UCF Wireless Solar Panel Monitoring System

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***Abstract* – The purpose of the wireless solar panel monitoring system is to improve upon the existing industry standard of the monitoring the array's total output power. Monitoring only the total output power is great for billing purposes but it is not enough for precise measurement of the real power output from the solar panels. University of Central Florida has requested a monitoring system that delivers closer monitoring, for instance, monitoring of each panel's voltage, current and temperature in an array. These readings should be remotely assessable and the measurements should be updated frequently in real time.**

***Index Terms* – Current measurement, solar energy, microcontroller, photovoltaic cells, solar power generation, voltage measurement, wireless monitoring.**

I.INTRODUCTION

Monitoring and troubleshooting of large arrays of solar panels is difficult and time consuming. A system is needed to regularly monitor each panel or a row of panels that reports any failure or malfunction promptly. The wireless solar panel monitoring system is a set of device which will be hooked on each panel in an array calculating voltage, current and temperature of that panel and sending the data wirelessly to the department of energy of UCF. Knowing ahead of time which panels are affected helps to quickly troubleshoot and correct any problems that may be hindering the solar power system from producing the most energy possible.

The design of this project contains multiple components. A major part of the design consists of the sensors that will monitor the current and voltage being produced by each panel in the system. Temperature sensors will be keeping track of each panel's actual temperature at all times. These sensors circuits will have to accurately measure the current and voltage being produced to an accuracy of within one percent. The next major component is the microcontroller, the choice of which depends on the need to be able to handle the number of analog signals from the sensors, convert them to digital value with enough precision to meet the requirements and send the information out to a serial port in an energy efficient manner. The communication system is designed to accept the serial input and format the information and interact with protocols that will allow the data to transmit to UCF's energy FTP server, in an energy efficient manner. The next major components are the power supply and the inverter. A solar powered power supply will be supplying power to all the sensors and microcontroller in the system. The inverter is necessary to convert all the DC power into AC power and will be tied into the electric grid. Finally the whole system will be put according to the description above and will look like the picture below.

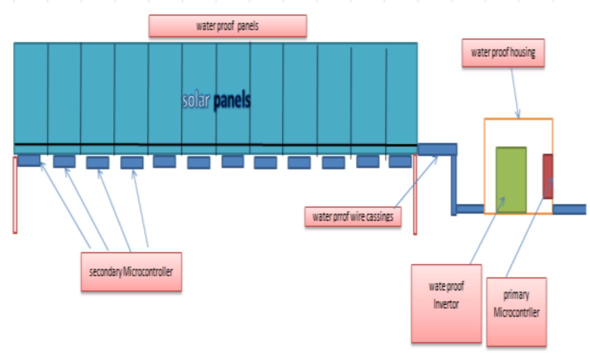

Figure 1: Blue boxes under each panel are where the sensors are installed which then feeds the data into the microcontroller.

The system is designed in such a way that it can be installed on each panel or can be installed on the whole array.

II.SPECIFICATIONS

The project sponsor gave only a few specifications such as cost and type of electrical data, but the designers added others that seemed suitable.

1) The system will consist of one primary unit which is a must and desired secondary units depending upon the number of solar panels.
2) It will be able to monitor the current, voltage and temperature every 3 minutes and transmit the results back to the central computer.
3) It will also have to alert the central computer of any interruptions or problems that can arise in the system such as sudden drop in performance.
4) The size of each secondary unit will be no more than 4x4 inches and the primary unit no more than 6x6 inches.
5) The data will be transmitted wirelessly.
6) This system should have a life of at least 20-25 years.
7) The cost for this system should be reasonable.
8) Must be easy to maintain and easy to install.

III.SYSTEM COMPONENTS

A. Current and voltage sensing

The monitoring system needs reliable voltage and current sensors that will stand the heat and give accurate reading during a rough weather. In addition, these sensors have to be affordable and easy to install so UCF can install one system for each array. The cost was the main issue in looking for the right sensors, so after much research, the current sensor chosen is the surface mount IC part ACS715. It is a low-cost sensor at around $5, reliable in all weather conditions, and can be installed without disassembling the conducting wires. For voltage sensing, a voltage divider circuit was implemented because it is cost-effective and doesn't dissipate significant power.

B. Microprocessor and serial communication

Since our input data is in analog form and our output communication is in digital form, it is necessary to employ some kind of microcontroller for reading, interpreting, and communicating the data. MicroChip's PIC18F87J11 was chosen for its twelve AD converters with twelve bits of precision, FLASH program memory, and internal clock. To simplify testing the prototype hardware and software a serial communications module was featured. A direct wireless connection on ZigBee network is used to transmit the readings from sensors.

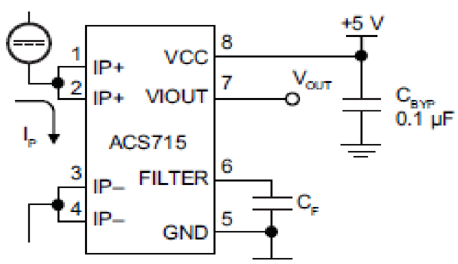

Figure 2. Current Sensor ACS715

C. Inverter

An inverter is a device that is responsible for converting DC to AC. An inverter should not be confused with a converter (regulates DC voltage) or a transformer (regulates AC voltage). An inverter is like a backbone for most solar power systems. The inverters most basic function is to invert DC electricity coming from solar panels into AC electricity with or without a battery connected in the middle of solar panels and inverter. Although there are some appliances and machines that can run directly with DC, most appliances are run only with AC and that is what feeds into regular wall power outlets in households, which makes it necessary to use an inverter with solar panels since solar panels are only capable of producing DC. We chose Fronius lG 3000 which is equipped with an LCD display which can display output voltage and output current. It has its own memory module which keeps the data stored for a certain period of time. Let's say if we wanted to copy the readings for past five days, it will be possible with such inverter. We can easily stick a flash drive and copy the data required. It is water-proof, weather-proof and long lasting, which means we can just hook it up to the panels and set it on a side without worrying about making a protective casing for it.

Figure 3. Fronius Power Inverter

D.Wireless Communication

For our project we will be collecting a lot of real time information, voltage, current, and temperature on each solar panel individually. Once this information is gathered we will use a form of wireless technologies to transfer the information to a location where it can be uploaded onto the internet. From there the information can be viewed from any location with an internet connection. Wireless technology has many benefits that wires cannot give you. The first one and probably the most important is the convenience. The ability to replace dozens of wires stretching hundreds of feet throughout your house with a single wireless router is its biggest advantage. XBee modem is one of the most convenient and least complex ways of designing a wireless network. They are capable of error correction are one of the easiest ways to create a wireless point-to-point or mesh network. They have error correction capabilities and are configured with AT commands (string of characters sent from a Data Terminal Equipment to the Data Communication Equipment while the modem is in a command state). The XBee RF modules are designed to meet IEEE 802.15.4 standards and are extremely cheap and low-power wireless network. The modules require minimal power and provide reliable delivery of data between devices. The XBee RF Modules interface to a host device through a logic-level asynchronous serial port. Through its serial port, the module can communicate with any logic and voltage compatible UART or through a level translator to any serial device. The module's picture and dimensions are shown in figure below.

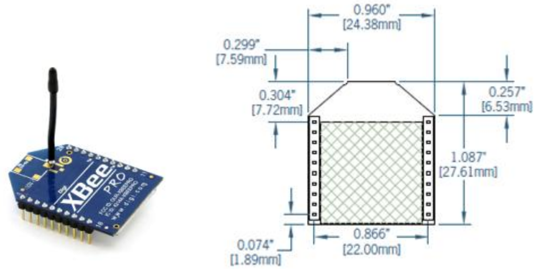

Figure 4. XBee-PRO Module

IV. Hardware Detail

A.Current Sensors

The that is used for the project design is the PCB mounted, low profile ACS712ELCTR-20A-T current sensor. This is a surface mount eight pin device that requires a 5V input voltage and produces a analog output voltage that is a measure of the induced current. Being that this is a surface mount Hall Effect device the current is measured by passing a current underneath the sensor in a copper trace or over the top of the sensor inside a wire. In some situations it may be desired to improve the accuracy of the sensing unit and this can be achieved in low frequency applications by adding a simple RC filter. Such a low pass filter improves the signal to noise ratio and therefore the resolution of the output signal. However the addition of an RC filter to the output of the sensor IC can result in undesirable device output attenuation [29]. The application for ACS712 current sensor can be seen in Figure 5. The noise reduction circuit that was discussed above will probably also be used depending on the amount of noise in the line.

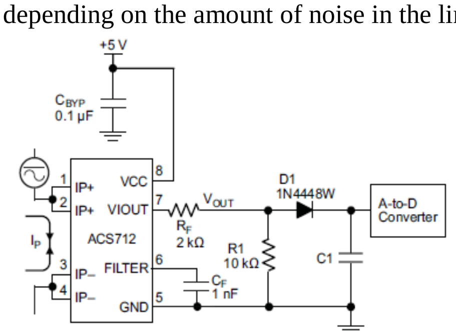

Figure 5. Current Sensor Application

B.Voltage Divider

The maximum voltage that a series-connected solar panel string can produce by law in Florida is 600 volts. Given this information, the maximum amount of power that our resistors must be able to handle has to be enough to prevent damage to the resistor, and our whole device, in case the voltage does reach the maximum value of 600 Volts.

V = 600V; P1 = 1W; I = (P1/V); I = 1.667 x 10−3

As you can see from the calculation above, it is important to not exceed .00167 Amps or approximately 1.60 milli-amps of current through a 1-Watt resistor in order to prevent resistor damage. Sensing circuit was designed to limit this current too far below this value of 1.6 mA as will be shown in the following calculation.

R = 10x10^6Ω; I=V/R ; I = 6x10^−5A

As you can see from this calculation the current will be approximately 60 micro-amps with a 10 Mega-Ohm resistor. This is far below the limit of 1.60 milli-amps for a 1-Watt resistor by a factor of approximately 1000. The following calculation shows the actual power being used by the 10 Mega-Ohm Resistor.

Pres(max) = V x I ; Pres(max) = 0.036W

As you can see the max power usage for the 10 MegaOhm resistor at a max voltage of 600 volts will be 0.036Watts. This measurement actually justifies purchasing lower wattage 10 Mega-Ohm resistors that will still satisfy the job and will likely help us lower our cost of the resistors which is used in the actual implementation of the voltage sensor circuit. Furthermore, as can be seen from the calculations above, we can safely use half-watt resistors or even as low as quarter-watt resistors without exposing our circuit to damage. The following calculations are the maximum currents allowed through a 1/2-Watt and a 1/4-Watt resistor:

I(.5W) = .5W/V ; I = 8.333x10^−4A

Limit will be 0.833 milli-amps.

I(.25) = .25W/V ; I = 4.167x10^−4A

Limit will be 0.416 milli-amps.
The figure 6 shows the circuit chosen for voltage

divider. As seen, for an input of 350V the output voltage is 3.536V. By adjusting the potentiometer, the value 3.5Vcan be obtained. The same for 180V if applied to the input, the output voltage will be 1.815V as shown in figure 6. Also, by adjusting the potentiometer, the value 1.80V will be obtained.

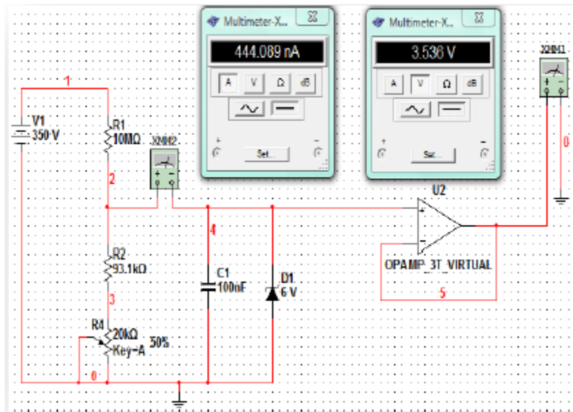

Figure 6: Voltage divider circuit shows an input of 350V and an output of 3.536V

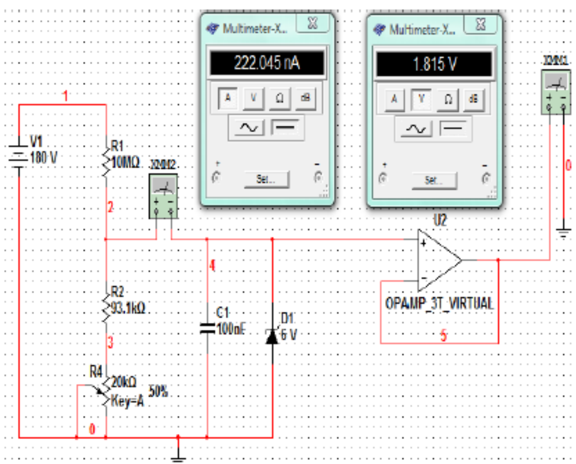

Figure 7: Voltage divider circuit shows an input of 180V and an output of 1.815V

C. Temperature Sensor

Temperature sensor chosen is the LM34 Precision Fahrenheit Sensor. It has an Accuracy of ½°F. It can read temperature reading range from -50 to +300°F. The LM34 has a low output impedance and precise calibration which make it easy to work with. This sensor outputs an analog voltage that is linearly proportional the Fahrenheit temperature +10mV/°F which makes it easy for the microcontroller to understand. To install this sensor, 20 Gauge wire leads is hand soldered to the leads of the sensor to provide the power and ground and to also retrieve the output. These leads will be brought directly to the secondary printed circuit board from the sensor. A picture of the sensor along with its dimensions is shown in figure 8 where figure 9 shows the physical layout of the temperature sensor.

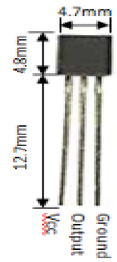

Figure 8. Temperature sensor LM34

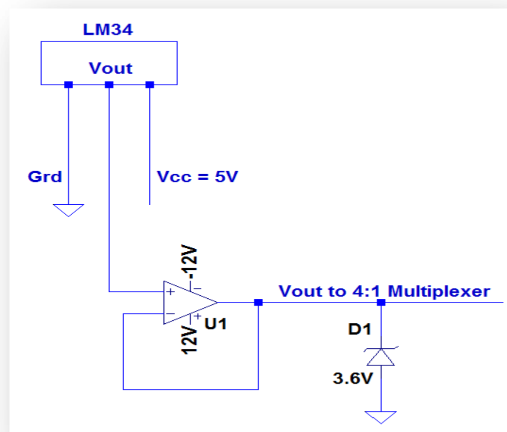

Figure 9. Schematics for the LM34

D. Multiplexers

Now that the data has been transmitted from the measurement equipment down the RJ45 line and to the primary printed circuit board, the data has to be moved to the Microcontroller in an orderly manner. The ideal situation would be to have thirty six analog signals come from the twelve different solar panel monitoring systems (secondary printed circuit boards) into three sixteen by one multiplexers. With this approach we could take all of the voltage measurements from the voltage regulators into one multiplexer, all of the analog current outputs into another multiplexer, and all of the analog temperature sensor outputs into the last multiplexer. From there all of the coding could be done to set the timing of

the multiplexers to read the data in the following manner:
Panel 1: Voltage; Current; Temperature
Panel 2: Voltage; Current; Temperature
Panel 3: Voltage; Current; Temperature
Etc

The multiplexer that was chosen for this project was the ADG409 by Analog Devices. This part is an analog multiplexer with four differential channels. The ADG409 switches one of four differential inputs to a common differential output as determined by the 2-bit binary address lines A0 and A1. An EN input on the device is used to enable or disable the device; when disabled, all channels are switched off. Figure below shows the multiplexer.

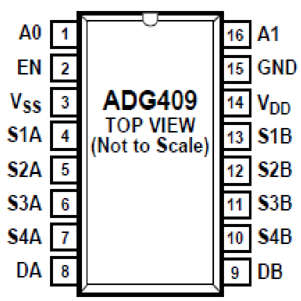

Figure 10. 4-1 ADG409 Multiplexer

E. Microcontroller

The microcontroller that was selected for this project comes from the PIC18 family of microcontrollers. In order to learn how this family of microcontrollers is programmed a development kit was purchased for this line of microcontrollers. "The PIC18 Development Kit is a complete bundle of the essential development tools needed to get started with your next PIC18 application. The kit includes a PIC18 Explorer Board, PICkit 3 Debugger/Programmer, USB cable, and a 9V universal power supply. The PIC18 Explorer Board includes both the PIC18F8722 and PIC18F87J11 microcontrollers and supports dozens of the general purpose PIC18 families using various processor Plug-in Modules (PIMs). PICtail daughter boards enable many different accessory boards to connect to the PIC18 Explorer Board for a flexible and complete development environment. The PICkit 3 allows debugging and programming of PIC microcontrollers using the powerful graphical user interface of the MPLAB Integrated Development Environment (IDE) via USB connection to the PC which also provides power. The kit also includes the FREE MPLAB IDE and FREE PIC18 C Lite Compiler for a complete code development environment. All of this was purchase from Microchip the producer of the PIC18 family of microcontroller. Below in figure a picture of the PIC18 development kit can be seen with all its accessories.

Figure 11. PIC18 Development Kit

The original PIC18 microcontroller is shown in the picture below. It is an 80 Pin Device with 68 I/O pins and is conveniently programmable in C. It has fifteen 10-bit Input A/D channels and 128 Kbit RAM.

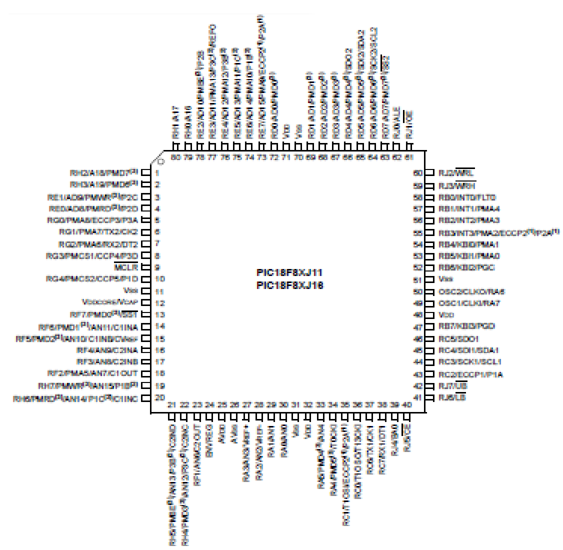

Figure 12. PIC18F87J11

F. Power Supply

The power supply was designed to have a small solar panel that is independent of the solar panel array charge a battery, a lithium ion battery, and that battery will supply the appropriate voltage to the monitoring system. The battery is in the range of twelve to twenty four volts dc because the monitoring system does not require a great deal of voltage. The monitoring system requires somewhere in the range of six to fifteen volts because the microcontroller needs between two volts and three and a half volts while the multiplexers require ±15V. The solar panel should be large enough to provide enough energy to the battery so that it is not depleted. The battery is connected to the solar panel and also to the primary and secondary printed circuit boards providing the power. The power comes from the battery into a terminal block on the primary printed circuit board and from there it distributes through a network of copper traces on the primary printed circuit board. The power is brought to the first two lines on the RJ45 cable and sent out to the secondary printed circuit boards. An approximation of between 4.5 and 5.5 volts is going to be sent to the secondary boards via the RJ45 cable. All of the connections on the primary board are made in parallel so it's the same voltage being used to supply everything. If the connections were made in series it would take a tremendous amount of energy to power the system so, the logical choice is to make all of the connections in parallel. This design provides sufficient energy for our monitoring system without being complicated.

V. SOFTWARE DETAIL

A. Software for Microcontroller

This implementation of solar array monitoring has the virtue of simplicity, which is reflected in the software. All the microcontroller has to do is read the AD converters, interpret this in terms of real voltages and amperages, and then send a formatted message out the serial port to the user. A flow chart for the program is shown in Figure 13. This approach is taken using C programming which controls all the functions shown in the flowchart.

B. Software for XBee

The program used to configure is called X-CTU which helps to configure and upgrade the firmware. X-CTU can be downloaded from a couple of websites which are devoted for XBee's users. After downloading and installing the program we will have to select the COM port and baud rate which is 9600 by default. Flow Control should be set as "None", Data Bits should be set as "8" and Stop Bits should be set as "1". After setting up the X-CTU, the program should like figure 14. And this is all what is needed to synchronize the XBee radios, the transmitter and the receiver, together.

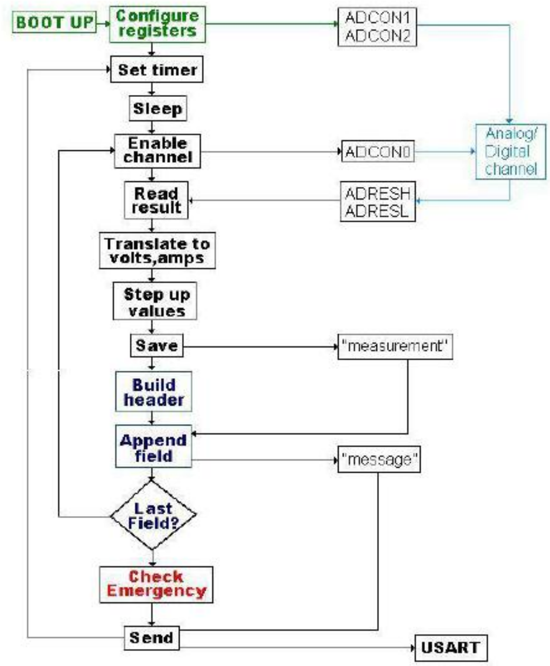

Figure 13. Software Flowchart

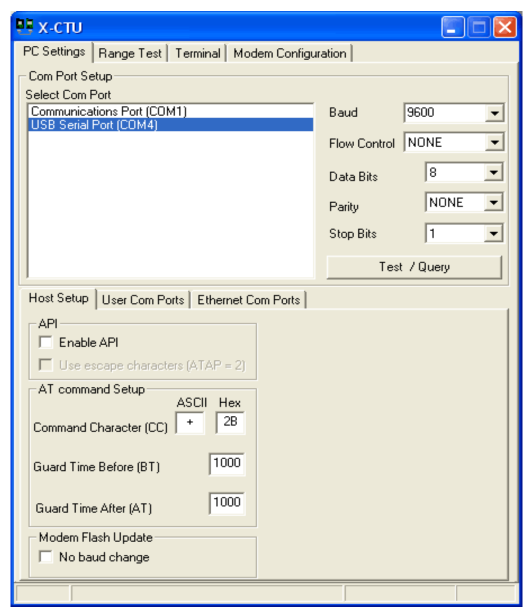

Figure 14. X-CTU Software for XBee radios

C. *Microcontroller and XBee Connection*

The XBee module is connected to the UART port on the PIC in order to communicate between microcontroller and XBee radio chip. To interface the setup in figure 15 is required which shows the schematics for the circuit. We will connect the XBee to the PIC18F87J11through a UART interface. In order to use the TX and RX pins on the microcontroller, Port C must be open so that we can use these pins for USART (Universal Synchronous Asynchronous Receiving and Transmitting). The PIC18F87J11 is capable of both synchronous and asynchronous operation but must be configured for asynchronous signal for the Xbee module. For successful serial communication, the UART's must be configured with the same baud rate, parity, start bits, stop bits, and data bits. On the microcontroller, pin 26 is for transmission and pin 27 is for receiving. We will add a voltage divider circuit to support the input voltage range of the UART serial signal to pin 2 and pin 3 on the Xbee chip.

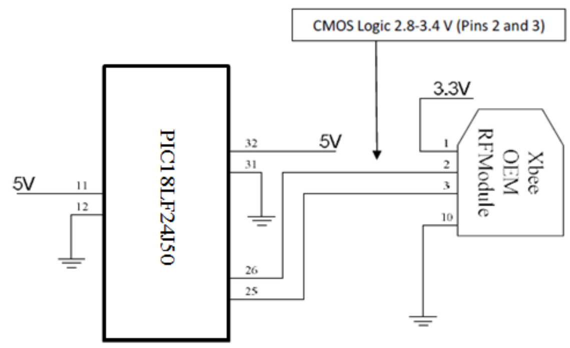

Figure 15. XBee to PIC connection

VI. COMPONENT INTERFACE

All the devices previously listed into a cohesive device and perform as a single mission. This mission is to collect data on the output of the solar device and send that to the internet. It does this by collecting energy for a wireless device by charging a battery. This powers a microcontroller and a sensor that collects that data and sends it to the base-station and that base-station will either display that data or send to the Internet.

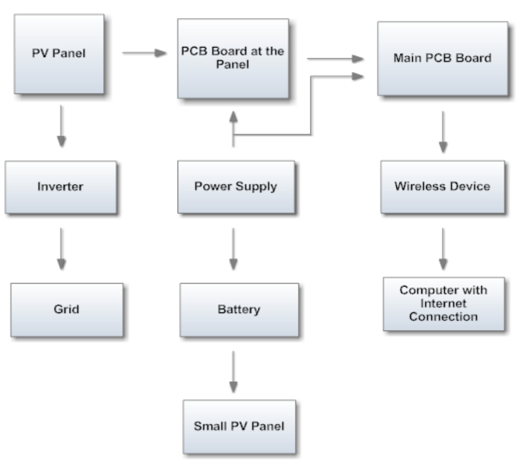

Figure 16. Design Architecture.

VII. GRAPHICAL DISPLAY

A website is uploaded and running showing a similar live data from the panels. A snapshot of the webpage is shown below.

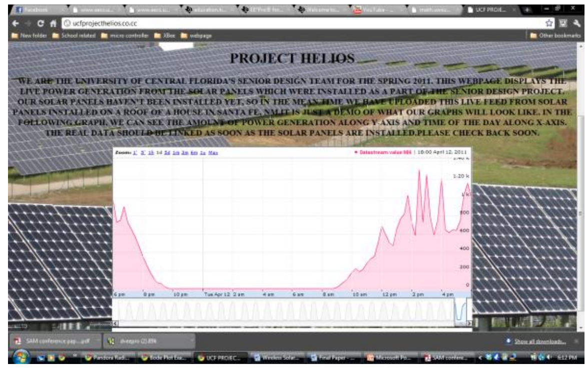

Figure 16. Graphical display of the data

VIII. CONCLUSION

Senior Design takes two-semester to complete, in that time our grouped learned how to meet objectives, work towards requirements, write professional and concise papers ranging from short essays to detailed Critical Design Reviews. It has been a priceless learning experience that has no equal within the undergraduate program and has made all group members better, more confident engineers.

XI. ACKNOWLEDGEMENT

First the group would like to thank our sponsor David Norvell from the UCF department of Energy for providing the idea we could form our project around, and to UCF radio club for assisting us with our programming code and answering our questions. The group gratefully appreciates the help of Dr. Arthur Weeks for spending his time guiding along and providing valuable information to help the group succeed in the project. We would like to thank our project manager and technical advisor Dr. Samuel Richie for his guidance and contributions. We also offer our thanks and gratitude to the professors who have so kindly agreed to review our project we have worked so hard on.

THE ENGINEERS

Michael Peffers, is completing his honor's degree in Electrical Engineering from UCF in May 2011. He is interested in design job and has a potential job opportunity with Texas Instruments. He intends to work on his Master's while he is employed.

Muhammed Khan, is completing his Electrical Engineering degree from UCF in May 2011. He plans to work and possibly get his MBA in a couple of years. He intends to acquire some international and management experience in the near future.

Michael Gannon, a senior student of the electrical engineering department at University of Central Florida is also graduating in May 2011. Going to pursue a working career in the electrical engineer profession and continue studies for Master degree in business administration.

Ahmad Buleybel, a senior student of the electrical engineering department at University of Central Florida. Going to pursue a working career in the electrical engineer profession and continue studies for Master degree in business administration. He intends to open up his own business and is going to pursue the PE license.

REFERENCES

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[3] Ramsey Electronics, "Lead Acid Battery Charger Kit," http://www.ramseyelectronics.com/downloads/manuals/LABC1.pdf

[4] XBee-PRO Module. http://ftp1.digi.com/support/documentation/90000976_C.pdf

[5] LEM, "Current transducer FHS 40-P/SP600," http://www.lem.com/docs/products/fhs%2040-p%20sp600.pdf