Alternative Energy Monitoring System

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1. INTRODUCTION

After any type of renewable energy project is implemented, there needs to be a way to monitor the environmental conditions such as temperature, solar isolation, wind speed, total voltage and total current and power calculations. The intent of this project is to construct a simple, easy to use piece of equipment that can be used both to scout potential sites for wind and solar power collection, and to provide continual monitoring of conditions along with power output for the life of the installation. Products similar to our project are available by companies that install solar arrays or wind turbines; however, our goal is to make a monitoring system that can be set up by a personal user and also for the device to provide its own power in order to make long term use in remote areas feasible. All this will be done while adhering to specific IEEE guidelines in the construction and use of our prototype.

1.2 IEEE Standards

There were three specific standards that this project adhered to:

- Rechargeable battery selection (485-2010)
- WLAN addressing (802.11)
- Conductor protection and fuse selection (242-2001)

The major reasons for selecting these standards were very dependent upon the functions of the subsystems they apply to. Since we wished for the prototype to produce its own power, we needed a way to store energy long term. In order to make sure we selected proper batteries for the project we decided to use IEEE standard (485-2010).

As with standard (485-2010), the selection of the WLAN addressing standard arose from the need to use wireless communication. It is important to note that most of the work for the implementation of this standard was completed through our use of the X-bee model wireless chip-sets. However, we did have to make sure we maintained addressing standards.

The standard for conductor protection and fuse selection was possibly the most important standard utilized in this project. There is a significant amount of low voltage circuitry in the system we constructed, and it was important for us to protect this from any fluctuations that might occur in the process of monitoring a much larger power generation system. We hope that in correctly choosing our components and taking care in our design we can protect our prototype from any reasonable power spikes.

Specification of what was done in order to follow these standards is included in the sections detailing those portions of the project.

1.3 Purpose

The purpose of our project is to design a monitoring system for atmospheric weather and alternative energy generation. The system will be able to take data gathered and store it for later analysis by the user. Additionally, while performing monitoring outdoors the system should be able to handle its own power needs.

Products similar to the one we constructed exist today. However, most are expensive and do not have the remote capabilities or data storage that we have implemented. In contrast to our prototype, these systems track current conditions and do not have the capability for long term storage. With the combined weather and energy production monitoring, our project gives the individual user data that would be difficult to obtain otherwise through use of a single device

2.1 Specifications

Our project was split into two distinct modules. The first is the Main Hub Module (MHM) that is used as the primary communications link between any remote hubs. It also houses all of the data processing, storage, and the main display for the system. The MHM will also gather the data needed from the alternative energy generation system. The second distinct module is the Remote Hub Module (RHM). The RHM is responsible for gathering additional atmospheric data and relaying it to the MHM in order to gain a better sample of the area's actual power generating capacity.

To communicate between the MHM and RHM, wireless communication was necessary in order to cover the area desired. As we intended this project to be for an individual user, the range we needed to cover would have to be sufficient to gain a believable average of the atmospheric conditions of an area a typical user might desire to cover. As the average size of property owned in the U.S. is difficult to determine, we chose a wireless communications system capable of broadcasting outdoors up to 100 meters. This choice would allow our system to cover a maximum area of 7.75 acres of land, with the use of at least four RHMs.

Another major design implementation in our project was the ability for the system to be powered off of a non-grid power source. As our monitoring system would be set up to gather data from an area for a matter of months, the ability to power the system without it being connected to a grid location became a primary concern for project feasibility. In order to overcome this issue we added a solar-battery system. The battery would provide power to the system during periods of time that solar power would be unavailable. The solar cell would be sized such that we would be able to charge the batteries with the excess power generated.

Our project's last specification was the ability to have a straightforward way of accessing and interpreting the data. If the data gathered are too difficult to access, the average user will not be able to perform the necessary data interpretation. As this is the end product of our entire project, a great deal of care had to be taken in order to ensure that our data gathering mechanism would work and keep the data intact even in the event of a total loss of power to the MHM. In order to accomplish this goal, we planned on using a comma-separated format along with an external flash memory module.

2.2 Main Hub Design

The MHM incorporated a large amount of components into its design. One of the main challenges to building the MHM was the integration of the components in a way that would allow us to make changes as needed to the system without having to dissemble the hub each time. We also needed to consider the usability of the hub. Since the main user interface would be in this hub, necessity dictated that there had to be control system and data display LCDs mounted in this hub as well. Careful thought had to be given as to how we would integrate these systems without causing dangerous electrical conditions or confusing layouts.

One main component to this is that we isolated the inputs from outside the hub (sensor and power) using bus bars. This allowed us to change the input location outside of the hub without having to disturb the data lines on the interior. It also provided a certain amount of stress protection for the system as well. If one of the sensors were to fall off or be pulled away, the bus bar would take the stress of that mechanical movement. If the inputs were directly connected to the Data Module or any of the voltage or power modules and this mechanical stress occurred, drastic damage to these modules could occur resulting in the loss of the module or the module working at a sub-optimal level.

Another factor in the MHM design was outdoor conditioning. Since the system would be working on monitoring atmospheric effects, it will also have to be protected against those same effects. While full protection against these types of effects was not implemented, certain design considerations were taken. The LCDs were protected from outside damage using a reinforced polycarbonate. This protection included resistance to water damage and physical damage taken from flying objects. The system as a whole was encased in a metal container. This also gave limited water resistance and physical protection.

Another consideration was weight of the hub. If the hub weighed too much, the system would be difficult to move around by an individual person. However, if the system were too light, there would be the chance that the hub would require a mounting system that would keep it from being easily moved by heavy winds or animals. Fortunately, the battery used in the system gave the hub enough weight without making it cumbersome.

On the interior of the hub, the main design issue that occurred was that due to the amount connections we had, we would have a large amount of extraneous wiring that would be detrimental to the operation of the hub. Mounting the sensor inputs on a PCB solved part of that issue. Running ribbon wire to the LCDs also helped combat the wire nest that threatened to develop inside our project.

Image 1: On the left is the MHM while the RMH is present in the middle of the picture. Both are being powered by the solar panels. As can be seen from a glimpse inside the MHM it took a lot of organizatio for all of the components to fit properly and allow it to close. Image is from a final test run.

2.3 Remote Hub Design

The RHM had similar design issues to the MHM. However, since the operation of the RHM was simpler, some of these issues resolved themselves. The excess wiring issue encountered with the MHM did not exist due to the minimal amount of wires actually needed for operation. Due to the fact that we did not have as many inputs as the MHM or the LCD displays in the RHM, we were able to have a better resistance to water contamination. The main design challenge with the RHM was the limited space that we had to deal with, especially as it pertained to the required battery space. However, due to the small power consumption of the RHM, the battery sizing ended up being a non-issue.

2.4 Voltage Regulation

In the MHM, the voltage regulation originally had two main outputs, +7V and +3.3V. The +7V output was used to power the Arduino Mega 2560. Since the +7V would not interface in charging the battery and the +5V regulator on the Arduino Mega 2560 was able to power all the other circuitry, we used the second input as a +6.3V regulator to charge the battery. In parallel with the switching regulation is a low voltage drop out linear regulator. As the voltage across the solar cell drops due to the atmospheric conditions, the switching regulation will drop out and the linear regulation will keep the voltage out at a constant. To switch between the two regulations, an OR-ing diode configuration is used that chooses which output to use based on which one has a higher potential. When in regulation, the switching regulation has a higher potential and will be chosen over the linear regulation.

Vin	Iin	Vout	Iout	Load	Efficiency
11.973 V	0.232 A	7.0 V	0.333 A	21 Ω	82.7%
11.973	0.330 A	6.3V	0.350 A	18 Ω	79.3%
11.973 V	0.301 A	3.3 V	0.600 A	5 Ω	55.0%
6.1V	0.135 A	3.3V	0.184 A	18 Ω	74.6%

Figure 1: Displays efficiency recording of tests conducted on the voltage regulation scheme.

The RHM voltage regulation worked similarly to the MHM voltage regulation. Notable differences were the fact that there was no parallel low drop out voltage regulation and all the power outputs were based off of the +3.3V out port. The first regulation was set to +6.3V in order to charge the battery leaving the +3.3V regulation to power the Arduino microprocessor and Xbee module. Efficiencies were the same as from the MHM voltage regulation because the same switching regulator chip was used. While the +12V to +3.3V regulation is fairly inefficient, the RHM uses so little power that it did not come into play.

This subsystem was one of the places where the "Conductor protection and fuse selection (242-2001)" was useful, especially when dealing with deciding how to fuse this circuitry. Fusing allowed us to protect the micro-controllers and by extension the Xbees from damage through over-current. Since our most fragile components were the micro-controllers, we based all of the fuses in the circuit on them.

Therefore we limited the current draws to 500 mA, which is about 100 mA less than the controller can support and is sufficiently high that normal operation should never trigger the fuse. Each power source was individually fused making sure that if one failed no other one would interfere with the fuse functioning properly.

Finally, our system used a transformer to help convert grid power into something usable by our voltage regulators as an additional option to power the main hub. The transformer we used in our project was a dry transformer hosted in an open-air setting. Since its power is drawn from standard building power we only fused our lower voltage side of the transformer to help protect it from an over-current situation. Finally, we made sure that our project would not be able to draw any non-linear loads through our AC-DC conversion. The addition was outside the scope and goals of the project but bears mentioning here simply because the (242-2001) standard also has guidelines for transformer use.

2.5 Power Generation and Storage Module

Both the MHM and RHM have a primary power supply of a 12V, 5 Watt solar cell. The backup power comes in the form of a 6V Sealed Lead Acid Battery. Working together, the solar cell provides enough power during the day in which to power the electronics of the system as well as charge the battery. During the night and parts of the day in which there is insufficient solar insolation to pull the solar cell to a high enough voltage to operate, the battery supplies the necessary voltage in order to power the system.

The Sealed Lead Acid Battery had to be sized so that it could provide sufficient power to the electronics of the system for a number of days without sun. We estimated that a fully-charged the system should be able to run off the battery for five days without sun.

Device	**Main Hub Power Consumption**	**Remote Hub Power Consumption**
Arduino Fio	X	0.225 Watts
Arduino Mega 2560	1.2 Watts	X
Xbee	0.15 Watts	0.15 Watts
Data Logger	0.149 Watts	X
LCD Screen x2	1.45 Watts	X
Total Power Consumption	2.95 Watts	0.375 Watts

Figure 2: This is max the power consumption chart for the MHM and RHM.

For the MHM, the power consumption will not always be 2.95 Watts. When not in use, the LCD screens will be deactivated, saving 1.45 Watts of power. Since the LCD screens are only for when the user must check the system, this will be an uncommon occurrence. Hence the nominal power usage of the MHM will be set at 1.45 Watts.

To calculate battery size for the system, we must first convert the power from Watts to Watt-hours. Multiplying the result by 24 hours will give us the power the hub consumes in a day. Finally, by multiplying the result by five days, we will get the total Watt-hours required for that stretch of time. Then we will divide the result by 6V as that will be our battery voltage. This will give us Amp-hours, which is the unit of measure that batteries are rated in.

Battery Rating Amp-hours= Hub Power Usage W*1hr*24hr/day*5day*6V

In order to satisfy the rechargeable battery standards, we used the above equation to calculate that the MHM required a 6V battery with a 29 Amp-hour rating and the RHM required a 6V battery with a 7 Amp-hour rating. Since we are using a low power system, it was not feasible to select a high voltage, low amperage setup to draw from the batteries. But, because of the small amount of power drawn it was acceptable. Also, we selected Lead-Acid batteries because they require very minimal maintenance over a long term and are readily available to replace when they reach the end of their life. Finally, since we used a voltage regulation circuit to obtain multiple available voltages, we were able to ignore temperature correction factor and simply sacrifice a small amount of charge during the cold months for this convenience. Furthermore, sealed Lead Acid Batteries with Amp-hour ratings very similar to our requirements are commonly available. This allows the user the ability to replace their hub backup power supply if the battery looses the ability to hold charge.

2.6 Wireless Communication

The communications block of our project is responsible for transferring information from the remote monitoring boards to the main processing hub. The remote locations are not designed to store any data; therefore we were forced to transmit all raw data from the sensors directly to the main hub before any signal processing was done. It is intended that all wireless protocols utilized in this project are in accordance with IEEE WLAN standards. That means specifically that we will be utilizing full 64-bit addressing instead of any 16-bit shorthand. This specific standard is especially important since this project will be in use around residential living space and there is no way to guarantee that anything less than unique addressing will prevent interference with any other personal wireless equipment available

Each of our Xbees had to be paired with a small microprocessor that was programmed to interpret the data from the analog sensors and serially relay the data to the Xbees. As mentioned in previous sections, all further data processing was to be done by the main hub. Because these stations are self-powering, the amount of power drawn by the wireless system became an important factor. The Xbees take up between 50 and 60 nW when in normal operation and power usage spikes when transmitting data. Therefore, the microprocessors were also required to control the sleep state signals for the transmitters and receivers. In order to save power, in between each data burst all RMHs were programed to place their Xbees into sleep mode.

In regards to the standards, WLAN addressing standards were followed using the non-shortened addressing available on the Xbee modules. They each have a unique IEEE 64 bit address that can be used instead of 16 bit short addressing. Finally, the radio waves and packet construction were both up to IEEE standards simply because we selected an RF chip that adhered to it. As stated in the introduction, most of the standards followed here accomplished by utilizing one of the operating modes available to the Xbees.

2.7 Data Processing Modules

All of the data processing is done through microprocessors. The two microcontroller boards for our project are the Arduino Mega 2560 and Arduino FIO.

Arduino Mega 2560

Mega 2560 is a microcontroller board based on the ATmega2560 with 54 digital I/O, 16 analog inputs, 4 hardware serial ports and a 16 MHz crystal oscillator and runs on 5VDC. This is the main hub that receives the sensors' analog signals. It also wirelessly receives digital raw data from the Arduino FIO, which is used for solar insulation sensor. Using the Analog reference, this microcontroller converts the analog voltage (0-5VDC) to digital output. After some arithmetic, the digital data outputs to two LCDs to display real time parameters of the performance of the green energy system, as well as the status of the system. In additional to displaying information on the two LCDs, the gathered data is stored on a SD card. Overall, this board was chosen due to the amount of analog inputs and digital I/O.

The first LCD is used to display system status, warnings and errors, while the second is used to display sensor information, which updates every second.

Initially, it was decided that the data storage would be done on the Arduino Mega 2560 board, which is why the board was chosen due to its on-board storage size. Since this system is intended to be marketable and to have a simple user interface, the Arduino data logger shield was chosen because of its simplistic storage and extraction of electrical and environmental data.

The data logger shield was also chosen due to one of its main feature, the RTC (Real Time Clock). Since the need for data analysis drove the requirement of having storage, timestamps become necessary in order for the user to understand the differences between the changes in the data on certain days and even over the course of the day.

Another very useful feature of the data logger is that the data is stored on a standard SD card, which can be plugged into any computer easily allowing data to be copied to another machine for further analysis. The overall choice of this device was due to its perfect compatibility with Arduino open-source libraries, "SD.h" and "RTClib.h". This was intended to help a user customize the function of the system to fit their own use, meaning the type of storage format and the intervals between the each time-stamp.

2.8 Sensors

The micro-controllers for our project are programmed to accept input from five different sensor types: Voltage, Current, Solar insolation, Wind Speed, and Temperature. It fell under our project's purpose to construct the sensors in cases where it became evident that doing so would be cheaper than purchasing one.

Voltage: To measure voltage we used a voltage divider circuit. We chose resistor values to scale in a manner that allowed us to read 0 to 4 V over the smaller value resistor. Scaled up, this allowed us a safe, low-current way to measure up to 200 V.

$$\text{System Voltage} = \text{Input Voltage} * 50$$

Current: Current was measured using a commercial current shunt that provided a voltage reading between 0 and 50 mV in a linear fashion to how the current increased. An Op Amp was then used to scale up the voltages by a factor of 100. The scaled voltage was provided to an A/D input on the Arduino Mega. Thus it is possible to attune the system to measure any current range simply by swapping shunts. The one we used for the demonstration allowed for measurements of up to 500 amps.

Temperature: Temperature was measured using a LM335Z sensor that used a temperature sensitive zener diode to track a voltage drop over a 1kohm resistor. The voltage changed according to 10mV per Kelvin. We then converted this number into Celsius for user convenience.

Solar Insolation: Solar insolation was simply a voltage measurement taken over a small load resistor connected to a small solar panel [1]. The small current and voltage range allowed for us to simply use an A/D converter on the micro-controller to pick up the voltage. We then used the following equation to transform that reading into a solar insulation reading.

Solar Insolation Wattsm2= V2RArea*Solar Cell Ineffciency Correction Factor

This is the second place where we were obliged to look to standard (242-2001). This is because here our project is interfacing with a power source that operates outside of power ranges our system was designed to handle. To ensure our system's safety we added a fuse in line with our current shunt to help guarantee separation between our project and any power generating system. This fuse was rated at 250 A to guarantee that the shunt used stayed within its operating range and did not malfunction. This fuse was a low voltage, current limiting fuse as defined in the standards.

3 TESTING AND RESULTS

The final testing of our project was reasonably successful and straightforward and the results are as follows:

Sensors

Solar Insolation Meter: Our solar insolation meter was accurate with less than a 5% error.
Thermometer: Our thermometer was accurate with a 5% error.
Ammeter: Our ammeter was accurate up to a current of 50 amps. This was the highest safe current we could produce with our test equipment and is a good proof of concept for being able to measure up to 200 amps. To do this we would simply have to switch out our shunt for one properly rated and recalibrate our readings.
Voltmeter: Our voltmeter was accurate with around a five percent error. We measured up to approximately 120 volts in the lab successfully. We did discover that there is a 1V floor to our method due to hardware limitations. We deemed this acceptable because our system is not intended to measure small voltages.

Wireless Communications

After we were sure that accurate transmission was occurring between our hubs we tested the strength of our signal simply by taking the box and walking away until we lost the signal and then measuring the distance. The effective distance for our transmitters was 75 feet if there were significant obstructions and around 100 feet if there was nothing between the hubs. This is less than we hoped but still enough of a range to cover approximately half an acre. We deemed this acceptable with the caveat that any new models would have external antennas added in order to improve the range.

Micro-controllers

All of the controllers in our system were tested and deemed to be working appropriately.

4 CONCLUSIONS

After testing our system in both controlled indoor and outdoor tests, we are pleased with its functioning. Besides the physical portion of the wind speed sensor, all of our sensors functioned according within the margins of error we allotted. The wireless communication system also worked the way it was intended to. Though only one remote station was working, we proved the concept well.

It was both very familiar and very different to work with industry standards on our project. While we were used to following similar guidelines in our laboratory classes, the reasoning behind the guidelines are usually self-evident and concrete. For example, any fusing used in a lab is much more likely to be for our immediate safety than to ensure that our project can withstand long-term practical use. Overall though, the experience was a positive one. It gave us all a little forewarning in what to expect when we all enter the workforce and allowed us to gain this practice in a controlled manner before much more might be riding on our design decisions than a simple course grade.

3.1 Possible Improvements and final thoughts

While our system function well, there are a number of design changes that could be made to improve the efficiency and functionality of the system. The first main design fix would be to obtain a functioning anemometer. Our attempts at constructing one were unsuccessful, and by the time we understood it was not feasible to make one ourselves, it was too late to purchase a replacement. Another change would be to increase the number of components mounted onto PCBs. Mounting additional components onto PCBs would help to eliminate excess wiring connecting the different components. In particular, the Arduino microprocessors could be mounted onto PCBs. This would allow a more stable connection to be made to the rest of the hub and prevent wires from coming loose from the inputs.

Another change to be made in the system would be to mount exterior antennas to the hubs. One issue that we ran into was that when the covers were placed onto the hubs, our wireless signal strength dropped noticeably. This prevented us from reaching the full range of the device and significantly reduced the area that we were able to monitor. We were made aware of easily-installed, off-the-shelf antennas capable of interfacing with Xbee modules after we had demonstrated our project.

A major change to the system would be the redesign of the voltage regulation scheme. While the scheme utlized is fairly efficient, higher efficiencies are possible. One way to do this is to incorporate both buck and boost conversions into the same voltage regulation. Doing so insures that if the voltage dropped far enough from the solar cell, the system would be able compensate by moving from the buck regulation we were using to a boost regulation. Another way of increasing the amount of efficiency of the system is to implement Maximum Power Point Tracking (MPPT) to the system. MPPT increases the power output of the solar cell by maximizing the fill factor of the cell.

There are a few different types of RF chips that we could have chosen for our project. However most others were not as simple to use as the serial line replacement option of the Xbee. And, when combined with Arduino's micro-controllers being designed to work specifically with Xbees, they were the best choice under our time constraints.

One alternative would be to use a mesh network instead of serial line replacement. While the stations themselves do not need this type of functionality, it would be a way of extending the feasible coverage area of our project without any hardware changes. This would happen by using some of the remote stations as relays for signals that originate from outside of the hubs final operating radius of 50 meters.

In order to implement this idea we would have to write specific software for both packet creation and a way to assign which hubs need relays and which hubs are to act as relays. This would either necessitate a competent programmer setting up the array, or it would require sophisticated enough software that the end user would need similar amounts of experience to edit the code and not break the network detection software. In the future it would be a great feature to be able to add, if we could get it to run “behind the scenes”. So, even though it was beyond the scope of this project we would endorse attempting to get a user friendly version of this added to future iterations of the design.

Overall, we were satisfied with how the project turned out. While there is room for improvement, we have created a working prototype that, with additional work, could become a functioning commercial product.

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