufficient non-volatile storage for all system configuration settings.
6. Shall be updateable through the power-company wireless interface.
7. Shall be capable of properly recovering from a failed software update.
8. Shall give authorized access to components of the system configuration as appropriate to the power-company and consumer.
9. Shall notify the power-company and the PICA base station once service has been restored containing the time of restoration and a voltage measurement.
10. Shall have a unique IPv6 address for the power-company mesh network.
11. Shall have a unique IPv4 or IPv6 network address for the local home-area-network.
12. Shall receive an NTP message from the PICA base station to set the hardware clock.
13. Shall synchronize the hardware clock with the base station time once per day.
14. Shall support on-demand hardware clock synchronization.

2.3.4 Hardware Requirements

1. Shall be completely enclosed in a weatherproof case, tolerant of extreme temperature differences.
2. Shall be completely AC coupled against transient AC voltages.
3. Shall be mounted in the same location as a standard power meter.

4. Shall provide non-volatile storage.
5. Shall be grounded.
6. Shall provide a hardware system clock, set by the software and synchronized with the PICA base station.

2.3.5 User Interface Requirements

1. Shall have a 160-segment LCD display module, viewable from outside the electric panel.
2. Shall be capable of interfacing with a web-based application for stand-alone configuration.
3. Shall provide push-buttons for viewing contents of the display module.

2.3.6 Power Requirements

1. Shall be capable of operating from line-voltage.
2. Shall be powered from before the master breaker, preventing the meter from losing power when the master breaker is switched off.

2.3.7 Safety Requirements

1. Shall meet or exceed safety requirements for devices inside an electric panel.
2. Shall be AC coupled against incoming line-voltage and current.
3. Shall be grounded.
4. Shall be sealed against the elements.
5. Shall safely isolate high-voltage areas.

2.3.8 Codes and Compliances

1. Shall be compliant with ANSI C12.19.
2. Shall be compliant with ANSI C12.21.

3. Shall be compliant with FCC Title 47 Part 15.

3 Design Goals

3.1 Provide a physical system that accurately monitors power usage by graduation

The design team is designing a home power monitoring system, and they would like the system to be working accurately by graduation. Graduation is in May of 2011, which means that the team has eight months to achieve this goal and create a working system that monitors the power usage of a home or business accurately.

3.2 Provide manuals for maintenance and user purposes

Some consumers do not have extensive knowledge of electrical systems or components. The design team would like to provide manuals to assist users for general purposes. Many systems and technologies today come equipped with instructions for setup, or a user manual for different controls. Sometimes the user manual will also show how the system actually works. The design team will look to create a manual that will include a brief overview of how the system works, ways to upgrade certain aspects, how to use the system once it is installed and setup, as well as any other pertinent information.

3.3 Seek out and collect prospective customer feedback for the proposed system

The design team will need to know if potential customers really want to receive this information, as well as how much they would be willing to pay for it. One of the first steps to a business plan is to see if there is a market need for the product or idea. The design team is also working with a business team who will assist them in identifying the market need and seeking out potential customers to get their feedback. This feedback from potential customers will also tell the design team how the customer would like to receive the information. The design team will also welcome any other potential feedback that could allow for a better system.

3.4 Accurately and safely, monitor and report real-time power usage information as relevant to a consumer and utility company

The information delivered to the consumer will need to be accurate, otherwise the system is useless and customers will not purchase it. The design team would also like to monitor this information in a way that is safe for the consumer. Reporting the information will be a key aspect of the system, because the consumer will be able to receive up-to-date information at an instance, which is better that once a month as is the normal billing cycle. The system will also be monitoring information that could be relevant to the utility company interest. The goal of the design team is to provide information both sets of pertinent to the utility company and the consumer, because the consumer and the utility company will generally desire different information.

3.5 Present power usage information in a way that is as understandable to an average consumer

The average consumer does not have an engineering background. The goal of the design team is to present the information in a very easy way for the consumer to see. To achieve this goal, the design team would like to display the power usage information in dollar amounts, which is what millions of potential customers really want to know. The information will also be able to display this information on an hour-by-hour, day-by-day, or week-by-week basis.

3.6 Test all necessary components for functionality, accuracy and durability

Good stewardship engineering work involves testing components for functionality, accuracy, and durability. The design team wants the customers to get what they pay for and testing all necessary components will allow the design team to stand behind their product with confidence.

3.7 Minimize on-site maintenance as much as possible

If consumers constantly have to call for on-site maintenance, their confidence in the product will decrease very rapidly. This will be very bad word of mouth advertising, which is what the design team does not want. On-site maintenance will be will also be costly for each party, both the company doing the on-site maintenance as well as the consumer. Some on-site maintenance may b

4 Major Design Decisions

The design team selected two categories or concerns by which to evaluate large design decisions. The first of these is that the project produces a unique product that is differentiable from any commercial product. The second concern is that the project must produce a product that has justified features, not merely innovative ones. This chapter gives a brief summary of these two criteria and a sample of design decisions in which they played a role in reaching the final decision.

The first of the two criteria requires that the result of any decision must help identify the final product as unique. Several commercial companies produce smart meters and have much greater market influence than a simple one-year project can assert. Therefore, in order to ensure market viability of the project's final product, the product must have unique and distinguishing characteristics, rather than trying to compete in price. This uniqueness should allow the project to succeed commercially. Accordingly, the final product of the project must include features that clearly distinguish it from the existing smart metering options.

No matter how unique or novel a product is, it must still justify itself and prove that it provides benefit to the consumer, to the power company, or even to both. There is a plethora of aspects to consider in defining benefits, but the design team selected six to target in particular. Namely, the design team chose to focus on the safety, benefit to grid operation, dependability, acceptability of physical size, ease of use, and acceptability of financial cost of the project's final product. While many extra features provide novelty or additional value, the time and budget constraints on the project limit the number and type of features that can be included. As such, a careful and guided selection of features is necessary to arriving at a final product. To assist in making these decisions, the design team created a decision matrix using the criteria listed above to evaluate a set of features that had been suggested for the project. [REFERENCE IT HERE AND INCLUDE IT AS A TABLE] Of the evaluated features, three clearly emerged as essential to the product: the ability to measure total power consumption, the ability for the monitored systems to still use electrical power, and the ability for the breakers to trip on user demand. As nearly every electrical system with a meter and breaker panel already has these features, the threshold of inclusion needed adjusting. By expanding the range of acceptable matrix scores, several more features joined the group of selected and justified test: throttling power availability, tamper detection, power quality monitoring, calculating the current system load, multiphase monitoring (where applicable), and circuit-by-circuit power usage measurements.

The decision to include circuit-by-circuit monitoring and solid-state circuit breakers also received support from the first criterion. From the sum of the team's research, and by additional affirmation from Consumer's Energy, circuit-by-circuit power monitoring would enter an empty market niche. In other words, a product that provides circuit-by-circuit monitoring would face no competition from other companies, as no other device would have that feature. This realization affirmed the attractiveness of the circuit-by-circuit monitoring as determined by the second criterion.

[INSERT BREAKER CLUSTER DIAGRAM HERE]

The relationship between the circuit-by-circuit measurements and the circuit breakers has evolved through several design decisions. In the original concept, a separate processor would examine each circuit's current measurements and compare the reading to a pre-determined value. If the measurement exceeded that value, the controller would signal the interruption circuitry to stop the flow of power. However, this requirement did not specify the exact method by which to interrupt the circuits, nor how this be functionally distinguished from a standard circuit breaker. After a formal discussion of the topic, the design team decided to enhance a standard breaker by adding sensors between the breaker and the circuit it controls. In this fashion, the design team could rely on standard and proven technology to perform the circuit interrupting while enhancing it with the sensors and electronics needed to collect information and establish a unique functionality. This idea stood for some time before the design team considered how such an approach would affect the total size required for each circuit. The team resolved instead to replace the standard breakers entirely and incorporate both power monitoring and solid-state circuit interrupting in the same form factor as the older parts. Using solid-state breakers eliminates the possibility of electric arcing, which allows current to flow even when the circuit breaker is tripped. In addition, eliminating moving parts should greatly reduce the delay between the time of the current overage and the electrical disconnect that the overage warrants.

Furthermore, the design team envisions these solid-state breakers to act and ship in groups, rather than individually. The team reached this conclusion after considering the technical requirements of the components within the breakers and the amount of circuitry involved in handling each breaker individually. The circuit-monitoring components of the solid-state breaker system will require configuration data at power-up, so combining monitors together for joint initialization, data collection, and management by one controller decreases the material cost and complexity. Additionally, as installation of any of these breakers will likely replace most or all of the traditional breakers in a breaker panel at the same time, bundling the circuit breakers and monitors into groups should convenience the installation personnel.

One feature with ethical implications involved whether or not the main electrical meter should have the ability to disconnect the electricity to the building by receiving a remote command from the power company. From the power company's perspective, such a feature saves the cost of labor to disconnect the building from the power lines manually. This doubles as a safety feature: electrical workers will not endanger themselves by working with residential voltage as often, and they will avoid confrontation with aggravated customers who have not paid their bills. The customer, on the other hand, might worry that a system error can occur and cause a complete loss of power because of this feature, even if it slightly decreases the overhead costs that the power companies pass on to their paying customers. The design team decided that the remote shutoff and re-connection feature provides a sufficient benefit to all parties involved to outweigh the risk of a system malfunction removing the power from a building. In addition, other smart meters already include this feature, so excluding it would put the project at a competitive disadvantage among smart meters.

5 E-Meter System Design and Alternatives

The following section examines the E-meter system design at a functional level. Figure 1 breaks down each of the major functional levels of the E-metering system. The three areas of design that will be broken down are electronic hardware, mechanical hardware, and software.

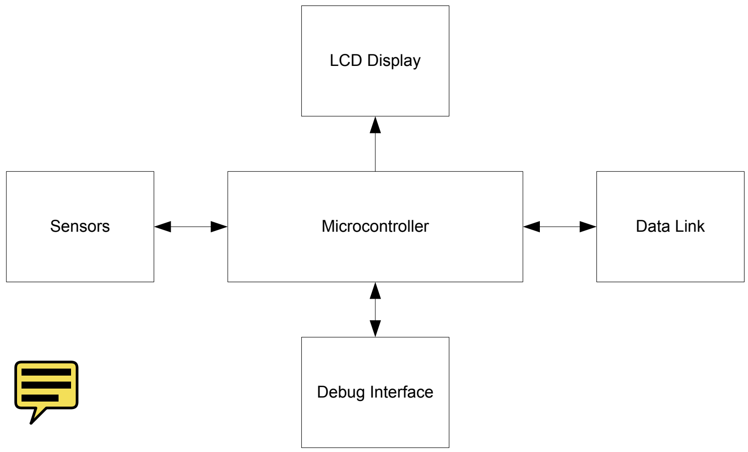


Figure 1: E-Meter functional block diagram

5.1 Electronic Hardware

At the center of the PICA E-meter is a Texas Instruments (TI) MSP430 processor, specifically tailored for three-phase metering applications. TI constructed the F471xx family of processors to be power efficient, running on 1.8V and drawing 350uA running at 1MHz. The system includes seven 16-bit Sigma-Delta analogue-to-digital converters, six of which perform metering while the seventh can be used for tamper protection or temperature readings. The MSP430 drives a 160-segment LCD display showing the real-time usage as measured in kilowatt-hours. Two LEDs provide visual indication of system status (power and activity).

ANSI codes C12.19 and C12.21 require that any electronic metering device display the instantaneous usage at the local metering unit. To accommodate this, the LCD display on the E-meter refreshes after every measurement to show the updated instantaneous usage, cumulative usage, and system status. In order to be compliant with FCC Title 47 part 15, regarding low-power radio transmissions from electronic equipment, only parts built in compliance with this statute will be used in the design.

Attaching current transformers to each phase of the line voltage allows the E-meter to monitor the current

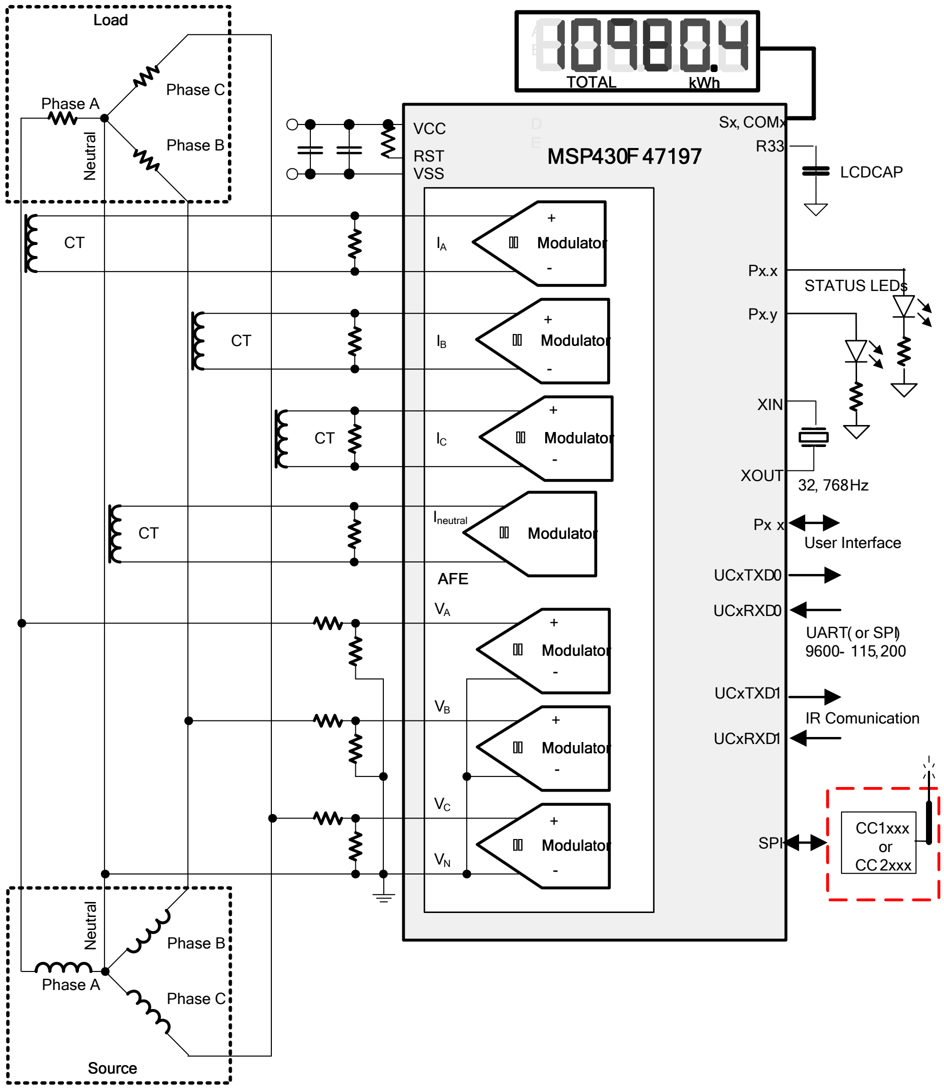


Figure 2: MSP430 System

draw from each phase. The hot and neutral lines of each phase pass through the meter to allow for measurement on each phase. The wiring inside the meter that passes through the current transformer must be capable of handling the current draw of the installation; thus, #4/0 wiring is used for any line voltage. Similarly, a resistor and capacitor network provides input to measure the voltage on each of the 3 phases. Figure 2 describes a high-level overview of the E-meter system centered around the MSP430F47197. As the E-meter collects data, it transmits the data to the MCU which sends it to the PICA base station or the utility company via a customizable interface which supports Zigbee radio, Ethernet, and serial RS232 communication protocols. The MSP430 provides support for all of these communications directly with one exception; Ethernet requires an extra microprocessor and hardware to handle the TCP/IP protocol. In an eventual production unit, Zigbee radio can provide the most bandwidth and longer range transmission of data back to the utility company. Additionally, the RS232 interface may disconnect to prevent tampering with internal settings.

5.2 Mechanical Hardware

5.2.1 Line Attachment Hardware

The E-meter system provides six screw-terminals on the base of the unit for connecting the pass-through current loops. Likewise, four screw-terminals connect the three phases and neutral lines to the meter input networks. Because each of the current sense inputs physically interrupts the supply lines, the mounting hardware includes redundant fasteners protecting against accidentally disconnecting the service line voltage.

5.2.2 Enclosure

In order to protect the E-meter components from the outdoor environment the system must be enclosed in a weatherproof case. The E-meter enclosure is composed of ABS, a heat resistant plastic. Plastics ensure that a loose wire cannot energize the case while still providing the durability of many metals. The case design allows for easy mounting on a variety of surfaces using standard fasteners and allows for access to the user interface controls.

5.2.3 UI Hardware

The E-meter provides several push buttons for changing the displayed contents of the built-in LCD screen. A closable lid protects the push buttons from the weather, as the power meter must be mounted on the exterior of the building. A protective glass window covers the LCD display. The design team chose glass because it can resist yellowing and remain transparent for a longer time than plastics when exposed to extreme outdoor temperatures.

5.3 Software

5.3.1 User Interface

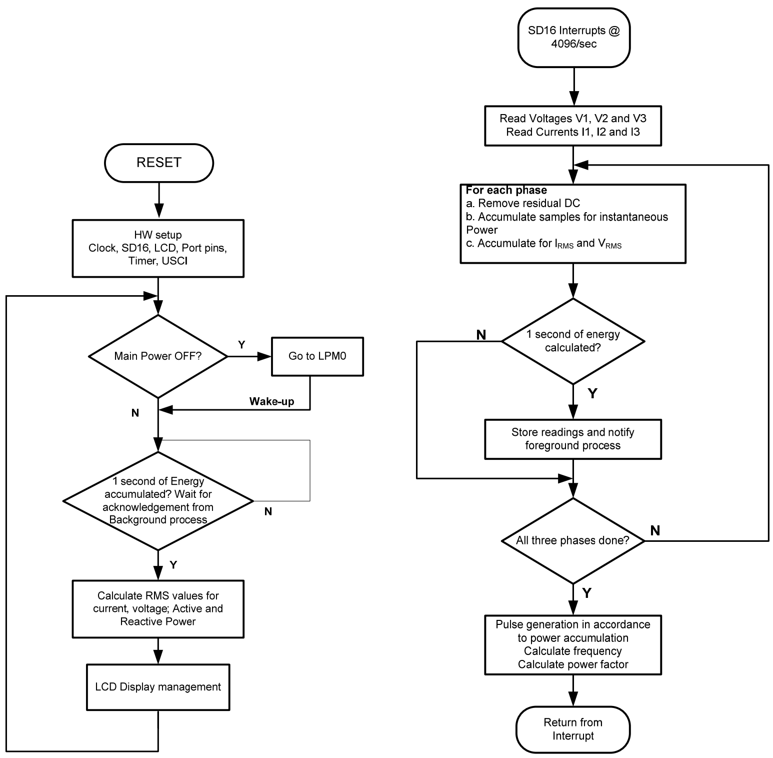
The user interface for the E-meter consists of a push button and a 160 segment LCD display module. For debugging purposes, the initial prototype includes an RS232 port capable of interfacing with PC software to load configurations and monitor internal dataflow.

5.3.2 Monitoring Algorithms

The background monitoring algorithm inside of the MSP430 microcontroller take measurements from the seven Sigma-Delta ADCs containing current and voltage data. Then for each monitored phase, the E-meter removes any residual DC offset present in the measurement, accumulates samples for instantaneous power measurements, and accumulates I_{RMS} and V_{RMS} computations. This algorithm will monitor for 1 second, storing each reading in onboard memory; then after 1 second of collecting data, generate an interrupt to the main process, calculate frequency and power factor, and transmit all data to the foreground process. A flowchart for this process, the background process, can be seen in figure 3b. The foreground, flowchart in figure 3a process then updates the LCD display, calculates values for RMS current and voltage, and calculates active and reactive power, and finishes by transmitting all data out over the Ethernet link before waiting for a new interrupt from the background process.

5.4 Alternatives

Very few alternatives exist for automated meter reading (AMR) and E-metering applications. The Texas Instruments MSP430 system on a chip is the first in this class of embedded systems widely available and



(a) Foreground process (b) Background process

Figure 3: Software flowcharts

commercially produced. Several other vendors supply various components, such as sensors and processors that combined can produce similar results. However, TI also provides a reference design for using their MSP430F47197 in an automated E-meter application, making this a very attractive solution for the design team. Analog Devices provides the closest competing chip for measuring energy consumption. The ADE7763 measures everything the TI MSP430F47197 does, but requires 1 chip per phase and an external microprocessor for control. This provides the obvious disadvantage of requiring more parts to accomplish the same task.

6 Solid-state Breaker and Monitor Design and Alternatives

6.1 Design Process

The design process began with deciding which functions the breaker monitoring system should include. After that, for each function, the team considered and researched potentially useful parts before selecting specific parts. Factors that influenced the decision included compatibility with other parts within the system, compatibility within the full product, cost, ease of use, availability, flexibility and reliability.

6.2 Options

6.2.1 Monitoring

Analog Devices ADE7763

The ADE7763 chip is capable of monitoring all of the necessary factors without a lot of extra functionality. It does not include any other compatible components, leaving more up to the designer.

NPX HVQFN33

The HVQFN33 monitoring chip is an option that covers all of the basics (Current, voltage, power, etc.) without a lot extra. It can also be ordered as part of a kit that includes a compatible processor, memory, external interface. It is an expensive option unless ordered in large quantities.

Teridian 78M6612

The Teridan 78M6612 is another chip capable of monitoring power. It includes an MPU core, embedded memory and external interface, making it a good choice because it doesn't need a lot of supporting parts.

6.2.2 Controller

Microcontroller

Microcontrollers offer the benefit of requiring minimal programming and specific capabilities, giving the designer a lot of flexibility.

FPGA

Using an FPGA has the benefit of lower cost and easier selection. It requires a more complex design, as its purpose is highly variable and designable.

6.2.3 Communication

Wireless

Wireless communication makes placement of subsystems much more flexible as they are not as constrained by the length of the cables connecting them. It typically requires more complex parts and board space and often consumes more power as well. Cost is significantly higher than other options.

Ethernet

Ethernet is common and inexpensive, making it a good choice if the system needs several connections. It is also reliable, even over long distances, so all subsystems do not have to be as close together as some other options.

Serial

Communication over serial connections is often beneficial because it is easier to communicate directly with chips through a UART or JTAG interface. It is also relatively inexpensive, and fairly common.

6.2.4 Display

LCD

An LCD display is very beneficial if a lot of information needs to be displayed. They are easy for users to read, making them a good choice when designing for a self-explanatory system. The major disadvantage is cost.

LED

LEDs are good for simple displays that show very few options or output. A large benefit is the ability to work them into nearly all electronic designs, and low cost is also beneficial.

6.3 Final Decisions

6.3.1 ADE7763

The main factor in the decision to use the ADE7763 chips was that samples were obtained quickly for free. Also, the ADE7763 chip is capable of the basic monitoring functions necessary for our circuit by circuit analysis without being overkill.

6.3.2 FPGA

An FPGA core was chosen primarily because of flexibility. Because of this, the design overall can have more options as an FPGA can work with a number of communication and monitoring chips. This also means processors don't have to be re-order when the original design doesn't work the way it was expected. Another reason an FPGA was chosen is that the team is familiar with FPGAs and programming them, making the project a little easier.

6.3.3 Ethernet

Ethernet was chosen because it is common, inexpensive, and reliable, it works well over long distances and is easy to use. Because it works well over long distances it doesn't force the separate modules to be as constrained by distance.

Ethernet also has the ability to work well when multiple systems are connected. This means that the MCU doesn't need a lot of additional parts to be able to communicate with both the breakers and E-meter.

6.3.4 LED

LEDs were chosen because all of the data from the breaker monitoring system is being passed to the base station to be read. Only status indicators are needed on the device itself. A set of LEDs is easy to for this, showing on/off very clearly. LEDs are also inexpensive and easy to obtain.

7 Base Station Design and Alternatives

The primary function of the base station is to collect, archive, and display usage information from other subsystems. To accomplish this function, the base station requires mechanisms by which to connect to the other subsystems, collect their data, process the data, store the data, and display the data.

In order to gather data from other subsystems, the base station requires the ability to create and configure connections with the other devices. As the design team is not designing the overall system with a particular house or building in mind, these connections must be flexible concerning the physical locations of the subsystems and must not assume that a medium of connection, such as a wired network, already exists between these two points. To minimize the invasiveness of installation, a wireless connection provided the best solution, as it requires no additional materials beyond the devices themselves in order to convey data from point to point. The design team selected the low-power mesh-networking protocol ZigBee (IEEE 802.15.4), rather than the more conventional Wi-Fi (IEEE 802.11) protocol. Many other common protocols could be used, as could a new proprietary method, but in the interest of reliability and fast design time, options such as Bluetooth, RFID, and CDMA do not fit the project goals. Although Wi-Fi technology is plentiful and familiar to a large part of the population, this makes it somewhat insecure, as a great many devices that can collect the data packets sent between the PICA system devices. This vulnerability could potentially breach the consumer's expectations of privacy and raise doubts as to the trustworthiness of the PICA product. ZigBee devices are considerably less common and are usually single-purpose devices, so a device with the ability to capture and analyze ZigBee packets in the same way a computer can with Wi-Fi packets would be much more uncommon. In this way, ZigBee provides security by obscurity, which Wi-Fi cannot. Wi-Fi does offer encrypted network connections, which can greatly increase the difficulty of data extraction, but this encryption also increases the difficulty of configuring the connection between the various subsystems. Likewise, the ZigBee protocol allows for encrypted connections between devices by exchanging encryptions keys, which would again increase the complexity of setup, unless such exchanges do not require a human to visit the individual devices.

Once the different subsystems have connected to the base station, the base station must collect their measurements and notifications. In theory, this should be a simple process after establishing a ZigBee connection; the devices would simply send their data over the ZigBee mesh to the base station. One issue is that unlike Wi-Fi, the ZigBee protocol emphasizes its reduced power requirements by transmitting intermittent bursts of information, which restricts the flow of the time-sensitive measurements. Although the client devices determine the required rate of data transfer, the base station may not be able to acquire every measurement from every device in real-time over the ZigBee mesh. It may be necessary to discard or digest data within each client device before broadcasting it over the mesh network, but this should not compromise the ability to relay measurements or critical events to the base station. That is, even though a measuring device could take thousands of measurements per second, it might not be able to transmit all of them within the narrow bandwidth of the ZigBee protocol. To deal with this, these fast-sampling subsystems may have to transmit summaries of its measurements to decrease the total amount of data to transfer in the same amount of time. Using Wi-Fi would get around this limitation, as data transfer can reach beyond 50 MB/s, more than enough for these purposes, but ZigBee should still facilitate communicating hundreds of samples per second, which should be more than enough for archiving and displaying the information.

After collecting data from the other subsystems, the base station must process the information before making it available for display and review. A wide variety of processor hardware and software would fit this purpose, as would many different kinds of storage media. In order to provide the flexibility and expandability of the base station functionality, the base station should run an upgradable operating system that a software developer can design and test on other machines as well as on the base station. The design team members who are familiar with Linux select Linux to serve as the base stationÕs operating system, as it is readily configurable and, with the proper tool-chain, allows the software developer to compile and test the software on a different machine. Linux is also a popular choice for running web-serving software and manage wireless networks, both of which are critical to the base stationÕs functionality. Additionally, Linux, through cross-compilation, can run a wide range of processor architectures, which does not restrict the hardware selection based on the software decision.

As the base station requires relatively few internal components to meet its design requirements, it will likely take the form of a single-board computer in a production scenario. However, due to the somewhat atypical ZigBee input and output, the design team decided to use an FPGA development board rather than acquire and modify an existing single-board computer. The FPGA will provide the central processing unit of the base station, which mandates the selection of a processor core. Initially, the design team considered an open-source implementation of the Texas Instruments MSP430 processor, but upon review and further investigation, lack of standard features such as a memory management unit, which Linux requires in order to function. Instead, the design team selected an open-source UltraSPARC core, as it seemed more full-featured and provided a more common architecture for compiling Linux and any associated programs.

Storing the gathered and processed data requires a long-term non-volatile storage medium. Despite the recent trends to move data into internet-based storage, the base station should be able to store data without assuming the availability of an internet connection. As a result, the measurements sent to the base station will be stored on a mass storage medium inside or attached to the base station. While magnetic hard disks provide a relatively low cost per unit storage, they tend to be physically large and consume more power while idle than their sold-state counterparts. Additionally, using removable flash media such as compact flash or SD cards would improve access times and lower power consumption relative to a magnetic hard disk. Additionally, these formats would permit the customer to remove or replace the medium in the event that the device should fail or become too full of data. While the former scenario cannot be avoided, the latter can be somewhat delayed if the base station compresses or summarizes data taken sufficiently far in the past, so some information would still be available for review without requiring the space of all the data points. Measuring data in real time is still a major feature, so it must remain in the system despite concern for long-term storage. The same granularity of data does not greatly benefit the user months later, but reducing the data to hourly summaries would still provide a fair amount of information, but would not require nearly as much space. In order to accommodate the development board used for the base station, compact flash cards will function as the storage medium. A hypothetical production model of the base station might use compact flash cards, SD cards, USB flash drives, or even an external hard disk, depending on how the design team evaluates each option when not already constrained by other hardware.

Just as many different devices can process and store the data, many different interfaces and formats can display the data to the user. In considering different methods of doing so, it is important that the interface encourage interaction with the system: it should be easy to understand and accessible to customers with a variety of technical skills and backgrounds. This requires a between the complexity for showing large amounts of information and elegance for relaying essential information quickly. In this regard, the interface should present useful information at-a-glance, but also allow for displaying more detailed or specific information by explicit human selection and interaction. Presenting this interface as a series of linked webpages over a local Ethernet connection provides this level of detailed information and configuration in a familiar format. Although the web interface presents an easily understandable interface to those who have a home computer network, it still presents a barrier of access to customers who might not have a home network. To accommodate such users, a separate display device will accompany the base station and can connect directly to it using ZigBee. This device may draw heavily from the web display, but its intent is to make that interface available to those without Internet-capable devices, as well and more convenient for those who do. The dedicated remote display also matches a feature provided by other smart home system vendors. The design team has not yet finalized a design for this device, but the device may become a separate subsystem after further consideration. The primary means of display for the base station will be the web interface, but will also provide a dedicated device for viewing that web interface at all times.

8 Verification and Testing Plan

9 Project Management

9.1 Team Responsibilities

9.1.1 Amy

Amy, along with Nathan, makes up the hardware part of the team. They are in charge making decisions regarding hardware-specific sections of the project. Amy is also in charge of the Breaker sub-system of the project. She has the most complete understanding of their functions and specific requirements, she may delegate sub-sections to other team members, but she will have a good grasp of how they fit into the larger system. A sub-system of the Breakers is the monitoring section, which the team delegates to Nathan. Nathan and Amy will be working together closely with the full sub-system of the solid-state breakers.

9.1.2 Nathan

Nathan is co-leader with Kendrick. They are in charge of scheduling and assigning tasks, scheduling meetings, keeping team on time, on task, and will answer project questions. Nathan, along with Amy, makes up the hardware part of the team. They are in charge making decisions regarding hardware-specific sections of the project. Nathan is also in charge of helping integrate the sub-sections into the whole system, which includes having a detailed, basic understanding of each sub-system, and knowing how each relates to the overall requirements and goals. Nathan is also in charge of the monitoring section of the solid-state breakers.

9.1.3 Avery

Avery is in charge of the Base Station section of the project. He has the most complete understanding of it's function and specific requirements. He may delegate sub-sections to other team members, but he will have a good grasp of how they fit into the larger system. He, along with Kendrick, makes up the software part of the team; they make decisions regarding software-heavy sections of the project.

9.1.4 Kendrick

Kendrick is in charge of the E-Panel section of the project. He has the most complete understanding of it's function and specific requirements. He may delegate sub-sections to other team members, but he will have a good grasp of how they fit into the larger system. He is also co-leader with Nathan and they will share duties as necessary. He, along with Avery, makes up the software part of the team; they make decisions regarding software-heavy sections of the project.

9.2 Schedule

In order to complete the project within the established deadlines, the design team established a schedule and task-oriented deadlines to supplement the larger senior design program-established deadlines. In doing so, the design team selected to address the individual subsystems individually. The design team will first focus on the solid-state circuit breakers and circuit-monitoring devices, which they hope to complete by the end of the fall semester. The other two subsystems, the base station and the main smart meter, will gain focus in the second semester.

The design team decided to address the circuit-by-circuit monitoring component of the project first because of its application to control systems. As members of the design team are taking a class in control systems during the fall semester, working on the breakers while also learning control theory seemed to create an advantageous symbiosis between working and learning. The control systems course also seeks to use aspects of the senior design project as learning experiences, so the motivation to combine the controls assignment and the breaker modules is twofold.

The design team has assembled its internal schedule into a Gantt chart to show the deadlines of tasks and the linkages between different tasks. Despite this planning tool and enumeration of tasks, the actual flow and completion of work is frequently different from its planned behavior. This is partially due to unexpected emergence of assignments and deadlines for the design project itself, but other classes also contribute unforeseen and time-consuming work that impedes progress in the project. As the semester progresses, these emergent due-dates should decrease in number and severity, allowing the design team to devote more time to the project.

10 Business Plan

10.1 Feasibility Study

10.1.1 Introduction

Many home and business owners have received electric bills and have sometimes wondered why it was so high. They generally wonder if they just simply used more energy that month or if one habit or appliance was to blame. However, they rarely see these questions answered. The PICA system will answer these questions without needing to go through the hassle of calling the power company and having a time consuming conversation. This feasibility study was conducted in order to gauge if the design team could develop this system in the time table given.

10.1.2 System Feasibility

The PICA system separates into three subsystems that will communicate with each other to form one system. The team of four electrical engineers brings many different talents, experiences, and interests to contribute to the project. Each subsystem divides to cater to each team member's area of interest and talent. By separating the system into different subsystems, it increases the feasibility of the system as a whole. This allows for each team member to do research, testing, and assembly separately. It also allows each team member to gauge time for parts to be delivery. The final step will be making sure each subsystem can communicate with each other. However, if the design team addresses these issues early, there should be fewer problems in the future.

10.1.3 Market Feasibility

Not only will the PICA system monitor total power consumption, but it will be monitoring power on a circuit-by-circuit basis. This functionality distinguishes the PICA system from anything else on the market now, which only allow for plug-by-plug consumption or whole home consumption. Circuit-by-circuit monitoring allows the consumer to identify their energy hogs without having to test each device individually. This functionality also makes the market feasibility much greater. Another feature that increases the market feasibility is the fact that the PICA system will also have the capability of notifying the consumer when peak pricing hours of the day are, which is when the power company charges more per kilowatt-hour.

10.1.4 Legal Feasibility

The PICA system will comply with all necessary codes and compliances, as well as keep the customer's information private. Many different implementations accomplish these legal requirements. The operating system will only give administrator privileges to the power-company and customers, which the application of the system specifies. The user interface will have a web interface for system administration, but the information will only be accessible to an authenticated administrator. The PICA system also needs to meet certain codes in order to be safe enough for the customer to use, which will also protect from unexpected lawsuits. Underwriters Laboratories (UL) is an independent product safety certification organization, which offers safety certifications to products[1]. The system will be UL certifiable. The system will also restrict electromagnetic (EM) radiation to comply with FCC Title 47 Part 15. It will also be compliant with ANSI C12.19 and ANSI C12.21 standards. The PICA system will also safely isolate high-voltage areas.

10.1.5 Schedule Feasibility

The timeline of the project is eight months. During these eight months, the team members will develop a prototype to test and make necessary corrections based on testing results. The feasibility of this schedule is within the range of time needed to complete this project. Team members holding other team members accountable for their respective tasks maintain this schedule. The system divides into sub-systems for each team member to work on also contributes to a feasible eight-month schedule. The team has milestones in a Gantt chart to help keep an accurate account of the timeline. Additionally, there is a project manager specifically responsible to keep tasks updated and keep team members on track.

10.1.6 Resource Feasibility

There are many resources available to the team that can contribute to the project. There are many different facilities to have space to work. People and company resources are great for the design team as well, because the experience level is much higher. Consumer's Energy has offered to be available for questions, should any arise. Mark Mitchmerhuizen is head engineer at Johnson Controls Incorporated and has volunteered to be a mentor to the design team. Calvin College has an electronic shop with free parts that are available for students to use. For the parts that are not available in the electronics shop, Calvin College gives the design team a three hundred dollar budget to use at their disposal. This could be a potential problem to feasibility, because due to the size of the project, the cost might exceed three hundred dollars. To account for this the team members are acquiring some part donations from companies willing to help.

10.2 Business Models

There are two basic business models when marketing and designing a product. In the first model a business sells essentially the same product as its competitors, but for a lower price. In the second model, there is no cost advantage but the product has a much better design than the competition. (Footnote acknowledging Biz Team) It is unlikely that our design will be cost-competitive when compared to either standard breakers or conventional electric meters. Including both circuit by circuit monitoring in addition to whole-home monitoring gives us a significant product advantage. This suggests model two be used when considering marketing options.

10.3 Similar Products

Right now, there are many different power-monitoring devices on the market. These devices range in size, cost, ease-of-use, features, accuracy, and method of installation. The products on the market today include The Kill A Watt, Electric Meter, Cent-a-Meter, TED (The Energy Detective), NILM (Non-Intrusive Load Monitoring), ENVI, Smart Watt, and Watts Up. Each of these devices both compares and contrasts with the PICA system.

1. The Kill A Watt is a product from P3 International. It connects to appliances by a power outlet and assesses efficiency. Only one appliance can be connected to the Kill A Watt device. The LCD display on the device will show the consumption by the kilowatt-hour within a .2% accuracy. The Kill A Watt will also display voltage, current, line frequency, and power within the same accuracy. It can be set up to calculate consumption by the day, week, month, or year. However, this information is not instantaneous when the device measured turns on. It takes a few seconds to register a change in voltage. The Kill A watt device costs about $25. However, there are other Kill A watt devices with more features that will cost more. The Kill A Watt EZ costs about $50 and adds the feature of

calculating how much an appliance is costing the consumer. The consumer would need to input how much the power company charges per kilowatt-hour. There is also the Kill A Watt PS, which costs about $85. This adds a few more features. It is also contains a power strip that will protect the device from power surges and lets the consumer plug in a set of devices to see the cost. For example, the consumer could know the cost of running a TV with a gaming system or DVD player connected as well. The feature can be obtained by taking a power strip that the consumer already owns and plugging in the Kill A Watt or the Kill A Watt EZ into it. Any of the Kill A Watt devices will not replace the electric meter outside the home. The reason for marketing this device is to increase convenience to the consumer.

2. The electric meter is what is outside of most homes. This device is provided by the power company, which measures the amount of electrical energy consumed by the home or business owner. The electric meter monitors total power installation usage. However, most consumers do not know exactly what the number they read of this device means. Typically, they calibrate in billing units and require periodic readings based on the billing cycle of the power company. In some areas of the United States, the rates of electricity are higher during certain times of the day, which means encouraging reduction of use during those hours. Some models also use relays to turn off nonessential equipment. The consumer's service provider solely monitors this device. The most the consumer does with this device is to read the number on the box.

3. The Cent-a-Meter is a product of Power2Save. This product uses a sensor technology to detect and monitor a magnetic field in the proximity of the consumer's household electricity power cable. The Cent-a-Meter has a receiver that calculates the current, voltage, and power, as well as the amount of greenhouse gas emissions. Once the device receives this information, it transmits it to a cordless main unit receiver on the wireless frequency of 433MHz. The range of the wireless transmission can be up to 100 feet away. The consumers receive a user manual and can mount the device themselves. However, a licensed electrician needs to attach the current sensor during installation. The Cent-A-Meter costs about $180 and it has about a 5% accuracy [2].

4. The Energy Detective (TED) is a product of Energy Incorporated. TED is a device that monitors whole power installation usage. This product requires an electrician for the setup, which includes installing the hardware and configuration of the software. This installation would involve tapping into the feed of the circuit breakers located inside the home; this tapping is the measuring transmitting unit of the device. There is also a pair of current transformers that will clamp around the

power cables coming into the home of the consumer. There is also a receiving unit display where the homeowner will get their information, which will plug into the outlet and display power usage in real-time (in kilowatts) with an LCD. The screen can also display power consumption in dollar amounts. However, TED also has some flaws. The interface to upgrade firmware in the gateway does not have a lot of feedback, meaning the customer could get confused very easily. There is no way of knowing if firmware ever updates in the remote sensor modules or on the LCD display. This product includes a ZigBee connection for the wireless display. A ZigBee connection is a wireless connection that uses an IEEE 802.15.4 radio to address sensing and control applications that require lower bandwidth, low latency, very low energy consumption (for extended battery life), and low cost [3]. However, there are different ZigBee types of connections and there is no way of knowing what kind of ZigBee the device uses. The communication link requires no configuration when installed, but a review on smartgridnews.com says that “the display is often inaccurate, it never displays anything other than zeroes for the min/max values on the various screens, it updates instantaneous kW readings sporadically – all of which reduce its usefulness. I only use the web interface,”[4]. TED costs about $240.

5. The Non-Intrusive Load Monitoring (NILM) is a product that allows the homeowner to add a technology to their electric meter. However, this technology does present concerns about privacy, because it can indicate certain behavior patterns of the consumer. It could indicate when consumers are out of the house, when they are using the shower, and other information that the consumer would not want known to a third party. Since this is technology provided by the power company, the user does not monitor it.

6. The ENVI Energy Monitor is a product from Energy Solutions Inc., which is a licensed distributor for Davies Energy Systems Incorporated. This product uses clamps that can detect a magnetic field as the current moves through the power cables to the home or business. The clamps will connect to a transmitter that will send a signal to a monitor in 12-second intervals by wireless communication. The monitor shows the consumer the energy usage in real-time. This device exports data by a USB cable to a computer. This is a tool for informational purposes and not a replacement to the standard electric meter. The cost of the ENVI Power Consumption Meter is about $129.

7. The Smart-Watt is a product from SmartWorks. This device does not use a display or user interface; the PC of the consumer controls everything. All of the data reports to a data collection server in an SQL Express database, which uses .NET as a platform for development. If the consumer sets up a

File Transfer Protocol (FTP) server, it allows them to share the data. A simple Google search will give systematic instructions on how to set up an FTP. The Smart-Watt reports data within a .2% accuracy. Depending on the desired current and voltage the consumer wants, the price can range from $169 to $249. This device is also strictly for providing information. It will not replace the standard power meter.

8. Watts Up is a product that is similar to the Kill A Watt device, except that it is much faster. This device will respond to a change in voltage as soon as the consumer turns the specific device on. It will record more information than the Kill A Watt device will, such as poor line quality, and highs and lows (the consumer can see power surges). There is also a device called the Watts Up Pro that allows for some additional features. The main additional feature that draws consumers to this device is a monthly energy savings calculation. The Watts Up device costs about $110 while the Watts Up Pro costs about $210.

9. The PICA system will not only monitor total home consumption, but will monitor it on a circuit-by-circuit basis using only one system instead of having to use multiple devices. Customers will be able to know how much power a single appliance or outlet consumes. This functionality will distinguish the PICA system from anything on the market now, because all other devices monitor plug-by-plug consumption or whole home consumption. Circuit-by-circuit monitoring allows the consumer to identify energy hogs without having to test each device individually

10.4 Pricing

The cost of the full system is somewhat meaningless because of the modular aspect of the product. Prices for the power company components will differ greatly from prices for the consumer's part of the product, and both components should be marketed and sold separately [5].

The final price for the E meter should consider the large number of devices per order. Pricing strategies should favor individual purchases when determining the cost of the breakers.

10.5 Production Costs

The raw costs of the individual parts for the product will be relatively low due in part to the fact that full scale production of the project will include manufacturing millions of the devices. The expected cost is not much more than 100 dollars per device, even when shipping and loss are factored in. [5].

Because of the detailed nature of circuit building and large scale of production, it makes sense to use a lot of automated equipment in the manufacturing process. This significantly raises machinery costs, but should reduce the need for a lot of manual labor. Automated equipment will also improve the quality of work, meaning there will be less loss due to the process itself. Because the product is a safety-critical device, the other high cost associated with the product will be inspection and testing of these devices.. The expected cost, before sales, is 400 dollars, including all aspects of design and production.

10.6 Target Market

The target market for this product is quite large because it includes a several different markets. The first market is the power company since they are responsible for providing each building with the electrical meters. The second major market is new home builders, since they have no sunk costs or working system to replace. The third market is home and business owners who have a high interest in the ’green’ market and desire to be very energy conscious and use their resources efficiently.

10.7 Target Market Research – note that this section is incomplete

The team has not conducted official target market research, but did talk to Consumer’s Energy, located in Jackson MI, and found that the primary market (power companies) is very interested in "smarter" products. Unfortunately, many companies like Consumer’s Energy have already looked into integrating "smart" systems, and once a solution is found and implemented they have little reason to spend the time and resources to make a small upgrade by switching the meters they use. However, a market still exists with the Power Companies that have not yet started using these "smart" systems. At the moment, the second market is smaller than in previous years due to the economic downturn.www.nahb.org However, housing spending has been increasing[6], leading to a need for safety systems that are required in every new building. This gives the product a consistent market, despite the weakened economy. Initial research for the third market indicates that the "green" market is still increasing, meaning the product has a good chance of success in that area.

10.8 Target Sales

Sales for the E meter system will be in mass quantities because orders will include enough devices for a city. These components are expected to be sold directly to the consumer. Systems such as the breakers and base station will be sold in much smaller numbers, possibly only a few at a time as homeowners have breaker boxes installed on a per-home basis. These can be expected to be sold through retailers like Lowe's or Home Depot.

11 Parts and Project Costs

As it is with many projects, the yearlong design project aims to produce a working and viable product while also remaining inside its budget. To achieve this goal, the design team established a budget for the project that contains a sizeable contingency fund to absorb the costs of unforeseen expenses. Whenever possible, the design team has sought to use sample quantities of components as well as pre-purchased equipment to reduce the cost of development. By employing these two strategies, the project expenses should remain within the pre-defined budget of $300-$500.

Due to the length and complexity of the PICA system and subsystems, much of the conceptual design will precede detailed design and implementation. As such, feature selection takes place without considerations of implementation or even possibility. This introduces a large amount of uncertainty in the total costs of development, mandating a contingency fund for component parts used in development and prototyping. The cost of other development materials, such as solder and design software, is negligible if the senior design program supplies these materials and software. While no contingency fund can accurately predict the contingency costs, the design team hopes to limit the number of significant design changes that mandate a change in parts and hardware.

As a second strategy for cost reduction, the design team also hopes to restrain cost increase by using samples and pre-purchased equipment. For example, the design team requested a sample of the Analog Devices ADE7756 power monitoring chips to use in the circuit-by-circuit power monitoring subsystem. Additionally, the design team will use a pre-purchased Xilinx Virtex-5 development board to design the base-station hardware, which allows the team to use high-performance configurable hardware without adding the cost of the kit to the project budget. The design team contacted a Texas Instruments representative and, through TI's university program, acquired a development kit featuring the TI MSP430 processor. Furthermore, the senior design program provided a desktop computer and engineering software to the design team, which, in a professional engineering firm, would represent a significant hardware and software cost. In this way, the design team gains the use of a wide range of hardware and software without adding the component costs to the project. While the total cost of the project remains uncertain until its completion, the design team remains confident that their budget estimates allow enough flexibility to accommodate unforeseen expenses.

12 Acknowledgements

13 Conclusions

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14 Appendicies