Smart Home Management System

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***Abstract* — An original high-level electrical and computer engineering project, the Smart Home Management System (SHMS) is a creative and practical project that utilizes modern technology with unique ideas. The objectives of this project are to reduce needless power usage in homes with a system that is effective at reducing power usage and noninvasive to daily lifestyle in a relatively inexpensive and simple way. The system will be powered by a 12V battery. The battery is charged by a solar panel that implements our group designed charge controller and power inverter. The system will enable home consumers the capabilities of turning on/off appliances such as lights, fans, and outlets via a mobile app and a website. In addition, the system will measure live voltage, current, and temperature via relays and sensors.**

***Index Terms* — Mobile app, website, relays, sensors, charge controller, power inverter.**

I. INTRODUCTION

Our population is bigger than ever before and continues to grow. Plus, there are more people that are living in cities than in the past. We are concerned with the power consumption in today’s world. A solution is to develop a home management system that will control and help run most of the household electronic devices more efficiently. The main idea is that with this system, the user will be able to see significant power bill reductions in a simple, nearly completely passive manner. The design of the smart home management system provides people with the luxury of using a smart home, tablet, and personal computer to manage their home electronics. The system enables the user’s smartphone to communicate with the power outlets, lights, and fan. In case people want to use their personal computers to monitor their homes while they are away, this task will be possible via a website where the user will be able to monitor their use of electricity and control their electronics. The website will provide access to a history of power usage throughout the day. In addition, the user would be able to determine which electronics are consuming the most electricity and identify those devices which are inefficient and should be replaced with more efficient ones. This way, it could be easily seen how much power is being used and how much money is owed to the power company on a daily basis, encouraging the conservation of energy. On top of that, the monitoring system will discourage consumers from wasting electricity on devices that are not in use since the consumers can see how much they are being billed which hopefully will provide a sense of urgency to the consumers to conserve energy and use it wisely.

II. PROJECT OBJECTIVE

The first ability is the ability to control the system by any android powered portable device via Bluetooth connectivity. The second ability is to implement connectivity to a local area network (LAN) via a router that allows connection to the LAN from any location by use of a virtual private network (VPN). By this method, the user can control their home electronics from any distant location on the planet that is internet accessible. The system features functions such as monitoring power usage for each power outlet, as well as being able to toggle on/off the power outlets, lights, and fans, both from the website and the mobile application.

We have created multiple modules for switching power on and off as well as monitoring current. A current flow and current measurement module are in series with each outlet in the system. The current used will be measured using a Hall-Effect current sensor. The main control device is an ARM Cortex-M3 microcontroller from the Texas Instruments Stellaris line of microcontrollers. The microcontroller handles communication with the website and the mobile application, toggling devices on/off and performing analog-to-digital conversion. Other additional features to the home management system are passive infrared (PIR) sensors that detect motion and toggle lights when movement is detected, and a temperature sensor to provide the user with real-time indoor temperature status of their home. The microcontroller will be receiving and transmitting this sensor data that the user can monitor via the mobile application and user website. The user will have the ability to cut power to any appliance or many appliances at the same time. This is accomplished by assigning device ID’s to each power outlet, light and fan. With each device having its own ID, the user can signal which one to toggle on/off, causing the respective pin on the microcontroller to go high or low.

With the project's expectations in mind, the wireless communication will require a device that can allow data to be transmitted between the units in distance of possibly 35 to 60 feet. As houses do not always come in convenient, tiny box shapes, the device used must reliably send the data from the measuring units to the display units, which would be set in a central location within the domicile. If the measuring units created a peer-to-peer network to pass along the data to the main unit, perhaps that could solve any issues in larger facilities. Also, with a wired network, data reliability must be taken into consideration and preserved over the existing power line infrastructure of the house.

The software goals of the project are to ensure that the user will want to save energy in a simple, passive way. The graphical user interface (GUI) for the project is a clean enough display that will not be distracting, but still informative enough that the user will want to look at it often. Also, the GUI must be responsive enough that the user does not feel frustrated while waiting for a window of their energy usage, by offering them many options to customize their experience. The demands of the project required the use of a microcontroller that could handle the potential constant transmission of data to and from the website and mobile application, while also sampling current and voltage to determine power factor calculations. This would be done by means of feeding sensor data into the integrated 10-bit, 500 kilo-samples per second (kSPS) resolution analog-to-digital converter. Additionally, the microcontroller is deemed to be small enough that the size of the sensor units would not become an eyesore to home buyers and will still remain applicable in an end user situation. Analyzing the project demands, a field programmable gate array (FPGA) would be overkill since there isn't heavy data processing involved. A microcontroller with enough flash memory, UART implementation, and a sophisticated analog-to-digital converter with the proper handling of interrupts is what's essentially needed for this project.

On a large scale, the smart home management system should be self-sustaining, utilizing no additional power from external sources to power the control system. Additionally, it would be practical to incorporate a large battery bank in order to handle a large load of appliances. For the purposes of this prototype, only one battery is used to demonstrate the concept. With the ability to monitor the home from any location that has internet access, the consumers are given the ability to narrow down and completely breakdown consumption of each device, giving the consumers the satisfaction of seeing the power they are saving from their electronic devices, and exposing the consumers to green technology and be energy independent.

III. System Components

The system is best presented in terms of system components. The individual physical modules, whether purchased or designed, that are interfaced to create the final product are described in this section.

A. *Charge Controller*

The charge controller is a vital component in every solar energy system. The purpose of a charge controller is to maintain proper charging voltage on the batteries storing the solar energy. If the input voltage from the solar array rises, the charge controller effectively regulates the charge going to the batteries to prevent overcharging. The use of a decent charge controller consequently extends the lifespan and improves performance of the batteries used in the solar energy system. Charge controller also performs controlled discharges, where it prevents a battery from being completely drained, which could also reduce the lifespan of a battery. The following figure shows the 12V solar charge controller that we are using in our project [1].

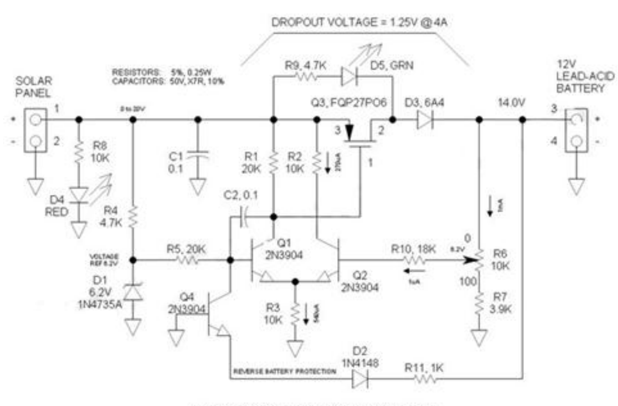

Figure 1 – Charge Controller Schematic

The following are some of the specifications: The solar panel rating is 50W with 4A, 12V nominal, with an open circuit voltage of 18-20V. The output voltage range is anywhere from 7 to 14V, depending on the level of the sun. The maximum power dissipation is 16W, including power dissipation of the transistor, which is D3 in the circuit. Typical dropout voltage is 1.25V at 4A, and the maximum current is 4A, which is the current limit provided by the solar panel characteristics. Voltage regulation goes to 10mV from no load to full load, battery discharge 1mA.

The charge controller includes LED indicators. If the Red LED turns on, it indicates the solar panel is active. If the Green LED turns on, it is an indication of the regulator limiting current meaning that the battery is fully charged or topping off. For dropout voltage, the input voltage exceeds the input voltage by 1.25V when charging at the maximum rate – the lower, the better. Low Dropout Voltage (LDO) is the catch phrase for anything under approximately 2V. This could potentially be reduced to below 1V by making D3 a Schottky rectifier. While current limiting is provided by the solar panel, it is not a commonly understood fact that the solar panel tends to be a constant current device. For this reason, a solar panel can withstand a short circuit. Therefore, the control does not need current limiting. For the float charge of the lead acid battery, this would control charging the battery at a constant voltage and also maintains a charged battery (float charge). The float charge voltage specification is a little lower than the charge voltage, so to accommodate both voltages, a compromise is reached by simply reducing the voltage slightly, which is how all automotive systems operate. To obtain the maximum charge in a 12V battery, the control is set 14V to 14.6V. Automotive systems further reduce voltage 13V to 13.5V in order to accommodate high temperature operation as the battery is usually located in the hot engine compartment, as the battery has a negative thermal coefficient of voltage. To set the voltage, the battery is disconnected and replaced with a 1kΩ dummy load resistor to the output. The resistor is necessary to shunt potential MOSFET leakage current as well as the green LED current.

Now we have the thermal management, which consists of a linear series regulator that dissipates significant power when the pass transistor is both conducting current and dropping voltage simultaneously, during the maximum charge rate when the voltage drop is low, the heat sink runs warm. When the battery is fully charged and there is low charge current, the heat sink is cold. However, when the battery starts to top off at the maximum voltage, the heat sink runs very hot; such is the nature of a linear regulator. At 4A, Q3 drops to 3.3V (assuming solar panel voltage is at 18V) and the remaining 0.7V is the D3 voltage drop P = 4A *3.3V = 13.2W. The heat sink is rated at 3.9°C/W, so the heat sink temperature rise to 13.2W * 3.9°C/W = 51.5°C. In addition, the 25°C ambient temperature results in a heat sink temperature of 76.5°C. While this may seem very hot to touch, it is still cool to the transistor that is rated for a junction temperature of 175°C.

The following figures illustrate the charge controller data obtained from testing throughout the process. An input point of 14.63V and output point of 13.95V were chosen as these values were best suited for the circuit.

3		Input	Output
4		14	13.34
5		14.12	13.44
6		14.2	13.51
7		14.3	13.61
8		14.41	13.72
9		14.49	13.82
10		14.63	13.95
11		14.74	14.06
12		14.93	14.258
13		15.12	14.46
14		15.28	14.65
15		15.4	14.74
16		15.62	14.95
17		15.73	15.06
18		15.84	15.16
19		16.04	15.36
20		16.27	15.59
21		16.49	15.8
22		16.71	16.03
23		16.93	16.25
24		17.12	16.4

Figure 2 – Charge Controller Data (Input vs. Output)

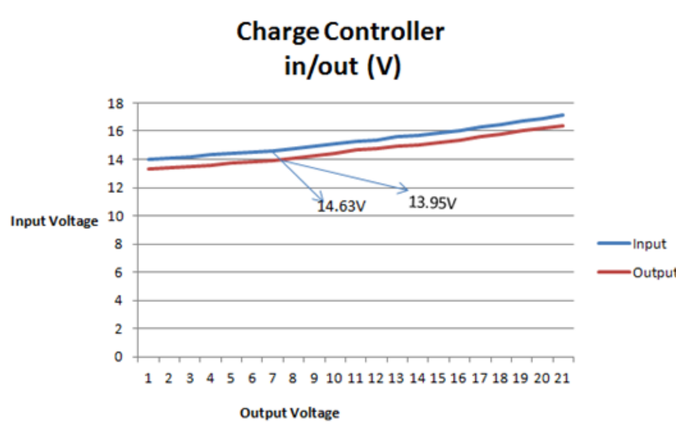

Figure 3 – Charge Controller Graph (Input vs. Output)

B. Power Inverter

Using energy acquired from the sun to power most everyday appliances would not be possible without a power inverter. Since batteries store the solar energy in a form of low DC voltage, a power inverter is used to convert it to a high AC voltage, typically 120 volts AC. This is the same voltage that is made available by utility companies in North America, as well as other parts of the world. Although an inverter's purpose is to convert a DC voltage to an AC voltage, not all inverters achieve the same outcome. The quality of the power inverter depends on its ability to create a clean AC signal. If voltage is measured with an oscilloscope at any traditional power outlet, the resulting signal would be a 120 V AC rms sine wave. The IR2153 integrated circuit gate driver controls the power inverter. This integrated circuit is much better than the 555 timer, since it has two outputs specifically designed for driving MOSFETs, also with protection against under voltage (low supply voltage). The following is the schematic of the power inverter circuit used in this project [2].

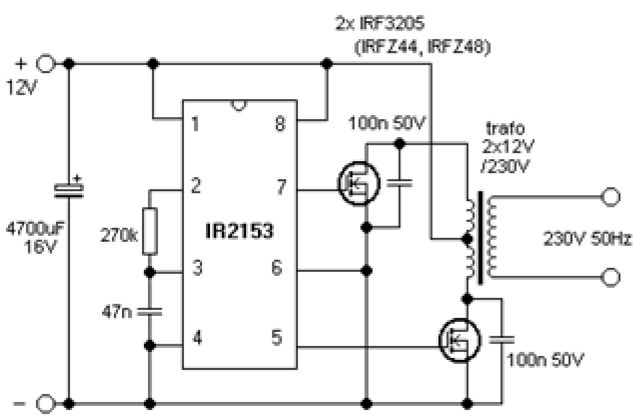

Figure 4 - Power Inverter Schematic

When it was first tested, we had erroneous data as the circuit was not working properly. After troubleshooting the circuit, we found the capacitor being used was too big, so we went in and changed the capacitor to a smaller value several times. Following that, we were then able to read some more accurate values. We started with 12.13V that was what coming out of the battery and the output of the power inverter was 108.96V AC, 56.3Hz. After the battery voltage increased, the output voltage of the power inverter also increased. This time, we were reading 116.86V AC for the output and the frequency was 59.3Hz. However, when 13.0V DC was applied to it from a DC power supply, the power inverter output was reading 117.2V AC with a frequency of 60.1Hz.

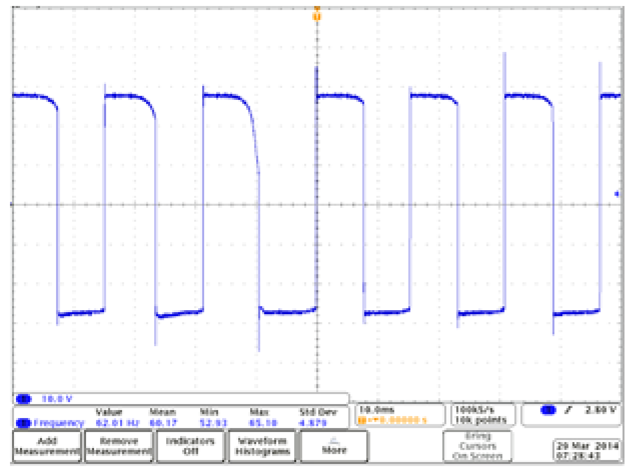

Figure 5 – Power Inverter Waveform

This is good for a high efficiency and reliability. The transformer is a main one with two 12V secondary windings which must be designed for the maximum load required. The heat sink of the two power transistors must have heat sink according to the load. They are mounted on isolation pads. We used one separate heat sink for each transistor and no isolation pads, while also making sure that the heat sinks are not touching each other and must not be grounded. The source must be sufficiently hard; the supply voltage should be in the range of 9-14V. If the supply voltage is lower than 9V, the IR2153 is turned off, preventing damage to the battery, inverter or powered unit. The supply is suitable fuse. In appliances that are not dependent on the frequency of 50Hz, the frequency would have to be changed accordingly. The model of the previous circuit used 50Hz, which we modified to give us about 60Hz, the frequency of mains power in North America. This reduces the standby power. The way we made the change was to change frequency by adjusting the values of Rx and Cx. We made Rx lower and the Cx bit bigger. It is also easy to modify the system from 50Hz to 60Hz just by reducing the oscillator Rx value by 1/6 which is from 270k to 220k. Although the MOSFET can be IRFZ244 for loads up to 200W, we chose to use the IRFZ48 which supports up to 350W. This type of DC/AC power inverter has non-stabilized square-wave output voltage.

C. *Relay*

The use of relays in this project is important to implement automatic switching of devices and lights. Relays are to be used by the microcontroller to electrically switch on/off a device or light appropriately when required. There is no question that this type of device is suitable and in fact necessary for this application. However, relays come in many different types, some being suitable for specific applications, while others suitable for multiple applications. The most command types of relays include electromechanical relays, reed relays, and solid state relays. The type of relay selected in this project was the solid-state relay. Since solid-state relays have no mechanical parts, their life expectancy is significantly higher than an electromechanical or reed relay. When there is no gate drive on the MOSFET, the drain-source channel on the MOSFET has a very high resistance providing the disconnection between the contacts. Although solid-state relays are not as robust as electromechanical relays and are susceptible to damaging surge currents, solid-state relays are still very useful in both DC and AC applications, even in high voltage scenarios. Solid-state relays are also silent since they contain no moving parts when switching.

D. *Battery*

There are two kinds of lead acid batteries. The first kind is a cranking or starting battery and it is used primarily in motor vehicles for delivering high amperage levels for short period of time at the vehicle's start. Physically, this battery contains a higher density of thin lead plates that assist it in performing this function. The second kind is a deep cycle lead acid battery. The deep cycle variety has thicker plates, which allow it to withstand the physical demands of a charge-discharge cycle. This type of battery is used in marine and electric vehicle applications. This second type of battery is what is being used in this project. Particularly, the battery selected is rated at 35 Ah, which is more than enough for the prototype to power low wattage devices.

E. *Microcontroller*

Since the goal of the project is power consumption, we need to find ways to use energy more efficiently. We researched a lot of energy efficient microcontrollers, and we settled on the Stellaris LM3S8962 from Texas Instruments, which is an ARM Cortex-M3 based microcontroller. The reason that specific one is appealing to us is that it's a high performance device with low power consumption. Some of the microcontrollers out there sometimes have trouble dealing with high voltage; some of their features become unstable or even unstable at different voltage levels. In some cases, their inaccuracies in analog peripherals, the limited operation, and the inability to write to non-volatile memory prevent designs from running at low voltages. All those problems lead to short battery life. The Stellaris family from TI spares us from those entire headaches. Another feature that makes it the ideal microcontroller for us is the fact that it contains an embedded web server. The web server uses lightweight IP (lwIP), which is an open source TCP/IP stack. The lwIP TCP/IP stack has the following features: Internet Protocol (IP) including packet forwarding over multiple network interfaces, Inter Control Message Protocol (ICMP) for network maintained and debugging, User Datagram Protocol (UDP), including experimental UDP-lite extensions, Transmission Control Protocol (TCP) with congestion control, RTT estimations, and fast recovery/transmit Dynamic Host Configuration Protocol (DHCP), Point to Point Protocol (PPP), Address Resolution Protocol (ARP) for Ethernet, AutoIP automatic link local IP configuration, Specialized raw API for enhanced performance, Optional Berkeley like socket API Supports multiple network interfaces and connections [3]. The Stellaris LM3S8962 microcontroller is based on the ARM Cortex-M3 microcontroller version. It has been optimized for single cycle flash usage, which provides outstanding performance. Cortex-M3 is also the only ARM processor core with deterministic interrupt processing, a required feature in deeply embedded microcontroller applications, and offers other features especially for the microcontroller market. Most importantly, the LM3S8962 requires no assembly code allowing everything to be written in C. The performance of the Stellaris MCU is at least 2 to 4 times faster on typical control applications using half the flash memory for the same code.

IV. USER INTERFACE

This project is greatly centered on allowing people to use technologies that they have at their disposal to individually switch on/off each power outlet and light source in the home. Many devices, more so inefficient ones, consume considerable electricity when not in use. Standby power is an issue that many people overlook, costing billions of dollars of wasted energy nationwide. We realized that people may not be willing to unplug a device every time that they have no use for them. Having people manually unplug all devices connected to the power outlets would remedy the situation, but for most, the constant action of plugging/unplugging devices is left to be desired. Therefore, this project is set out to eliminate the existence of standby power by giving the homeowner ultimate control of the electricity flowing through each power outlet, as well as light fixture. The solution to this would be to provide the homeowner with this ultimate control directly in the palm of their hand.

The need of a database is required in order to enable the user to have control of the smart home features. This is a requirement to maintain the security of the smart home management system. If unauthorized access to the system were to occur, an intruder could maliciously gain control of the home's automated features. Although still not perfectly secure, the database would provide an additional line of defense by requiring the user to input the correct user identification and password information in order to gain access to the smart home management system. In order to achieve these tasks, a properly configured relational database written in MySQL is required. The database takes a name, a username, and a password in order for an account creation to be initiated. Those data are saved in the database. Once that user tries to access the site, he/she will have to enter the username and password and the information will be compared to the ones saved in the database. If they do match, the user is granted access to the sites otherwise no access is granted. Being able to insert or retrieve data from the database will be made possible with the use of PHP. We are using PHP and MySQL to connect to a local host, which we will have to store data. The website is a combination of PHP, CSS, and HTML. Before a user can access the features of the home, which are turning on/off lights, fan, and outlets, that user should first create an account; the creation of the account is made possible with the help of the database. The database will take the information and save them. Once that user has an account, he/she will be able to use the options provided on the webpage to control all those features mentioned above. The main web page contains six buttons, two of the buttons are turning on/off lights, one of them will be used to turn on/off the fan, and the other three will be used for the outlets.

The reason why we have three for the outlets is that one of them will be used to turn on/off one entire outlet, and the other outlet will have a button for the top and a button for the bottom. The way it works is that if something is plugged in the top on and the bottom one is not being used, the home owner can just cut off electricity going to that bottom one and vice versa. In order to host the website, we are using an embedded web server on TI Stellaris LM3S8962. We entertained the idea of using a web hosting site, but had to put aside that idea because we were having trouble getting the features that we needed. Some of the hosting sites supported different kinds of databases, and every single option that we considered had pros and cons. In the end, we went with the embedded web server accessible from a local area network. That decision was easier for us due to the fact that we would not have to pay for hosting.

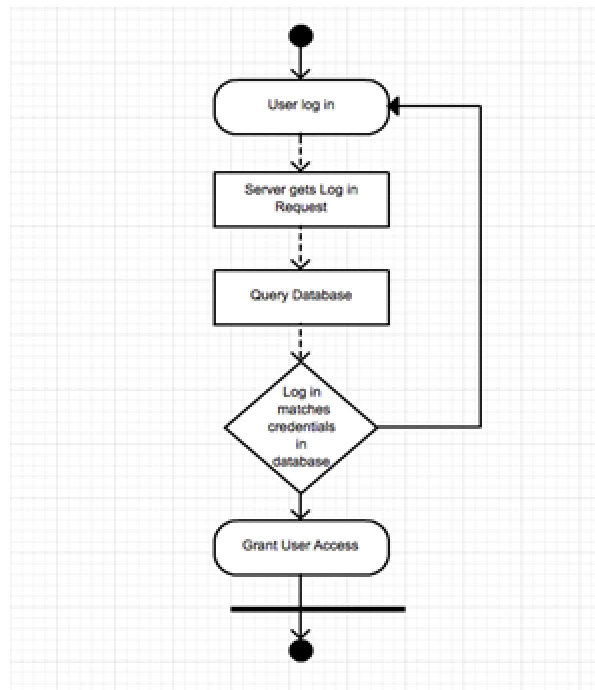

Figure 6 – Website flowchart

The Android app on the other hand is close to what the website is expected to do. It too contains six buttons with two for the lights, one for the fan, and three for the outlets/ the only difference is that there will be no user log in is required. It also keeps track of which lights/outlets are turned on or off at any given time. The Android app is intended for convenient use within the home. Since its communication with the microcontroller is via Bluetooth, the range is limited at up to 60 feet.

V. POWER FACTOR

The derivation of power consumption is a feature included in this project that is meant to provide the use with information regarding how much power an arbitrary load consumes. With this information, the user is able to keep track of the amount of money spent on energy usage. To obtain a derivation of power consumption, the amount of current being drawn by the load must be determined. To accomplish this, a Hall Effect senor is used to obtain the current flowing through the load in series. The part chosen is the ACS714 from Allegro Microsystems. The output of the Hall Effect sensor is an analog signal that varies linearly with the bi-directional AC sampled current. The particular Hall Effect senor chosen can sense a range of plus/minus 20A. With no current flowing through the sensor, the output voltage is ½ of the supply voltage. While there is current flowing through the sensors, the output voltage varies 100mV for every 1A of current. For example, if the supply voltage is 5V, the output voltage is centered at 2.5V and changes by 100mV per ampere of output current, with positive current increasing the output voltage and negative current decreasing the out voltage. The output voltage is then fed into a 10 bit analog to digital converter that samples the signal. The following equation is used to convert the data obtained from the analog to digital converter to a current value in amperes, where ADC_Val is the sample obtained from the analog to digital converter, Vcc is the supply voltage, and I_{RMS} is the RMS current.

$$ADC\_Val = \frac{1024}{Vcc} * \left(\frac{Vcc}{2} + \left(I_{RMS} * 0.100 \right) \right) \quad (1)$$

Selecting a supply voltage of 3.3V, (1) can be simplified and solved for RMS current by the following equation:

$$I_{RMS} = 0.0333 * \left(ADC\_Val - 512 \right) \quad (2)$$

The maximum and minimum values for ADC-Val are 1023 and 0, respectively. This suggests that the maximum sensing range becomes approximately plus/minus 17 A, given a supply voltage of 3.3V. However, careful attention must be paid to the amount of voltage being placed on the analog pin of the microcontroller. The tolerance of the analog pin used for analog to digital conversion is 3.3V. With no current flow, the output voltage is approximately 1.65V. Subtracting 1.65 from 3.3 gives 1.65, which leads to a sensing range of approximately plus/minus 16.5A. Therefore, this unit would be able to function properly when used with a typical 15A circuit breaker found in residential homes. Obtaining the RMS current from the analog to digital converter requires sampling the signal for duration of the period. The period is 1/f, where f is the 60 Hz signal. This approximates to a period of about 16.67 milliseconds. The analog to digital converter of the LM3S8962 microcontroller has the ability to obtain 500 kilo-samples per second, equating to 1 sample every 2 microseconds. This means that one can obtain approximately up to 8,335 samples for the duration of the period of the 60 Hz signal, since 16.67 mill-seconds divided by 2 microseconds equates to 8,335. However, this sampling frequency is unnecessary to obtain a legitimate approximation of the signal's amplitude. For instance, obtaining 50 samples in one 16.67 mill-seconds period should deem sufficient to capture the necessary data. This would lead to obtaining roughly one sample every 333 microseconds. The number of the samples taken can be varied to produce a desired result. In calculating the amount of power a load consumes, the voltage across the load must also be sensed. This can be accomplished by use of a voltage divider and full wave rectifier. The voltage divider is used to step down 120 VAC down to approximately 2 VAC. The full wave rectifier is used to rectify the alternating signal as shown.

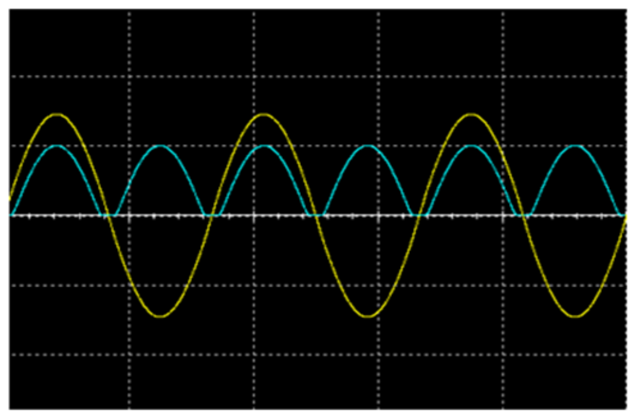

Figure 7 – Rectified Waveform

The rectified signal seen in Figure 7 is then fed into analog to digital converter. Obtaining the RMS voltage is similar to that of obtaining the RMS current in which enough samples must be taken in order to determine the amplitude of the voltage. While it would be easier to use a smoothing capacitor at the output of the full wave rectifier, this would lead to losing important phase information required to calculate the power factor. For loads that are not purely resistive, finding the power factor is crucial in determining the actual power consumed by the load. The following formula is used to calculate the power factor.

$$PF = \cos\left(\theta\right) \quad (3)$$

In (3), the value of the represents the phase angle between the voltage across and current through the load. Obtaining the phase angle can be determined by calculating the time difference between zero crossings of the voltage and current waveforms. Once the time difference has been obtained, the phase angle can be derived from the following equation, where Θ is the phase angle in degrees, f is the signal frequency, and Δt is the time difference between the zero crossings of the voltage and current waveforms [4].

$$\theta = \Delta t * f * 360° \quad (4)$$

By being able to calculate the power factor, one can more accurately determine how much power a load consumes, particularly for non-resistive loads.

Conclusion

Energy conservation and going green has become a top priority in today's society as the environment continues to be harmed by pollution caused by the use of fossil fuels. The motive behind this project is to promote energy conservation methods, as well as the use of renewable energy. The use of solar energy is amongst the most popular forms of renewable energy used today. This project promotes the use of solar energy to power everyday home essentials such as light and low-power electronics. Overall, this has been a successful project. We have demonstrated what we have learned in the class room to the lab. We have learned a lot from this project, from finance, research, time management, and teamwork. These lessons will be very valuable to us as we are moving forward and starting out our careers.

Acknowledgement

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Biography

Danny Aybar is currently a senior at the University of Central Florida and will receive a Bachelor's of Science in Electrical Engineering in May 2014 with a minor in Computer Science. He is currently working at Lockheed Martin Missiles and Fire Control as a student intern and has accepted a full-time position as a Systems Engineer specializing in system integration. He plans to pursue a Master's of Science in Computer Engineering with a focus in computer security.

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