Power-aid

Christian Aranha, Chris Diller, Arman Murat, and Kurt Riecken

School of Electrical Engineering and Computer Science, University of Central Florida, Orlando, Florida, 32816-2450

***Abstract* — This paper explains the design methodology used in our project to calculate the voltage, current, and power in our power strip module. In addition, the details for the wireless communications and LCD control system for our project are discussed.**

***Index Terms* — Current measurement, Displays, Indoor communication, Power measurement, Transceivers, Voltage measurement,.**

I. Introduction

Each year as we develop and mature as a nation and as a species we become more aware of our carbon footprint we leave behind and all of the natural resources we consume. We are becoming more responsible when it comes energy consumption and also monitoring how we are using the energy and how we can conserve it. If each person had the ability to monitor how their electricity was being used in their home and how it affects their monthly power bill they might be willing to change there bad energy consuming habits.

The concept of our project was to design a home energy management system that would be beneficial to the homeowner by providing them with important information regarding the energy consumption of their individual household appliances. Our power strip modules were designed with a single duplex receptacle to allow for the connection of up to two home appliances. These power strip modules include circuits that will monitor the instantaneous voltage and current applied to the individual appliances. By calculating the delay between the voltage and the current we were able to determine the phase angle of the circuit and therefore were able to calculate real and apparent power of the appliances. This information is then sent back to a controller wirelessly that is then further processed to determine things such as instantaneous power consumption, daily power consumption, and total power consumption since last power bill. The controller then communicates with a LCD touch screen monitor that gives the user access to the system. The power strip modules also contain a contactor controlled by a microcontroller to allow the user to remotely turn on and off appliance through the LCD touch screen monitor. This gives the user an easy way to control multiple appliances from one location while having information available at their fingertips.

II. Power Strip Modules

A. Microcontroller – ATMEGA 328P

The first major component of the power strip module is the microcontroller that does all of monitoring and power calculations of the appliances connected to the power strip module. The ATMEGA 328P is interfaced with three major components including a Hall effect current sensor, voltage divider, and the ZigBee Series 1 RF transceiver. The Hall effect current sensor and the voltage divider are analog signal and utilize the ATMEGA's analog inputs. The ZigBee utilizes UART communications and is connected the RX and TX ports on the ATMEGA. The ATMEGA only requires a few external components to become fully functional including a regulated 5VDC power supply, a 12MHz crystal oscillator, and a few capacitors for the crystal.

During the development of interfacing the external components with the microcontroller we used the Arduino development board. This board can be powered and programmed via USB for quick debugging and implementation. The Arduino comes standard with the ATMEGA 328P, which is powerful enough for the purposes of our project. The Arudino platform uses its own programming language although it is almost identical to the C programming language with a few minor changes. The Arduino also allows us to speed up the development stage due to its interface. It is very easy to upload software to the chip. With just a few jumpers we can directly upload software to the chip on the printed circuit board. By developing in this format we are able to make quick changes to the design even in the late testing phases.

B. Hall Effect Current Sensor

The most imperative part of the project was to measure the power correctly therefore we needed an extremely accurate current sensor. The current sensor was the component needing the most accuracy because the voltage divider used for calculating the voltage was simply the input voltage multiplied and a constant allowing the signal to appear identical to the input, but just at a lower potential. The current sensor however uses the Hall Effect therefore the output was a voltage signal that was proportional to the current flowing through the circuit.

We chose to use the Honeywell CSLA2CD displayed in figure 1 as our current sensor. This sensor can be powered with 8-12VDC and the output is related to input voltage through the following equation:

$$I_{sensed} = V_{out}\frac{\sqrt{2}}{2}/.033$$

We choose the reference input voltage to be 9V because we are using a 9-volt battery for the power supply to the entire power strip module. As seen from the equation above relating the output to the input DC voltage bias we notice that the output will always be a constant 4.5VDC signal with a sinusoid proportional to the input riding on top of it. This is exactly what is needed because of the voltage constraints of the analog inputs of the ATMEGA 328P. The ATMEGA 328P requires that analog inputs never dip into a negative voltage range, which is why this type of sensor is ideal for our application.

Figure 1: Honeywell CSLA2CD HECS

SUPPLY VOLTAGE
- ***MIN – 5.4V***
- ***TYP – 8V***
- ***MAX – 13.2V***

SUPPLY CURRENT
- ***TYP – 13mA***
- ***MAX – 20mA***

C. Voltage Divider

To Monitor the voltage terminals for the outlet we had to step down the high voltage coming from the wall outlets to level within the limits of the ATMEGA 328P. By measuring this voltage we are able to calculate total and apparent power being used by the appliance. For the purpose of the experiment this outlet is supplied with a conventional 120RMS voltage. This sinusoidal from the wall outlets dips into negative voltages so a bias must be applied to the sinusoid by using a DC voltage. We decided to bias the signal with the same 5VDC power supply used to power the ATMEGA 328P. This allowed us to simplify the overall circuit by only requiring one 5V linear regulator. By stepping down this voltage and then shifting the signal to the positive ranges we are able to calculate the voltage coming from the outlet.

D. ZigBee

The ZigBee Series 1 RF module was utilized for the communications between the power strip modules and the touch screen controller. The Zigbee module itself needs a 3.3VDC regulated supply, but our design is only using one 5VDC linear regulator for the main power supply. Because of this we bought a small adapter for the Zigbee, which allowed it to be powered from the 5V linear regulator. Our touch screen controller uses the Motorolla 68HC11 as the microcontroller, which uses RS232 for communications. Shortly after interfacing the touch screen controller with the ZigBee module we realized they use to different communication protocols. The ZigBee uses UART communication protocol with TTL. A 1 is represented by a 3.3V signal while a 0 is represented by 1.2V. The Motorolla 68HC11 instead uses RS232 communication protocol. To allow for these devices to communicate a MAX232 serial converter was used. This allows the negative signals coming from the Qscreen controller to be inverted and stepped down to our required 0-3.3V range.

E. Powering the Power Strip Module

The power strip module is powered using a 9VDC battery. All of the components of our circuit with the exception of our current sensor operate on a 5 volt signal. By using the 9VDC battery we can supply both the current sensor and the 5V regulator with 9V. All of the remaining components are supplied with power directly from the regulator.

F. Solid State Relay

The solid state relay in our power strip module is used to turn the appliances on and off. This relay is controlled by the ATMEGA 328p. From the figure 2 below, the microcontroller can control the relay depending on which signal it receives from the LCD controller on the control panel. When a signal to turn on the outlet is received the Arduino sends a 3.3 volt signal to the transistor which allows current to flow through the relay turning on our appliance. When there is no voltage applied the transistor the relay is switched off. The relay operates within a range of 16 to 24mA.

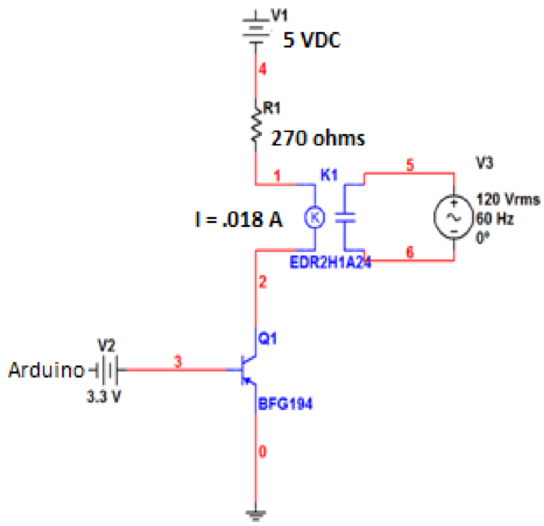

Figure 2: Relay Circuit

G. LCD Graphical user interface

After careful considerations of the needs and goals of this project we found that the QScreen Controller™ from Mosaic Industries, Inc. best suited those requirements. The QScreen Controller™ is a combination of a C-programmable single-board computer with a touch screen operated graphical user interface. This touch screen monitor is powered by the Motorola 68HC11 microcontroller, which we were very familiar with from the laboratory section of Embedded Systems class. The fact the each of the group members is familiar with the C-programming language as well as the assembly language of the Motorola 68HC11 is what lead us to selecting this product for our project.

Because this project is a proto-type of product that would be utilized in consumer household, appearance and size were of great importance and concern. We envision this touch screen controller to be mounted near the houses existing thermostat so for cosmetic purposes we want our display to be about the same size as a standard thermostat. After taking measurements of a few thermostats we found the average to be 4" tall and 6" wide. The QScreen controllers overall dimensions were 4.125" tall and 6" wide making it the ideal candidate for size requirements. A picture of the overall appearance and design of the QScreen controller can be seen below in Figure 3. As you can tell from the figure below the QScreen controller would surface mount perfect in a household wall with a cutout not much bigger than needed for a typical switch or receptacle outlet box.

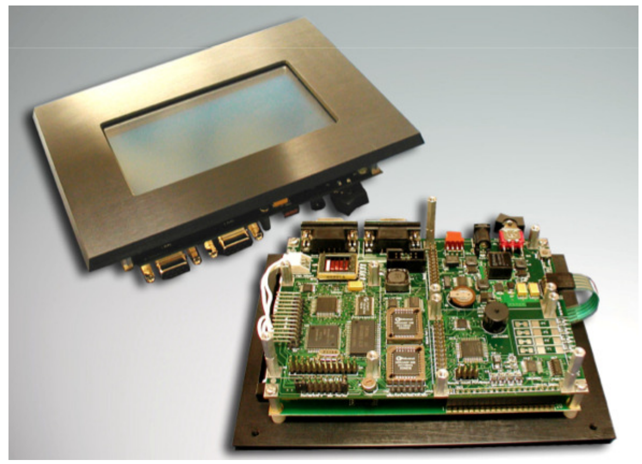

Figure 3. Qscreen Controller

The QScreen controller is equipped with a touchscreen operated graphical user interface on a high-contrast 128X240 pixel display with a 5X4 touchscreen overlay. The screen itself measures 4.8" diagonally and is a high contrast CCFL white-on-blue monochrome LCD. The user does have the ability to control backlight and contrast of the screen using software provided with the product. Because of the ability to navigate through different menus this size screen is more than enough to satisfy the requirements of this project.

As noted earlier the main reason for using the QScreen controller is having previous knowledge of the Motorola 68HC11 as well as the C programming language. The QScreen controller gives the programmer the option of programming in either Control C or QED-Forth. We chose to use Control C as our programming language for the programming of this project. Control C tm cross-compiler comes with the purchase of the QScreen controller is written by Fabius Software Systems and customized by Mosaic Industries to facilitate programming the QScreen controller in C. It is a full ANSI C compiler and macro pre-processor. The compiler supports floating-point math, structures and unions, and allows you to program familiar C syntax. Programming is easy done using an interactive debugger and multitasking executive. The controller is pre-loaded with hardware control routines including drawing functions for the display. After programming in ANSI C by compiling our code on our PC and downloading the code to the QScreen Controller it will then be automatically executed. The real time operating system and onboard flash memory manages all required initializations and auto-starts our application code.

Now that we have selected the touch screen monitor for the project we need to design the functionality and appearance of the interface to the user. We want to avoid a busy screen and keep it simple and easy for the user to read. Multiple pages will be avoided so as not to lose the user in navigation throughout the program. A preliminary touch screen output can be seen below in figure 4. As you can see the legend indicated that a boxed area with the dotted background will be the only input area for the user. These areas include the adding a module, and turning modules on and off.

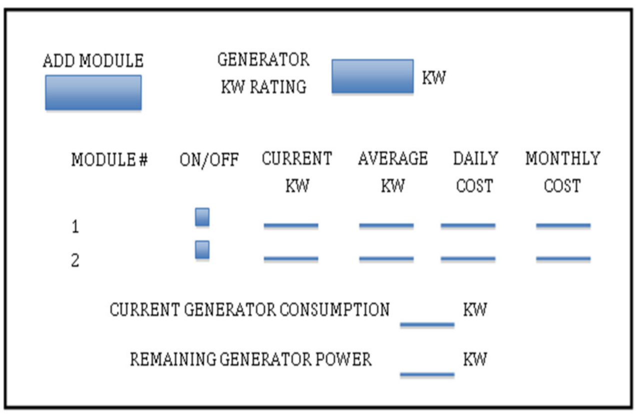

Figure 4. LCD Graphical Interface

We wanted to make sure the product is expandable to the user, which is why we included the “Add Module” feature. This allows the user to make the initial investment of the touch screen controller and maybe one or two power strip modules to test out and use in their house. At any time in the future they can always purchase another power strip module and connect it to their existing network. All the user need to do is plug in the power strip module wherever they would like to use it and then simply walk to the touch screen monitor and click “Add Module”. This would automatically recognize the power strip module just plugged in and would assign to it the next number in the module list. It is important to note that if the user wished to add multiple power strip modules at the same time that they would have to plug each one in separately and click the “Add Module” button before plugging in the next. The reason for this is when the user clicks “Add Module” the program is going to be looking for new devices and if more than one is available an error might occur.

The next feature the user will be able to control is turning the power strip modules on and off. This option can be used during normal power operations, but is mainly intended to be used during times of emergency generator power. During normal power operation the user should have all the modules powered on and simply turn off their appliance how they normally do. The only advantage to using the on and off feature during this time is to conserve power on appliance that draw power even when they were off such as televisions, computer, etc. This way you can shut the power off to them via the touch screen without having to unplug each power cord from the wall. The main purpose of the on and off feature is used when the system is in emergency mode. As soon as normal power is lost and the transfer switch switches over to emergency mode the QScreen controller will automatically shut off all power strip modules and wait for the user to decide what modules they want on. By looking at the “average power consumption” column the user can identify normal instantaneous power draw from individual appliances measured in KW. The QScreen knows the KW rating of the generator since the user initially input its value. As the user turns on individual power strip modules the program will calculate the remaining available generator power and report it back to the screen. This way the user will be able realize when they were approaching the limitations of the generator. Safety features will be added to insure the user does not accidentally turn on an appliance that would overload the generator causing failure.

The user will also have the ability to enter the KW rating of their home generator. This is important for the “emergency mode” operation of project. The software will monitor the usage of power from the generator as well as all the power strip modules and will compare to make sure the power consumption of the all the power strip modules together does not exceed the rating of the generator. If this were to happen the generator would fail and the project would have not satisfied its goal.

III. OVERALL DESIGN

A. Intentions and Goals

The intent of our project is to design a home energy management system. This system will be versatile in that it will be beneficial to the homeowner during both normal power operating conditions as well as during times of utility power loss. While operating under regular conditions a user should be able to see their current cost of operation. By simply glancing at the LCD unit one can see how much power the home is consuming in both KWH as well as monetary cost per day or month. Under conditions in which the home is being powered by a generator the user may need to keep only certain appliances on. Appliances such as the refrigerator would become a priority. Depending on how much power a generator can supply to the home the homeowner has the ability to run all their essential and non essential appliances without fear of overloading their generator. The overall design can be seen in figure 5 below. Each module communicates with a main controller. This controller in turn displays all relevant information to the user. If there is a loss of power detected the Automatic Transfer Switch will transfer power to the generator. Once this switch is detected the system goes into an emergency mode. Under these operating conditions the main controller must be careful as to not overload the generator.

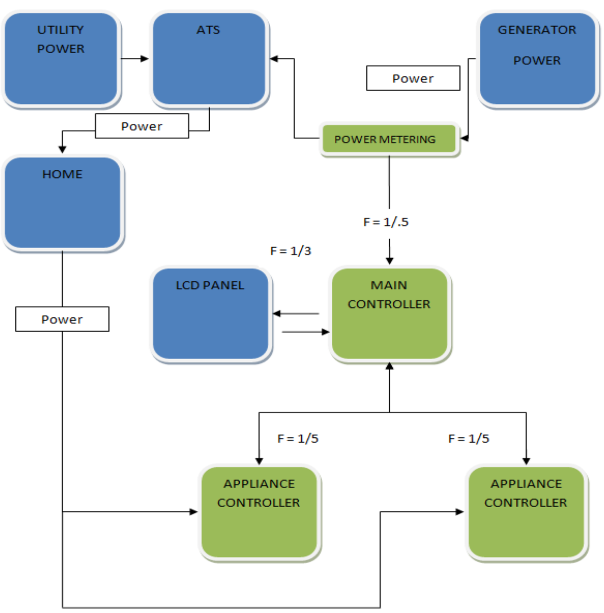

Figure 5. Design Layout

Often, the average homeowner is unaware of the many details and tremendous amount of power that go into allowing their lives to run as normal. Questions like, "Can I run my hot water heater on a generator?", "How much power do I need to keep the refrigerator on?", or "What were my limitations for powering my computer, television, stove during power failure?" would be simplified and answered in our design, while still giving the end-user as much control as possible.

The main design of our project begins with the loss of normal power, at which point the generator already connected to the user's home would turn on in response to a signal from a microprocessor. That microprocessor would be constantly monitoring the current coming from the main, "normal", power source; as soon as the current disappears, a signal is sent to the generator to turn on and take over power for the house. Our design will be a power strip module that resembles the surge protector power strips which can be used at one's computer desk to plug in your computer and its peripherals. It will have two or three outlets to plug in any standard utilities. These power strip modules will have voltage and current sensing circuits which will be constantly taking measurements related to power consumption. The power strip modules will also contain contactor circuits to allow the user to remotely turn on and off the appliances through the LCD touch screen monitor. This information (current and voltage readings) will then be processed at a microcontroller (embedded in the power strip module), and then transmitted wirelessly to the main microprocessor in the LCD.

The wireless communications in our system will be done using a single protocol. Shown below in Figure 6, each wireless device will be a transceiver (i.e. had the ability to transmit and receive data); they will not communicate with each other, but only to and from the central microprocessor (in the LCD). The wireless transceivers will be used over a short range in our prototype; this can be extended to the end-user as well, assuming the main processor in the end product is located near the center of the house. This aspect will allow for lower power usage, as well as lower costs for the transceivers.

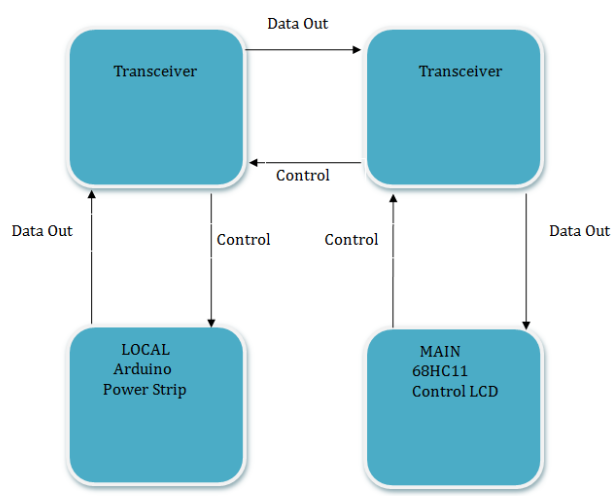

Figure 6: Wireless communications block diagram

The LCD will contain the main "hub" microprocessor which will collect data from the power strip modules and is where the bulk of the calculations and decisions will be made. This display will be the interface between the user and the software which will control whether or not outlets in the power strip module were supplied with power. During normal operating conditions, the user will be able to control which outlets will be turned on (supplied with power) and also have the ability to turn off any or all of the outlets. There will also be a section on the LCD which will provide the user with pertinent data about their power consumption. In this section, an emphasis will be placed on "useful" data; that is, we don't wish to give overwhelming amounts of graphs and numbers which may require knowledge of math to interpret and understand. The LCD will show information in as simple a form as possible, while still providing important, useful data. The data shown will be facts such as:

1) Instantaneous power consumption
2) Individual appliance power costs
3) Daily power consumption
4) Current rate of power consumption
5) Total power used since the last power bill

An emphasis will be placed on showing as many dollar amounts as possible, so the user can more easily relate to the information on the screen. Abstract figures, graphs, and even most other data will be shown for the purposes of the demonstrations, and on a limited basis at that. This process is intended to help the user to more accurately monitor control their power usage, in order to meet their monthly power consumption goals.

B. Requirements and Specifications

Each microcontroller will measure a specific current. The accuracy of these currents should be precise enough to prevent damage to any appliances or the generator. We will set our initial goal to reach a precision of 100mA. The main unit will receive power reading information from all the other microcontrollers every two seconds. The main unit will provide absolute instructions to all other microcontrollers. It must have the ability to stop and resume power consumption of any outlet in the home. These criteria will be set by the user through an LCD input screen.

In case of an overload of the secondary power source appliances will shut down in order to prevent damage. The generator specifications will be input by the user through the LCD. By specifying how much power the generator can provide our software will be able to monitor to see if the appliances are within range of overloading the generator. The software will then provide a barrier so a user cannot turn on more appliances than the generator can supply.

The power strips must be able to achieve these specifications as part of our design:

1) Send data every 5 seconds.
2) Enter sleep mode for 5 seconds in between packet transmissions.
3) Measure currents up to 15 amps.
4) Measure voltages of $120V_{rms.}$
5) Up to 2 appliances can be connected to any power strip.
6) Have a line of sight range of at least 100 feet in an indoor environment.
7) Have a range of at least 50 feet between two rooms.
8) Power readings must be measured within an error margin of 5%.
9) Must have an ADC that is 10 bits wide for 1024 steps of resolution.

The Main control station will consist of a controller that receives information from all the power strips and displays this information on the user controlled LCD display. This station should be able to send and receive information from the LCD. If the LCD relays information to shut down a specific appliance an interrupt signal must be sent to relay that information.

The specifications for this unit were as follows:

1) Receive data from 2 different power strips every 2 seconds
2) Communicate this data to the LCD module 3 seconds
3) Receive and transmit information with an accuracy of 3 decimal places with the local microcontroller.

C. Power Strip Module

The power strip module will contain all of the components we researched and documented in our design. The main components of the power strip module include a duplex receptacle, power relay for switching the receptacle on and off, a current transformer for measuring current, a potential transformer for measuring voltage, a Atmega 328p microcontroller for power calculation and a RF wireless transceiver for sending a receiving data from the main touch screen monitor.

Each power strip module is independent from the system and they can be added or removed from the system at anytime without repercussions. The 68HC11 microcontroller scans the network for incoming transmissions. If a new power strip module is detected than it is immediately accounted for.

Figure 7 below is the wiring schematic of the power strip module and give a clear indication of the functionality of the circuit. Please refer back to the design section for a breakout of all the components and their functions.

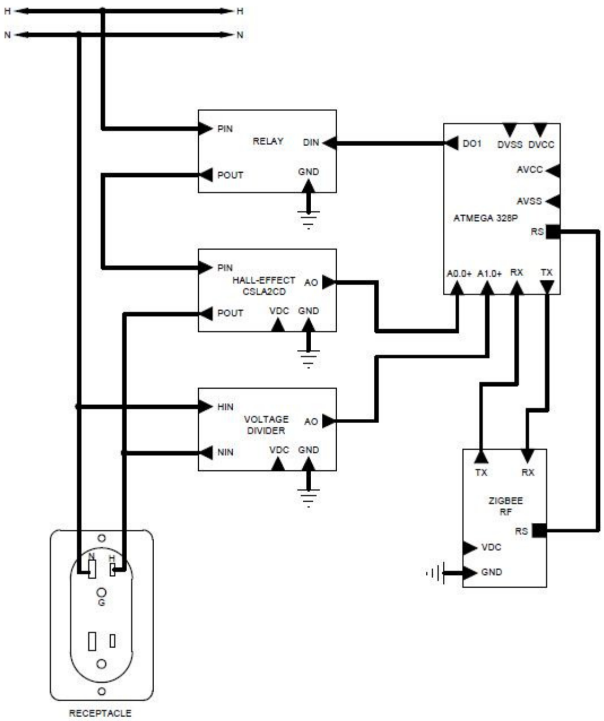

Figure 7. Power Strip Module Schematic

D. Coding

Our code begins with the connection of the power sources to our microprocessor, then an initial system reset. The next step is the hardware setup, including: analog-to-digital converter, digital general-use I/O pins, Clock system, timer, and Universal serial asynchronous receiver/transmitter (USART). With the main power on, the system will check for a signal from the power strip module to ensure proper connectivity. Once this is passed, the energy accumulation phase can begin as seen in figure 61. First, a small amount of time (perhaps 1s) of data is accumulated. Then, a check in the system is made to see if enough data has been gathered for calculations of current, voltage, power, etc. If not, the system returns to the previous step and gathers another second's worth of data. When a sufficient amount of information is stored, the system will move to the next step and calculate the RMS values of the parameters needed. These will be stored and then sent to the wireless transceiver through the SPI/UART (Serial Peripheral Interface/Universal Asynchronous Receiver/Transmitter). After transmission of the data, the system will return to the beginning of the program (but after the initial setup of the clock, port pins, etc) and perform a system check for the main power. The process will repeat indefinitely until the power is disconnected or an interrupt signal is received from the hub microprocessor in the LCD.

E. Printed Circuit Board Schematic

After carefully designing the voltage and current measuring circuits and their connections between Atmega 328 and Xbee modules on the bread board and testing them, our next important task was to implement the same circuit to a PCB. Our main concern here was to do the wiring right so that all the components were able to communicate with each other flawlessly. A wrong design would cost us both money and valuable time which was imperative since the deadline for our project to be completed was close.

We used Cadsoft Eagle for our schematics and PCB design. Although it is a very well developed program we were not able to find all the parts we were using for our project in Eagle's library so it was a time consuming challenge for us to make some of the most complicated parts. Below our PCB schematics is shown in figure 8.

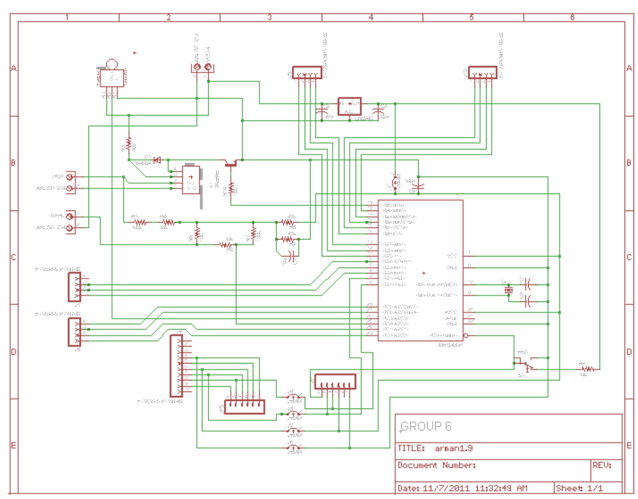

Figure 8. PCB Schematic

After the completion of the schematics we converted the file into a PCB layout. Since our project was about measuring the power consumption accurately, we needed current passing through our PCB. Considering high currents being measured such as 10 Amperes or higher, our trace widths were supposed to be designed accordingly for this high current consumption otherwise this high current we were testing would have burned our board.

Our choice of PCB development house was 'Advanced Circuits' which turned out very convenient for us to work with since they had a very well structured website where we submitted our Gerber files easily and tested our design for errors. Another convenience was to receive our PCB's earlier than the anticipated delivery time. Finally, after we soldered the parts we got to test our Printed Circuit Boards and they both turned out to be working flawlessly.

IV. CONCLUSION

The engineering industry had been built around the needs of the consumer, be it those of individuals, companies, or military corporations. Necessity is the mother of invention (perhaps in our field more than any other), and everything that goes into our jobs and products (what we do for the products we sell, how we do it, and what features go into it) is almost always derived from the end-user's needs and means.

Through the last decade, our country had seen enough financial hardship and stress to suffice for a lifetime, and as a result, more and more people were concerned over every penny that comes and goes through their households. More recently, this had encouraged the practice of trimming the use and overuse of household utilities to save money on everything from gas to water and electricity. While their efforts were certainly applauded, most homeowners were not aware of the numerous appliances that they take for granted which may drain a large portion of their monthly energy budgets. Turning off the A/C in the summer or the heat in the winter is one option that many have embraced, but having the ability to monitor all of the smaller appliances in the home may also help lead to more energy-aware consumers. Thus, the main goal of our project is to aid the homeowner in his goal of lowering his monthly electric bill by showing the power usage as well as the costs of running appliances.

Chris Diller is a senior electrical engineering student at the University of Central Florida and will be graduating in Fall 2011. Before coming to UCF Chris became a licensed journeyman electrician working on commercial constructions projects for four years. He currently interns for TLC Engineering for Architecture a large MEP consulting engineering firm. Chris took and successfully passed the F.E. exam in April 2011 and plans on perusing his P.E. license. Chris will be starting full time with TLC Engineering for Architecture days after graduation in December.

Arman Murat is a senior electrical engineering student at the University of Central Florida and will be graduating in Fall 2011. Before his education at UCF Arman was an entrepreneur in retail. After his graduation he hopes to pursue a career with a prestigious engineering company preferably in Design and Power fields.

Christian Aranha grew up in Brazil until the age of 10 when he moved to the United States. He will be graduating during the Fall 2011 semester from the University of Central Florida with a degree in electrical engineering.

Kurt Riecken is a senior electrical engineering student at the University of Central Florida. He will graduate with honors in the spring of 2012 with degrees in Electrical Engineering and Music Performance. In the following fall semester, he plans on continuing his education in a Master's program.

ACKNOWLEDGEMENT

The authors wish to acknowledge the assistance and support of Mosaic Industries, Arduino®, and Advanced Circuits.

REFERENCES

[1] House, Feng; Yu, Percy, "Implementation of Single-Phase Electronic Watt-Hour Meter Using the MSP430AFE2xx," *Application Report.,* Texas Instruments SLAA494, May 2011.