DEPARTMENT OF
ELECTRICAL & COMPUTER ENGINEERING

UNIVERSITY OF CENTRAL FLORIDA

EEL 4915
Senior Design II

Integrated Renewable Power System Controller

Group 28

Karel Castex

Julio Lara

David Wade

Jing Zou

Sponsored by Progress Energy

Table of Content

Chapter 1: Executive Summary

As the demand of renewable energy increases, solar and wind have become more and more popular among all of the energy sources. However, due to the unstable and uncontrollable nature of natural resources, relying on solar or wind source solely may not be able to produce enough power to meet the demand. Moreover, the performance of a solar or wind system independently can be quite inconsistent. Therefore, in general, wind and solar are integrated together in a power system synergistically to improve the overall stability. Nevertheless, in reality, it is difficult to charge the battery using both wind and solar energy at the same time. This is because source impedances of the wind generator and the solar cell are very different. Moreover, wind and solar increase power system variability and uncertainty. As a result, the group is motivated to design a controller that will make the isolated integrated renewable power system more efficient and stable.

The goal of this project is to design a controller that optimizes the performance of an energy-efficient, standalone, renewable-energy-sourced integrated power system. The group's intention is to design a controller that is able to optimize the performance of both energy sources, control the charging process, and monitor the system in various conditions. The microcontroller-based controller detects the instantaneous variations of both wind and solar source, and then optimizes the charging operation through proper charge controllers. As a result, the entire system of the integrated renewable power system (IRPS) contains a solar panel, wind mill, control box, battery bank, and a power outlet to the loads.

In the overall system, the wind turbine and solar panels collects powers and feeds them to the control box. Then control box sends the inverted power to the battery bank for storage, or it passes the power and diverts to the diversion loads. The wind power charge controller has a rectifier that will convert AC power which collected from the turbine into DC power and then store the power in the Battery Bank. At the same time, Solar PV panels have a different and separate solar charge controller. This controller controls the power coming from the panels to the battery bank. The batteries can supply electricity when the wind turbine and solar panel do not produce sufficient energy for the power consumptions. Since most appliances and other house loads are usually run by AC power, an inverter will be inserted to take DC power from the batteries and convert it to 120 volt AC. Furthermore, for the excess power that cannot be stored in the battery bank, a dump and diversion unit is included to divert it to a resistive load.

Within the control box, several features are added to make the operation on the system more user-friendly and facilitate the testing process in this project. Three LCD screens, including a High Contrast LCD battery voltage, High Contrast LCD turbine amperage meter, and Battery status LCD, are attached to the control box. The LCD screens displays the current live metrics of the system to users as feedback.

Chapter 2: Project Description

2.1 Motivation and Goals

A common interest in power electronics and power systems was the initial motivation that directs the group to develop this project of designing a power system controller. Moreover, inspired by the fast development of innovative technologies, the group aim to advance with times, and apply what was learned in class with real life problems. Additionally, as world population grows, the shortage of resources increases dramatically. The consumption of power and energy increases as well. To conduct a research on renewable energy becomes appealing more than ever.

Renewable energy sources are those have no undesired consequences during the process of power production. All of them have lower carbon emissions comparing to conventional energy sources. Among those renewable energy sources, wind and solar are considered the most environmental friendly forms of energy. However, due to the unstable and uncontrollable nature of wind and solar resource, relying on either source solely may not be sufficient to make a stable and consistent power supply system. Consequently, the power consumption of solar and wind energy are the lowest among all of the renewable energy for the past decade (illustrated in Figure 2.1). In order to increase the consumption of solar and wind energy, a much more stable, consistent, and reliable solar and wind power system need to be developed. One way to improve the overall performance of the system is by integrating those two energy sources together.

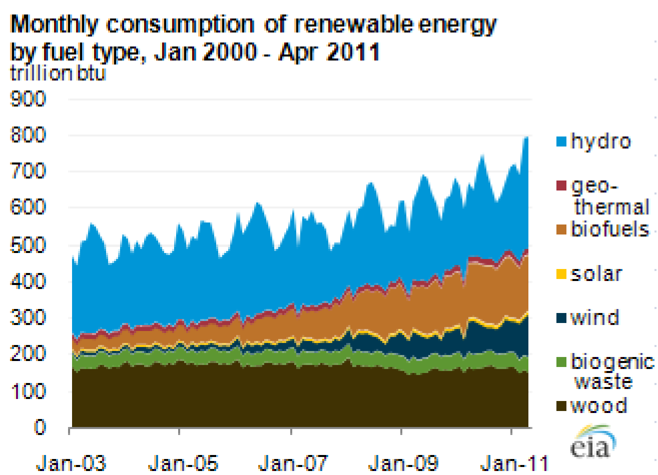


Figure 2.1 Monthly Consumption of renewable energy by fuel type, Jan 2000 – Apr 2011. Permission requested from the U.S. Energy Information Administration (2011).

While integrating the two energy source together may seem to be more reliable of the single sourced system, there still exist elements that will influence the overall stability and consistency of the power system. Therefore, in this project, the goal is to design a controller that can optimize the overall performance of an energy-efficient, standalone, renewable-energy-sourced integrated power system.

2.2 Objectives

The primary objectives of the overall system are small-scaled, self-sustained, energy efficient, environmental friendly, low maintenance, and user friendly. All elements within the system, such as microcontrollers, sensors, and monitoring electronics devices should consume the lowest amount of power as possible.

2.2.1 Small-Scaled

The system is small-scaled, and the purpose is to illustrate the idea of green energy production for average home use.

2.2.2 Self-Sustained

One of the major objectives of the project is that the power system operates independently from other power sources. The system is not connected to the power grid as well.

2.2.3 Efficiency

The most important purpose of the project is to design a controller that optimizes the performance of the integrated system. In other words, it is to make the system work more efficiently. With the intention of doing that, it is essential for the controller to monitor the charging process of the battery and implement a more efficient battery charging algorithm.

To make the charging process more efficient and easier to implement, the case study conducted by Mu-Kuen Chen, Department of Electrical Engineering, at St. John's University, Taiwan was adopted. In his conference paper “The Integrated Operation of Renewable Power System,” he emphasizes the difficulty in integrating wind and solar source with respect to the effect of source impedance. He suggests setting different charging modes to optimize the charging operation [1]. Therefore, the system is able to charge the battery bank by using both sources sufficiently.

2.2.4 Environmentally Friendly

The entire system should not produce any undesired consequences to the environment. The use of renewable energy sources will reduce greenhouse gas emission.

2.2.5 Low Maintenance and User Friendly

The system is portable so that the user will be able to set up the system in a remote location without any external power sources. The controller box will be small in size. There is a LCD screen on the controller box to show the current live metrics of the system, including the input voltage, output voltage, input voltage, output current, and battery charging status. Users can monitor the system any time they want. Moreover, there are buttons for the user to turn on or shut down the system manually as desired. Minimum connections are kept to the controller box so that there will be little confusion at the set up process.

2.2.6 Input 1: Solar Power

Solar Power is generated by a solar voltaic panel. This is rapidly becoming a mainstream way to generate power in the commercial world as well as residential. The main objective of this system is to charge and store energy efficiently into a battery. Therefore the objective of the solar panel is to help accomplish this task. However, the panel alone is not the only component to complete this task. The charge controller and voltage regulators attached to the output of the solar panel plays just as big if not bigger role than the panel itself. With this aside the goal for the solar panel will be to research as many different types of panels and determine which one will be the most efficient choice for our region of the country.

2.2.7 Input 2: Wind Power

Over the last few decades renewable energy has started to gain its ground. Of all the different kinds of alternative energy sources available, the use of wind power has been growing steadily. Wind generators are available for homeowners in the market today, most of them relative easy to assemble. More homeowners chose to have a wind generator to work along with PV panels to make their system more productive. To make a wind generator working efficiently, homeowners also need to purchase some extra equipment necessary such as, rectifiers to stabilize the output AC current, charger controller to distribute the energy where most needed, power divert, and DC-AC converter. However, among all these components the most important in terms of efficiency is the charger controller. Most of the charger controllers nowadays are composed of either simple electrical components or are switch controlled systems. These systems usually are wasting energy by distributing the excess current to the dump load or simply do not charge the batteries efficiently. This design proposes a new way of managing resources by implementing microcontrollers with smart algorithms that charge the batteries faster and efficiently. For this reason a wind generator was added to the design, to show that combined with PV panels the smart controller will handle both sources smartly and efficiently

2.2.8 Control Box

Control box is the project definition for the consolidation of microcontroller unit(s) and sensors which make possible to be knowledgeable about system status. The sensors duty is being on top of system measurements at every moment and be able to feed microcontroller inputs to allow data to be analyzed. Having the microcontroller aware about what is happening in the system will create whole system reliability since critical decision can be taken dodging painful situations where some components can be seriously damaged and further causing system malfunctioning. The control box is the brain with the responsibility of accomplishing this project's main purpose of maximizing energy harvested and making the system work under optimal conditions.

2.2.9 Energy Storage

The performance of the batteries in a renewable energy system is the key to its success. The main objective of the batteries is to maintain the consistency and balance of energy within the renewable energy system. There will be two batteries used in our Integrated Renewable Power (IRP) System to store the energy that is collected by both the solar panel and the wind turbine when there is an excess of supply. Both of the batteries will be used when the power collect by solar panel and wind turbine is not sufficient enough to supply the loads, as well. Therefore, the battery is required to have a large capacity so that users can run the loads at any time as they desire. The battery-bank helps stabilize the system by ensuring that there will be sufficient power supply to the load. The batteries should be low cost, technological matured, and efficient.

2.2.10 Output

The output of the system should reach between 110 and 120 Volts in AC power for the user to plug in electronic devices and run them. The outlet should be safe for both the users and the electronic devices.

2.3 Project Requirements and Specifications

The operation of the system is required to be able to produce steady output power and charging the batteries twenty-four hours a day in spite of the variations of the solar and wind strength. All of the internal components should consume as little power as possible. Moreover, the system must be safe both for the user to operate on and the appliances to work with.

There are three categories of specifications, including power generation, control box, and power charge, storage and delivery specifications. The input and output of each component in every category are related with respect to the amount of power flow in the system. The power generation specifications are shown in table 2.1 below.

Solar Panel	
Output Power	>75W
Open Circuit Output Voltage	>12V
Short Circuit Output Current	>4A
Weight	< 20lb
Wind Turbine	
Output Voltage	>12V
Output Power	> 450W
Generates power at	> 8mph
Size	Small

Table 2.1 Power Generation Specifications

The most important part of this project is the design of the control box. It major parts of the control box are the microprocessor and the LED display. The implementation of the design will be constructed on a custom ordered printed circuit board (PCB). Table 2.2 shows the specifications of the microcontroller and the LED in the control box.

Microcontroller	
Clock Frequency	Low
Serial Ports	Yes
Programming Language	High level similar to C
Programming Memory	≥16K
Analog Pins	Yes
Digital input/output Pins	Yes
PWM Output Pins	Yes
Programming Debugging	Yes
Power consumption	Low, good sleep mode
LCD	
Current Draw	Low
Voltage	Low
Lines Needed	1 to 3

Table 2.2 Control Box Specifications

In order to charge the battery, the power produced by both sources has to meet the input requirement of the battery bank. Therefore, a DC/DC inverter will be inserted at the input of the batteries. While with the purpose of powering electronic devices with AC power, a DC/AC inverter needs to be inserted at the out of the batteries.

Battery Bank	
Voltage	12V
Depth of Discharge	75%
Lifespan Cycles	1000-2000
Efficiency	72-78%
Cost	Low
DC/DC Inverter (Voltage Regulator)	
Maximum Voltage	> 15V
Output Voltage	> 12V
DC/AC Inverter	
Continuous Max Power	1200 - 1500W
Input Voltage	12V
Output Voltage	110-120VAC

Table 2.3 Power Charge, Storage and Delivery Specifications

Chapter 3 Research

3.1 Related Projects

As the fast increasing demand of renewable energy, there are numerous researches on making a more stable, consistent, and efficient. Among the renewable energy related projects conducted by undergraduate university students, almost 80 percent of the projects are on solar energy or wind energy alone. Due to the intermittent and unpredictable nature of the renewable energy source, depending either solar or wind energy source solely is considered unstable and inefficient. Therefore, it was decided to improve the overall stability and consistency by integrating the two energy source together.

A project conducted by a group of senior design students in University of Central Florida has involved in integrating renewable energy. However, their design involves human powered mechanism as one of the inputs [2]. This will increase the system size and cost as a stand-alone renewable power system. Another disadvantage in this project is that the group did not implement an efficient battery charging algorithm. This disadvantage will lower the overall efficiency and quality of the power system.

In addition, another group of senior design students provided more insight to the maximum power point tracking for the solar system which satisfied the requirements of the university's senior design. The format of this paper will be a reference of this documentation.

There is also a project that designed by University of Alaska Fairbanks. The project is to develop a stand-alone generation system for an off-grid remote community in Alaska by integrating renewable energy sources with existing fossil fuel based generating system [3]. This project is designed for a larger scale. Moreover, by integrating with the fossil fuel based generation, there will be more emission produced by the system.

3.2 Solar Power

3.2.1 Advantages and Limitations

Solar power is an alternative power source that is both abundant and clean. However solar power has a limitation which is the main reason it only accounts for about 4% of the world's electricity [1]. The biggest advantage to solar power is that it emits no greenhouse gases, which makes it an incredibly attractive energy source to help curb climate change effects on our planet. A good example of this feat is Italy's Montalto di Castro solar park which avoids 20000 tons of carbon emissions a year [2]. Another enormous advantage for solar power is infinite free energy. Solar does not require any raw materials such as coal or oil to be continuously transported to the power plant adding more cost to the product.

The labor cost is also significantly lower at a solar power plant than a fossil fuel one because the sun and the solar semi-conductors do most of the work. Solar power is largely unaffected by the politics that endlessly drive the price of fossil fuels up. The US gets a large amount of its oil from regions of the world that are extremely volatile or unfriendly to US interests. Prices of fossil fuels have more than doubled in the past decade due to price manipulation through wars and politics [2]. However the sun is an unlimited source of energy and the price has halved in the last decade, and will continue to decrease as the technology to harvest it increases. Furthermore solar power doesn't require us to mine raw materials which destroy the environment. A terrible example of this is Canada's tar sands which is currently destroying the Boreal forest in Alberta which accounts for 25% of the world's intact forest. It also creates toxic pools of byproducts that are large enough to see from space [3].

Despite all of the advantages that solar power has, there are just as many disadvantages that hinder solar power's use as a major power source. The most obvious disadvantage is that solar energy cannot be harvested at night. This is a big problem because during the winter months there are more hours of night than that of day. Sometimes we are unable to collect the suns energy even during the day due to weather and atmospheric disturbances. Another limitation is the inefficiency of the solar panels ability to collect the sun's the light. Currently solar panel efficiency is around 22% which means a large quantity of surface area is required to produce a significant amount of energy [2]. However technology is tirelessly improving this number and will eventually no longer be a limitation to solar power, but at this time it must be listed as a disadvantage. Another limitation lies in the storage process which has not yet reached its potential. The current solar drip feed batteries available are more suited for home use instead of large scale solar power production [2]. The final and most important limitation is the cost of installing solar panels. There is a large upfront cost and is the equivalent to paying for 30 years' worth of power just to install the system [2]. However technology will eventually help bring down this cost as it increases and energy subsidies are put in place by governments around the world.

3.2.2 Solar Cells and Manufacturing Technology

There are many different types of materials used to make solar cells. All of them vary in their cost and efficiency characteristics. For this project the design will be looking for as high efficiency as can be possibly achieved while staying inside the budget. The system will need to charge the batteries as quickly as possible because there are only so many hours of day light each day. Solar panels are broken up into two different categories, silicon and thin film. Silicon has been around and studied much longer making it the more reliable of the two technologies. The efficiency of the solar panels by definition is the ratio of electrical output power to the amount of sunlight received. The equation for the energy conversion efficiency can be seen below in EQ: 3-1 where P_m (in W) is the maximum power point, E (in W/m^2) is input light, and A_c(in m^2) is the surface area of the panel [7].

$$\epsilon = \frac{P_m}{E * A_c}$$

EQ: 3-1 Energy Conversion Efficiency

There are several factors for the conversion efficiency; some of them are reflectance, thermodynamic, charge carrier separation, and conduction efficiency [7]. These aspects can be difficult to determine so the project will be using data found through research of each type of solar cell's specs. As can be seen below in Figure 3.1 which is plot of efficiency versus time the two different types of solar cells which are being considering (silicon and thin film) are both represented.

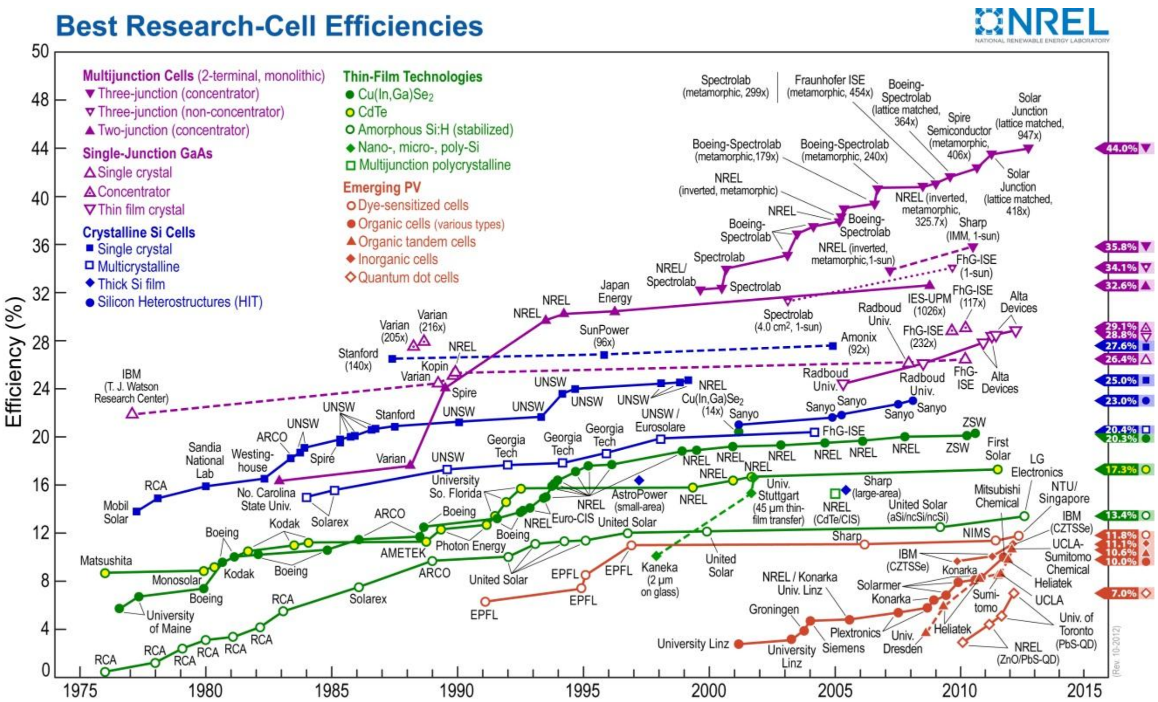


Figure 3.1 Best Cell Efficiencies created by L.L. Kazmerski. This work is from the public domain.

Figure 3.1 clearly tells us that the silicon has a greater efficiency than the thin film technology; however there is a need to study all of the types of materials used in order to make a good decision. Both technology types can be broken into either mono-crystalline or polycrystalline subcategories. A common material used in making mono-crystalline thin film panels is gallium arsenide (GaAs) . Some materials used to create polycrystalline thin film panels are; cadmium telluride (CdTe), amorphous silicon (A-Si), and copper indium gallium selenide (CIGS) [8].

3.2.2.1 Mono-Crystalline Silicon

Mono-crystalline silicon panels are the most efficient and dependable technologies available in the solar panel industry. This is because they are the oldest form of this technology and they have had the most testing [4]. Mono-crystalline solar cells tend to be around 17% efficiency and the other types (polycrystalline and thin cell) are usually about 10% efficiency [9]. This high efficiency means that mono-crystalline silicon will get the most watts per square foot. Since the design will be limited on space and require high efficiency, mono-crystalline silicon seems to be a good choice for this project. However despite the high efficiency of this type of solar cell they can be very expensive. Mono-crystalline panels are also difficult to install because they are extremely fragile which can be an issue when the panels are being shipped to us as well [4].

3.2.2.2 Polycrystalline Silicon

Polycrystalline silicon as the name suggests is made of multiple silicon crystals molded together to make one silicon panel. Polycrystalline or multiple crystal panels are popular for residential use because of their low cost and average efficiency [9]. As stated above the efficiency is not as high as mono-crystalline so it has always been assumed that the mono-crystalline are superior, but this is not necessarily true. After much time spent looking at different companies specs on their products, it is clear that polycrystalline panels vary quite a bit from each other and should be considered on a case by case basis. Some of the examples that have been found include Conergy's Powerplus P series modules have a maximum efficiency of14.13% and Suntech's polycrystalline Pluto technology has been able to achieve a 20.3% [10]. These numbers were of course reached in laboratory conditions, however they are still impressive. The prices for this type of solar panels are perfect for our budget and will most likely be the panel type used for this project.

3.2.2.3 Thin Film and Amorphous Silicon

Thin film and amorphous silicon panels are the newest generation of solar technology. Thin film panels can be produced out of many different compounds that were mentioned earlier in this chapter. Once the thin film is manufactured it is usually placed between two glass panels to protect it, this will make the thin film panel quite a bit heavy then its silicon counterparts. The semiconductor is place between the glass plates. A flexible laminate can also be used to protect the semiconductor. The laminate is becoming more commonly used in thin film panels making them cheaper and faster to produce, because the entire panel is considered a solar cell.

There are many advantages to using thin film technology. The laminate makes them flexible and easier to mount on uneven surfaces. This means that thin film panels are also more durable from weather damage. If a thin film panel is damaged it will still work at a lesser rate. This is not true with silicon solar panels, when one cell is damaged the entire panel will not work at all. The use of laminate thin cells can also be more useful in residential applications because the traditional roofing materials can be replaced all together with the thin film panels. This is possible because of how much less thin cells weigh compared to its silicon counterpart. Thin film panels also work much better under hot conditions. They will not lose nearly as much efficiency as the temperature increases. This makes thin film cells a good choice for hotter climates such as the Southwestern region of the United States. Thin film panels also perform better than the competition in the shade and low light conditions. However thin film and amorphous silicon also have some disadvantages.

The most significant of those disadvantages is their efficiency. Thin film panels range around 4% - 7% efficiency [11]. This means that more than twice as many thin film panels are required to produce the same amount of power as its silicon competitors. This is the main reason thin film technology has not replaced the silicon technology. The efficiency has not quite matured yet, but it could surpass the efficiency of the silicon panels by 2020 [11]. As exciting as this new technology is it will be difficult to implement it in this project at its current efficiency level. The silicon panels will be needed for more testing due to the inherent inefficiencies of thin film technology.

3.2.2.4 Copper Indium Gallium (de)Selenide (CIGS) Thin Film

Copper Indium Gallium Selenide or CIGS is another type of thin film semiconductor material. CIGS is a material that strongly absorbs sunlight thus requiring a much thinner film than other semiconductor materials. CIGS absorption coefficient (10^5/cm for 1.5 eV) is higher than any other semiconductor used for solar panels. CIGS is mainly used in the form of polycrystalline thin films and the best efficiency was achieved in December of 2005 at 19.5% [17]. Higher efficiencies around 30% can be achieved with the use optics to concentrate the sunlight onto the panels. The market grew for this PV at a 60% annual rate from 2002 to 2007 [16]. Like other thin film panels the CIGS compound is layered on a glass back plate. Since so little of the material is needed the CIGS thin film panels are extremely light weight. Due to the ever increasing efficiency associated with CIGS panels their production is projected to increase rapidly in the future. Unfortunately these panels tend to be extremely expensive due to their vacuum based fabrication process [17]. Therefore CIGS thin film panels will not be considered for the solar panel of the project.

3.3.2.5 Cadmium Telluride CdTe Thin Film Panel

Cadmium Telluride or CdTe was one of the orginal materials used in thin film technology to try and improve the low efficiencies experienced with amorphous silicon. Like CIGS, CdTe is also manufactured on a glass substrate. CdTe is the most common and the most cost effective type of thin film technology on the market currently. Similar to CIGS CdTe panels perform better in the shade and low light conditions than silicon does. Unfortunately CdTe panel’s efficiency maxed out in 2001 at 16.5%, and their average efficiency is around 7% to 12% [18]. Another disadvantage to the CdTe thin film technology is that Cadmium is extremely toxic and Tellurium supplies are scarce. This leads to CdTe panels being exceedingly expensive and toxic to people and the environment.

3.2.2.6 Gallium Arsenide GaAs Thin Film Panel

The final type of solar panel to be discussed in this research is Gallium Arsenide or GaAs thin film panels. Like CdTe panels, GaAs panels are extremely expensive and toxic. Gallium is an extremely rare material and Arsenic is a very poisonous substance. People can become very sick and possibly die if the panel gets damaged and the semiconductor is exposed. However the efficiency of a GaAs thin film solar panel is quite a bit higher than that of a CdTe panel. GaAs efficiency averages around 20% to 25%, with a record near the 30% mark [19]. This is because GaAs as a semiconductor material has a nearly ideal band gap. Like the other thin film types of material, GaAs has insensitivity to heat thus helping the efficiency rating. Not only is GaAs resistant to heat, but it is also resistant to radiation. This makes GaAs solar panels ideal for space applications. However the disadvantages of GaAs far outweigh the benefits and will not be further pursued for this project.

3.2.3 Photovoltaic Effect in Solar Cells

To help make the decision of which type of solar panel would fit the needs of this project this paper will have to discuss how the solar cell actually works briefly. Solar cells are made of semi-conductors which respond to the sun's light. The determining factor of how the semi-conductor will respond is the band gap [13]. Silicon or Germanium is the most common types used because they are abundant and engineers understand how they respond quite well. The sun's light is made up of different types of light which have different energies levels. There is the low energy infra-red light, the intermediate energy visible light, and the high energy ultra-violet light. The Earth's atmosphere and magnetic field protect us from the harmful ultra-violet light so solar panels on the surface of the planet don't need to worry about this type as much. No one semi-conductor has a band gap that can respond to the full range of the sun's light [13]. Solar panels have been invented that can respond to the full spectrum of the sun's light by layering different types of semi-conductors with different band gaps in series [13]. However the manufacturing process of these panels is extremely difficult and expensive, therefore they are not readily available to the consumer market.

The solar panels which are in the consumer market are usually made up of one or two types of semi-conductors which can have their band gaps modified by different doping techniques [12]. When the photons hit the solar cells the semi-conductors will absorb the photons that have energy equal to or greater than that of the band gap. This promotes electrons in the conduction band which is how energy is produced in the cell. If the photon's energy far exceeds the band gap the energy will be dissipated off as heat and if the energy is much smaller the photon will just pass through the solar panel and no energy will be collected from it [12]. Obviously the goal of the solar panel is to produce power so the solar panel needs to create current and voltage from the photons to make power.

There are two important parameters for both the current and the voltage. The current has I_{sc} (short-circuit current) and I_{mp} (maximum-power current), the voltage has V_{oc} (open-circuit voltage) and V_{mp} (maximum-power voltage). V_{mp} and I_{mp} are the parameters that best express the performance of the solar cells which is called the fill factor. The fill factor should be around 80%-90% for high efficiency solar cells. The ultimate goal is to choose a semi-conductor material that has an optimal band gap near the middle of the energy spectrum. This will ensure that the panel can collect the highest possible amount of solar radiation that the selected material is capable of obtaining.

3.2.4 Photovoltaic Panel Performance

Solar cells can be extremely inefficient which was talked about in the previous sections. Further research will be needed to examine the other factors that will affect the panel outside of the physics of the semi-conductors and ascertain any possible ways to increase the performance of the panels. Some of the issues being examined are the electron-hole recombination rate, temperature effect, and the light absorption efficiency. The impurity concentration of the polycrystalline silicon will increase the electron-hole rate which will result in a decrease of the panel efficiency. This is the main reason mono-crystalline panels perform better than polycrystalline [14].

Temperature is another factor that can negatively affect the performance of the solar panel. Contrary to popular belief, the efficiency of the solar panel decreases as the temperature increases [14]. This occurs because the magnitude of the electric field at the p-n junction is reduced due to the temperature increasing the conductivity of the semi-conductor. This will result in a disruption of the charge separation causing a lower voltage across the cell [14]. However the higher temperature will cause the electron mobility to increase which will cause a slight increase in current, but this is insignificant in comparison to the voltage loss. The optimal environment for a solar panel to operate is sunny and cold temperatures. Unfortunately for this system it is being built in an area that does not get cold often. Some improvements could be added such as adding a coolant system to the back of the panel, but this is costly and time consuming. The temperature effect will have to be kept in mind for any inefficiencies that are noticed. Most solar panel manufactures will include a temperature coefficient in the specs of their product to allow the customer to have an idea of the panel's efficiency in certain temperatures. Figure 3.2 depicts the temperature effect on PV panels below.

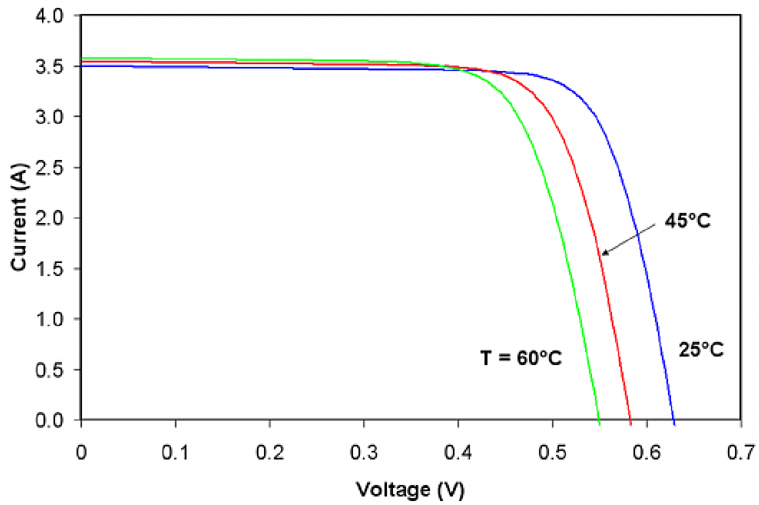


Figure 3.2 Temperature effect on PV panel performance with permission of solarpower2day.net

The last inefficiency is light absorption which was discussed in the earlier section. The semi-conductors can only absorb photons that have energy equal to or greater than their band gap. This results in quite a bit of lost energy due to light having a different energy. Many solar panel companies will engage in band gap engineering which will maximize the amount of light the solar panel is able to absorb. The design engineer can choose to create smaller band gaps to capture the lower energy photon. However the lower energy light will result in a lower voltage. The engineer could increase the band gap to gather more of the higher energy photons, but the panel will not absorb the lower energy level photons causing a lower current. A balance has of these two different ways of band gap engineering must be found to ensure an optimal solar panel. Another thing to remember is that much of the light is lost due to reflection. This is why most solar panels will have a layer of anti-reflection material on top of them to minimize this negative effect.

3.2.5 Solar Radiation

Solar radiation is the electromagnetic radiation that is emitted from the sun and is collected by the solar panel to produce power. Solar radiation is measure in kilowatt-hours per square meter per day (kWh/ m^2/day). Figure 3.3 below shows the annual solar radiation of the United States. As can be seen in the figure the best location for solar power in the country is the southwestern region with around 7.5-8.0 kWh/ m^2/day. Central Florida averages per year around 5.5-6.0 kWh/ m^2/day according to the figure below [15].

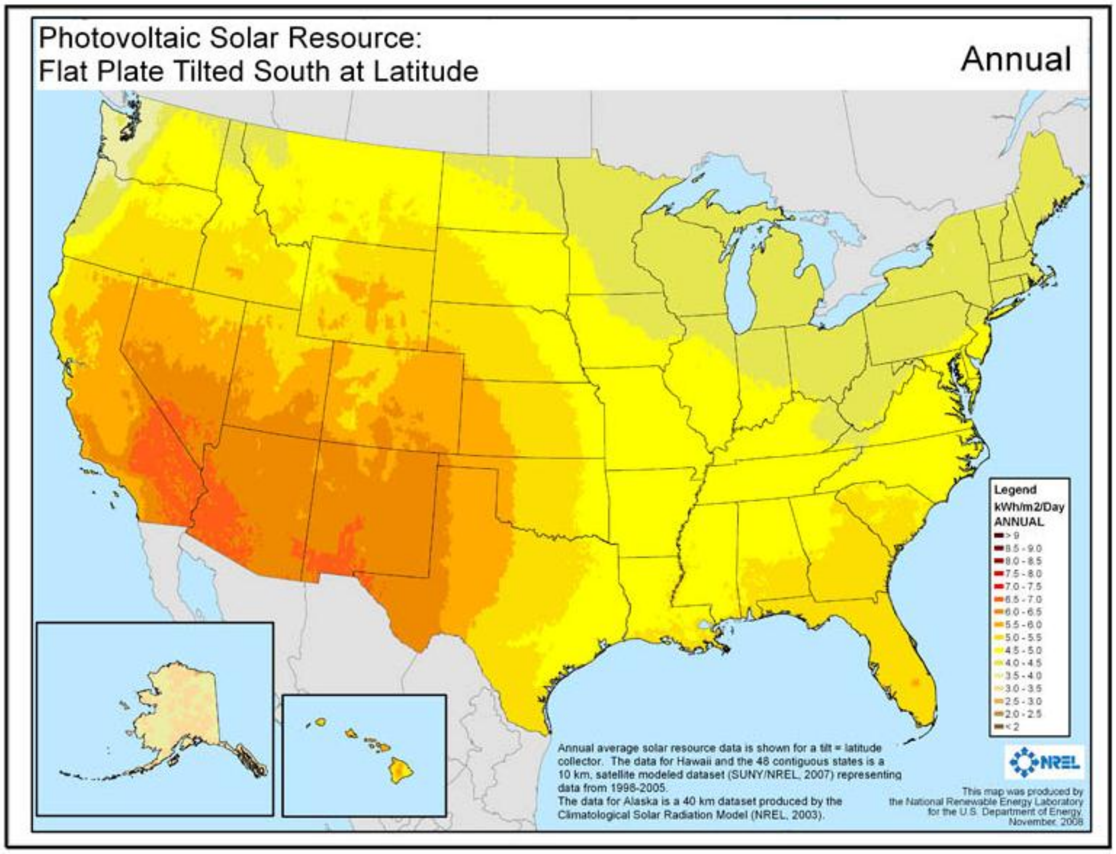


Figure 3.3 Annual Solar Radiation of the United States with permission from NREL.

There are many different methods to optimize the solar radiation collected by the solar panel. Some of those methods include preprogramed angles for each hour of daylight, solar tracking/ light concentration, and MPPT (Maximum Power Point Tracking). The first method is exactly how it sounds. The solar panel is mounted on a double axis mechanism and is moved to pre-determined angles for each hour of day light. Solar tracking also requires the solar panel to be mounted on a double axis mechanism with its movement controlled by the sun's intensity. The light concentration implements mirrors or lenses around the panel to intensify the light's concentration. The MPPT system is a more indirect approach that controls the photovoltaic output voltage and current to optimize the efficiency. An example would be if the battery requires a larger voltage the MPPT system will recognize this and increase the output voltage while decreasing the output current to maintain the same photovoltaic power level.

3.3 Wind Power

3.3.1 Advantages and Limitations

Wind power is a natural resource that is free, unlimited and renewable. Well-designed blades can capture wind more efficiently to maximize rotor's output current. All this energy produced by the turbines it's free of any type of emissions or other pollutants that may create greenhouse gases.

Since wind turbines come in a wide range of sizes, they can be used by anyone to produce their own additional input power for their household use. Usually, private companies create wind farms to produce up to 1000MW of electricity. However, remote areas that are not connected to the electricity power grid can create their own wind farm to supply their own demand of electric power.

Due that the space required to install a wind turbine is very minimum, wind farms can have hundreds of wind turbines. Wind farms do not use very much surface space; in the case of agriculture, this allows to farmers performing ground activities without complications.

Many land owners benefit from wind turbines when a company plans to create wind farm. Companies have to pay for the space that their wind turbines use. This is a great, complementary, source of income that boosts local economies. In addition, many people view wind farms as an interesting feature that enhance the landscape.

As there are great benefits from the generation of electric power through wind turbines, there are some limitations and disadvantages. Wind has an immense power but is not continuous and constant. Winds may vary from zero to hurricane force winds. This factor unleashes other subsequences. The production of electricity is not constant and cannot be predictable all the times. Moreover, if a wind turbine gets exposed for long periods to strong winds, this can break apart the whole wind turbine and reduce production of electric power.

One major challenge to the industry of wind power generation is that to create enough electricity for a small community of 50,000 people they need to install hundreds of wind turbines. How many wind turbines would be required to satisfy the demand of larger community for instance 120,000 people? Space is a key factor that will always be taken into consideration when building new wind farms.

Some people argue that wind turbines, when active, produce high level of noise. This can get challenging to solve when all wind turbines are combine to create wind farms. However, technology has improved wind turbines and now they are much more quiet machines.

Some other people think that wind farms are grotesque in form and shape. They feel that the landscape is being changed completely by the creation of wind farms. Natural view of countryside and coastal landscape are not enjoyable because they are being corrupted by large and tall structures that never belonged to the country side.

3.3.2 Wind Power Mechanism

Generating electricity from wind is relatively simple. All effective wind turbines often have 3 blades that are aerodynamically constructed to easily create a rotating movement as air blows. The blades spin a shaft that is linked to a generator that creates the electricity.

When the wind blows, the blades create a lift, similar to the wings of airplanes and the blades begin to rotate. When the blades rotate, a low-speed shaft is spanned 30 to 60 times in a minute. This low-speed shaft is connected with a gearbox or a high-speed shaft that accelerates the rotation to 1000 to 1800 rotation in a minute. The high-speed shaft drives the generator and produces electricity. The generator is then connected to an electric power grid.

Generating the Power:

Four factors determining the electricity capacity of a wind turbine is wind velocity, tower height, air density and blade radius.

Wind velocity determines energy generated. Wind is never even, sometimes strong and other times weak. However, wind turbines do not operate in too strong or weak winds. If the speed is too low, for example, below 8 miles per hour the turbines will not work. The ideal speed is winds in the range of 25 to 55 mph. If the wind goes above 55mph the turbine is switched off as damage can be caused.

A tall turbine is usually more efficient. There are two reasons for this, being that more winds can be captured at higher altitudes and there is less turbulence (winds are more constant).

Air density determines the kinetic energy of winds. The more dense the winds the more capacity do they have to propel the turbine to turn. In high-altitudes the air pressure is lower, in other words the air is lighter and is thus less effective location for wind turbine to operate. In lower-altitudes such as near the sea level, the air is dense and heavy making it much more effective to turn the wind turbine.

The radius of the blades determines the amount of wind that can be harvested. A large blade will be able to yield much more wind and thus the diameter of the blade can as substantially establish power levels. [20]

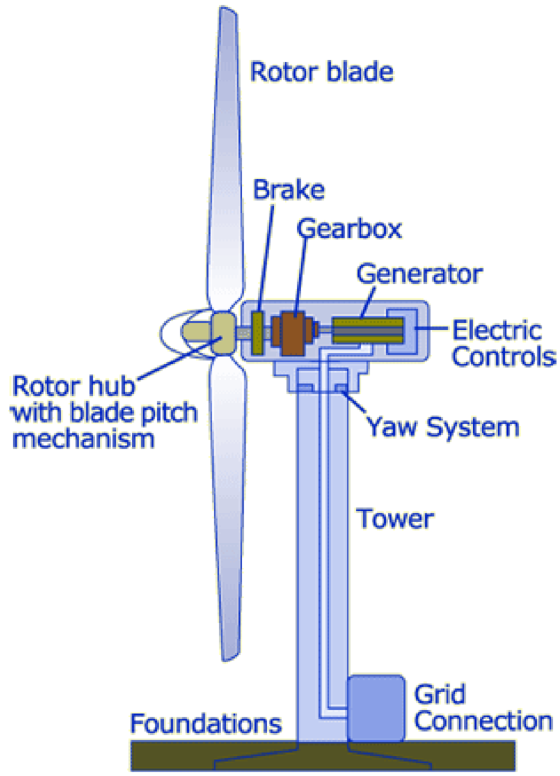


Figure 3.4 Wind Generator Mechanisms

3.3.3 Wind power Performance

Ideally, our project would work for a combined system of wind power and solar energy that both combine will deliver up 1.5 kW for a typical household. To satisfy this demand, a wind turbine capable to deliver up 1KW at 24 V will be needed. There are many products in the market that with such specification that would fit for our project. However, the prices of an standard wind turbine that delivers up to 1KW range from $800 to $1000. Our budget is very limited and acquiring such turbine will leave us in negative. Since, our main goal for this project is to build an integrated circuit box that controls input power from solar and wind energy, stores the energy, manage the excess of energy, and delivers energy efficiently; the wind turbine will be scaled down.

For testing and illustration purposes, a wind turbine that delivers from 250 to 400 Watts will work perfectly for our project. These turbines vary in price from $130 to $400. This input power combined with solar energy will be enough to change the 12V battery bank and deliver the excess to load if the system has some components plugged in.

3.3.4 Capacity and Production

For this project it is important to know how much capacity wind power is produced in the US since the controller box can be utilized along with installed wind turbines. Capacity and production are two of the main factors that make wind power more attractive as an alternative source of electricity, today. According to the Global Wind Energy Council or GWEC, the new global total capacity at the end of 2011 was 238 GW, representing cumulative market growth of more than 20%, an excellent industry growth rate given the economic climate, even though it is lower than the average over the last 10 years, which is about 28% [21]. In the United States, the posted annual market growth of more than 30% in 2011, adding 6,810 MW in 31 states for a total installed capacity of almost 47 GW, and cumulative market growth of nearly 17%. While the US market struggles with uncertainty surrounding the extension of the federal Production Tax Credit (PTC), wind power is now established in 38 states, and the footprint of the US turbine and component manufacturing industry covers 43 states. This means that US manufacturers were able to supply about 60% of the content for the US market in 2011, up from just 25% a few years ago. All things point towards more growth in 2012, although this is clouded by dim prospects for the 2013 market, depending on the fate of the PTC [22].

So far this year, according to the AWEA, 2,800 megawatts (MW) of wind, along with 1,400 wind turbines have been installed across the US, helping the wind industry reach this fantastic achievement. Many of the new installations have come from new projects in Nevada, Idaho, Iowa, Hawaii Oklahoma, and California. Some of the key projects that are going in across six of these states, according to the AWEA include: Pattern Energy's Spring Valley wind farm, 30 miles east of Ely, Nevada (151.8 MW). Enel Green Power North America's Rocky Ridge wind farm in Oklahoma (148.8 MW). enXco's Pacific Wind project in Kern County, California (140 MW). Utah Associated Municipal Power's Horse Butte project in Idaho (57.6 MW). First Wind's Kaheawa Wind II wind farm in Hawaii (21 MW) [23].

What has occurred in the wind industry with the US reaching that plateau is quite remarkable. Consider that between 1981 and 2003, 5 GW of wind power was generated. That number doubled to 10 GW by 2006, then 25 GW by 2008, and now 50 GW in 2012. Also, Nuclear energy was the last new energy technology to reach 50 GW, done in the late 1970's and 1980's.

Wind potential is enough to take out coal power plants in the US. 50 GW of wind provides the same amount of energy as 44 coal fire power plants, or 11 nuclear power plants. The future potential to move at a lightning-fast pace and replace these sunset energy sources is very realistic, especially when you consider that 39 states now have utility-sized wind farms, according to the AWEA.

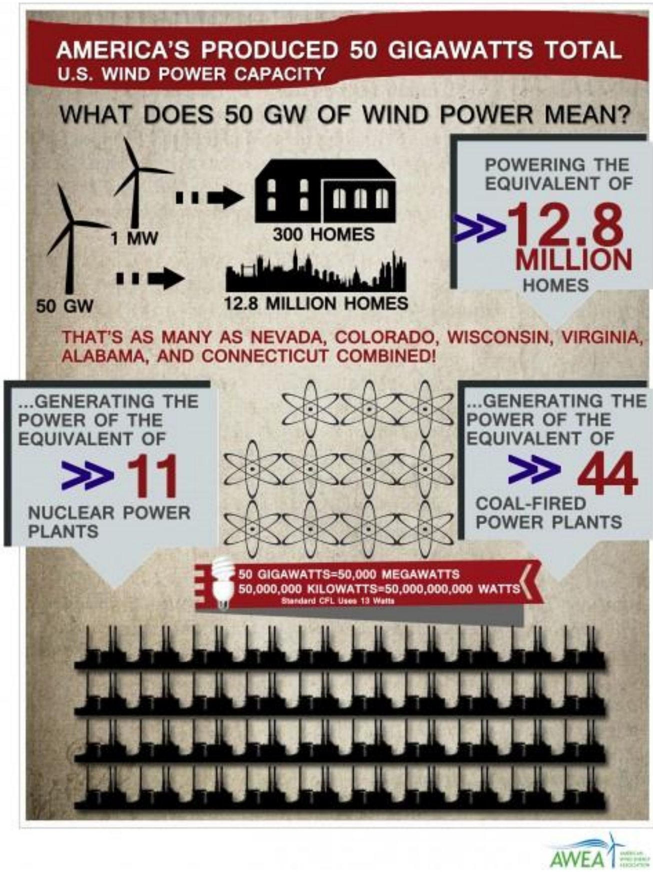


Figure 3.5 AWEA Infographic

In August of 2012, the Energy Department released a new report highlighting strong growth in the U.S. wind energy market in 2011, increasing the U.S. share of clean energy and supporting tens of thousands of jobs, and underscoring the importance of continued policy support and clean energy tax credits to ensure that the manufacturing and jobs associated with this booming global industry remain in America According to the 2011 Wind Technologies Market Report, the United States remained one of the world's largest and fastest growing wind markets in 2011, with wind power representing a remarkable 32 percent of all new electric capacity additions in the United States last year and accounting for $14 billion in new investment. According the report, the percentage of wind equipment made in America also increased dramatically. Nearly seventy percent of the equipment installed at U.S. wind farms last year – including wind turbines and components like towers, blades, gears, and generators - is now from *domestic manufacturers*, doubling from 35 percent in 2005. The growth in the industry has also led directly to more American jobs throughout a number of sectors and at factories across the country. According to *industry estimates*, the wind sector employs 75,000 American workers, including workers at manufacturing facilities up and down the supply chain, as well as engineers and construction workers who build and operate the wind farms.

Technical innovation allowing for larger wind turbines with longer, lighter blades has steadily improved wind turbine performance and increased the efficiency of power generation from wind energy. At the same time, wind project capital and maintenance costs continue to decline, driving U.S. manufacturing competitiveness on the global market. For new wind projects deployed last year, the price of wind under long-term power purchase contracts with utilities averaged 40 percent lower than in 2010 and about 50 percent lower than in 2009, making wind competitive with a range of wholesale power prices seen in 2011.

Despite these recent technical and infrastructure improvements and continued growth in 2012, the report finds that 2013 may see a dramatic slowing of domestic wind energy deployment due in part to the possible expiration of federal renewable energy tax incentives. The Production Tax Credit (PTC), which provides an important tax credit to wind producers in the United States and has helped drive the industry's growth, is set to expire at the end of this year. The wind industry projects that 37,000 jobs could be lost if the PTC expires. Working in tandem with the PTC, the Advanced Energy Manufacturing Tax Credit provides a 30 percent investment credit to manufacturers who invest in capital equipment to make components for clean energy projects in the United States. President Obama has called for an extension of these successful tax credits to ensure America leads the world in manufacturing the clean energy technologies of the future. [24]

3.3.5 Distribution of Wind Speed

The strength of wind varies, and an average value for a given location does not alone indicate the amount of energy a wind turbine could produce there. To assess the frequency of wind speeds at a particular location, a probability distribution function is often fit to the observed data. Different locations will have different wind speed distributions. The Weibull model closely mirrors the actual distribution of hourly wind speeds at many locations. The Weibull factor is often close to 2 and therefore a Rayleigh distribution can be used as a less accurate, but simpler model.

Power generation from winds usually comes from winds very close to the surface of the earth. Winds at higher altitudes are stronger and more consistent. Recent years have seen significant advances in technologies meant to generate electricity from high altitude winds. [25]

3.4 Charge Controllers

The main reason a system needs a charge controller is to protect the battery from overcharge and over discharge. Systems that have small, predictable, and continuous loads may be able to operate without a charge controller [26]. However solar and wind power are nowhere near being predictable or continuous so the design will need to implement charge controllers to help our batteries charge efficiently and without damaging them. As was discussed in earlier parts of this chapter, solar disadvantages are when the sun is not out, the weather is interfering, and the wind is not continuously blowing. Implementing an efficient charge controller will allow us to overcome the inherent shortcomings of wind and solar power. A correctly operating charge controller will also prevent overcharge or over discharge of the battery regardless of temperature or seasonal change in the load profile, which will be another major reason for applying this component into our system.

There are many different algorithms used for the different types of charge controllers, but they all have the same basic parameters. The manufacturer will usually give you these parameters in their spec data sheets which give the limits such as load currents, losses, set points, and set point hysteresis values. The set points are usually dependent on the temperature of the controller and the magnitude of the battery current [22]. There are four basic charge controller set points which are; Voltage Regulation set point (VR), Voltage Regulation Hysteresis (VRH), Low Voltage Disconnect (LVD), and Low Voltage Disconnect Hysteresis (LVDH).

The voltage regulation set point is the maximum voltage that the controller will allow the battery to reach. The controller will either discontinue battery charging or begin to regulate the amount of current being sent to the battery once this point has been hit [27]. The voltage regulation hysteresis is the difference between the VR set point and the voltage at which the full array current is reapplied. The greater this voltage span, the longer the array current is interrupted from charging the battery. If the VRH is too small, then the control unit will oscillate, possibly harming the switching element or any loads attached to the system [26]. This is an extremely important factor to the entire system and will have to be monitored closely or the charging effectiveness of the controller will suffer.

The low voltage disconnect is the voltage point at which load is disconnected from the battery to prevent over discharge. In other words the LVD is the actual allowable maximum depth of discharge and available capacity of the battery. The LVD does not have to be temperature compensated unless the battery is operating below 0°C [26]. Similar to the VRH the LVDH is the difference between the LVD set point and voltage at which the load is reconnected to the battery. If the LVDH is too small, the load will rapidly cycle on and off at low battery state-of-charge which can damage the controller. If the LVDH is too large, the load may remain off until the array fully recharges the battery [26]. A large LVDH could increase battery health due reduced battery cycling. However the availability of the load would be sacrificed. All four of the set points described above will have to be analyzed in depth as the charge controller is put through the design phase of the project. The set points are crucial to the health of the battery and charge controller.

3.4.1 Shunt Controller

After discussing the basic theory of the charge controller above the methods of actually controlling the charging of the battery should be examined. There are two basic methods that could be utilized for this project and they are series and shunt regulation. Both of these methods can be highly effective for the charge controller with each having benefits and limitations. First the shunt controller method, which is tends to be designed for PV systems with currents less than 20A. The shunt controller interrupts the current by short-circuiting the array to regulate the charging of the battery. This could cause the battery to short-circuit as well so a blocking diode will be needed in series between the battery and the switching element. This controller type also requires a large heat sink to dissipate the excess power [26]. The shunt controller can be split into two different algorithm types; linear and interrupting. The shunt linear algorithm maintains the battery at a fixed voltage by using a control element in parallel with the battery. This relatively simple design is usually implemented with a Zener power diode which can drive the cost up and limit the power ratings of the controller [22]. The shunt interrupting algorithm is a more typical use of a shunt controller by simply short-circuiting the PV array to terminate battery charging. Shunt interrupting method is also known as pulse charging [27]. The figure below depicts the daily profile of the shunt interrupting controller.

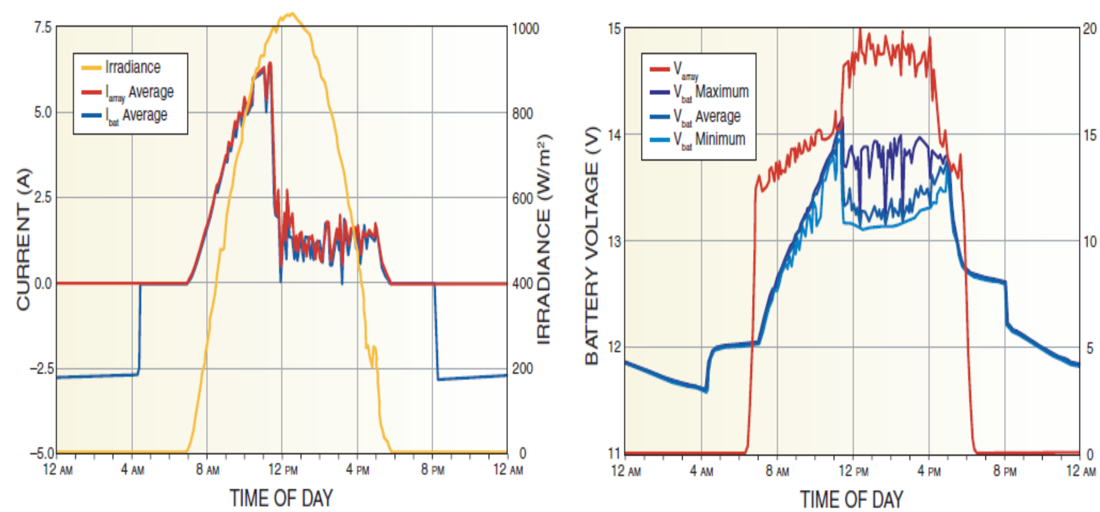


Figure 3.6: The Daily Charge Profile of a Shunt-Interrupting Controller.
Permission from American Technical Publishers Pending

3.4.2 Series Controller

The series controller uses some type of control element in series between the solar array and the battery. The series controllers, like shunt controllers can be broken down into two different subcategories; interrupting and linear. The interrupting series controller typically will use a blocking diode for the switching element and the controller will open the circuit to terminate the battery from charging. There are many different algorithms for the interrupting series controller such as 2-step constant current, 2-step dual set point, pulse width modulation, and sun-array switching. All these different algorithms essentially accomplish the same task inside the charge controller. The daily charge profile of the interrupting series controller can be seen in the figure below.

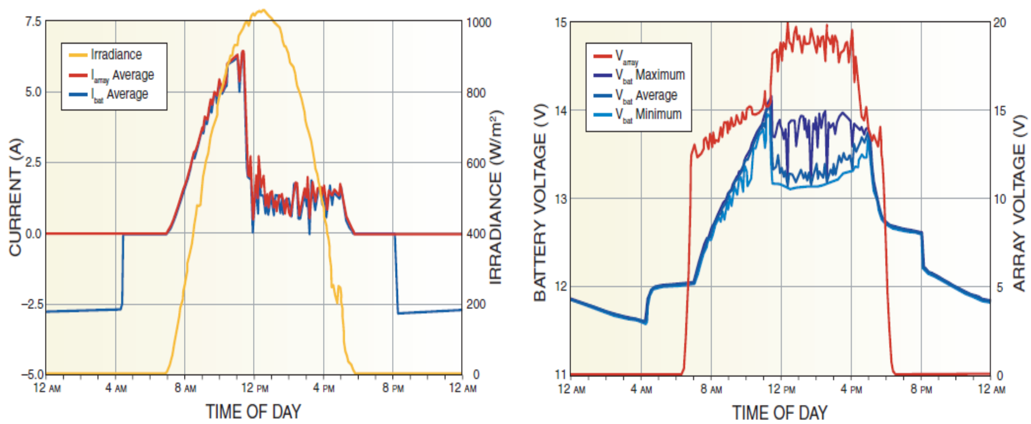


Figure 3.7: The Daily Charge Profile of a Series-Interrupting Controller. Permission from American Technical Publishers Pending

The second type of the series controller is the linear series. The linear series controller has two subcategories which are; constant voltage and constant current modified. The constant voltage algorithm will dissipate the balance of the power that is not used to charge the battery. This type of algorithm is highly effective for a system that is using a valve regulated (sealed) battery [26]. This is the type of battery that will most likely be used for this project therefore this type of algorithm will be the first one to be tested for the charge controller. The last series algorithm is the constant current one. This is a multi-step algorithm that switches to a preset constant current rate to control the charging of the battery. The battery voltage is then set to a specific voltage which depends on the chemistry of the battery. The charge rate will then return to constant current linearly as the battery voltage decreases [27]. The daily charge profile of the series linear controller can be seen below.

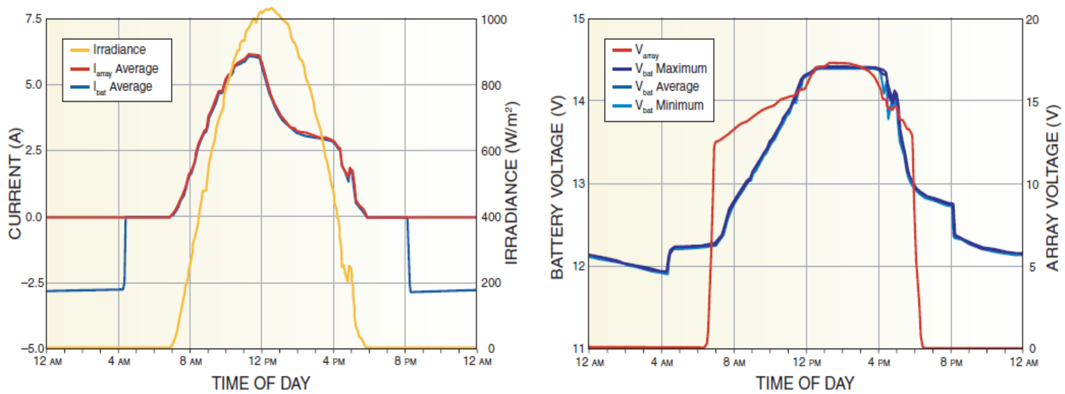


Figure 3.8: The Daily Charge Profile of a Series-Linear Controller. Permission from American Technical Publishers Pending

3.4.3 Maximum Power Point Tracking (MPPT)

Maximum power point tracking or MPPT is a technique used in a charge controller for getting the maximum voltage possible out of the solar array. Solar cells have a non-linear output voltage which is known as the I-V curve. This is due the complex relationship between the solar cell, solar irradiation, temperature, and total resistance. It is the purpose of the MPPT system to sample the output of the cells and apply the proper resistance (load) to obtain maximum power for any given environmental conditions [37]. The fill factor is a parameter that deals with this non-linear electrical behavior. The fill factor (FF) is defined as the ratio between maximum power of the solar cell to the product of the open circuit voltage (V_{oc}) and the short circuit current (I_{sc}). Therefore the maximum power can be calculated with this equation 3.2 shown below [37].

$$P = FF * V_{oc} * I_{sc}$$

Equation 3.2- Formula for Maximum Power

Now that the maximum power has been explained it is easier to understand where the maximum power point is located. Since P=V*I the maximum power point location can be determined through simple calculus. Therefore the maximum power point location can be defined as dP/dV=0 [37]. This means that the maximum power point location is at the knee of the I-V curve. The purpose of the MPPT system is to track this location for the maximum power. The MPPT can be seen below in Figure 3.9 intersecting all the I-V curves at the maximum power location during varying sunlight.

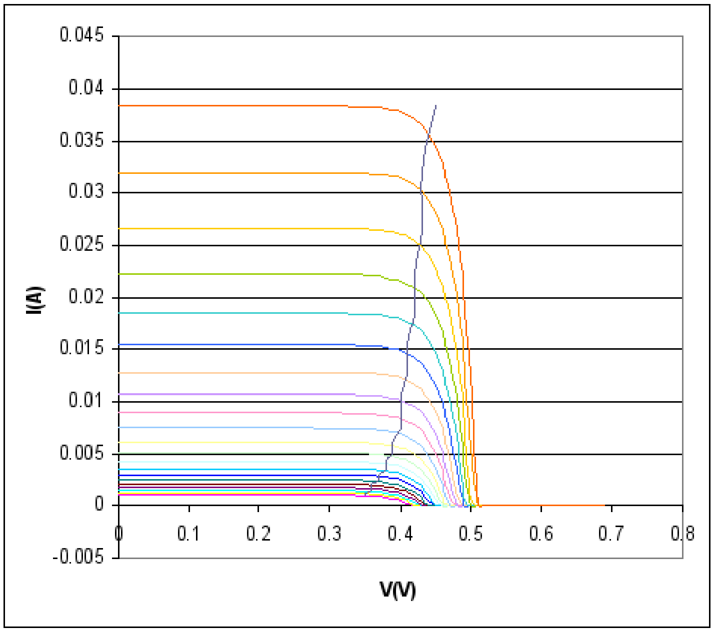


Figure 3.9: Solar Cell I-V Curve in Varying Sunlight. Permission from Creative Commons

There are several common methods that are used to implement maximum power point tracking. These approaches all vary on complexity based on the type of tracking they utilize. The three most common types that will be talked about in this research paper are: Perturb and Observe Method, Incremental Conductance Method, and Fixed Voltage Method [37].

3.4.3.1 Perturb and Observe Method

This method of power point tracking constantly checks the voltage or current (depending on the system) and continuing to increase the voltage as long as the power continues to increase [38]. After the maximum power point has been passed the algorithm will notice the power dropping and start to decrease the voltage to compensate. Figure 3.10 depicts the algorithm iterating over the power curve.

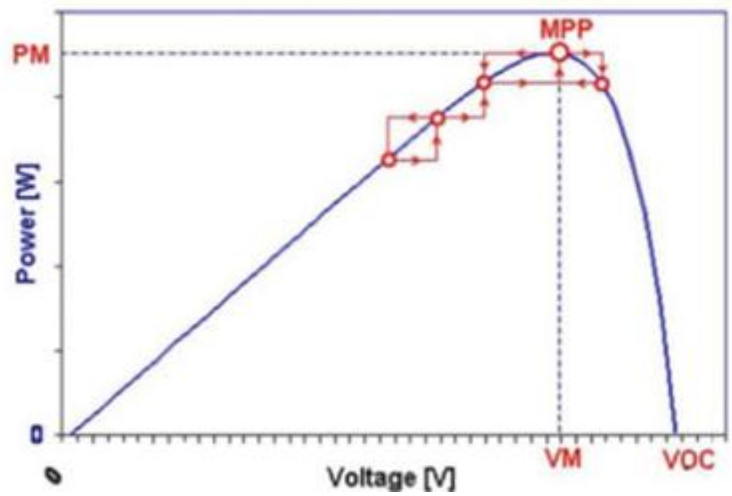


Figure 3.10: MPPT Perturb and Observe Method Permission from American Technical Publishers

The main disadvantage of the Perturb and Observe algorithm is that it has difficulties when dealing with low irradiance. This is due to the algorithm oscillating around the maximum power point which inevitably leads to inefficiencies. Another disadvantage is when the power curve flattens out the Perturb and Observe Method has trouble determining where the maximum power point actually is located. The final disadvantage to be discussed is that the algorithm has difficulty dealing with rapidly changing conditions. This can sometimes lead to the algorithm to take iterations in the wrong direction [39]. Despite all the disadvantages, this algorithm is the most commonly used MPPT method because of its simplistic design.

3.4.3.2 Incremental Conductance Method

Another MPPT algorithm that is a bit more accurate and complex is the Incremental Conductance Method. The main idea of this algorithm is to compare the differentiation of the power with respect of voltage to zero and determine if it is greater than or less than zero. This algorithm can be seen in Figure 3.11, notice how the differential is less than zero after the maximum power point location and is greater than zero before it.

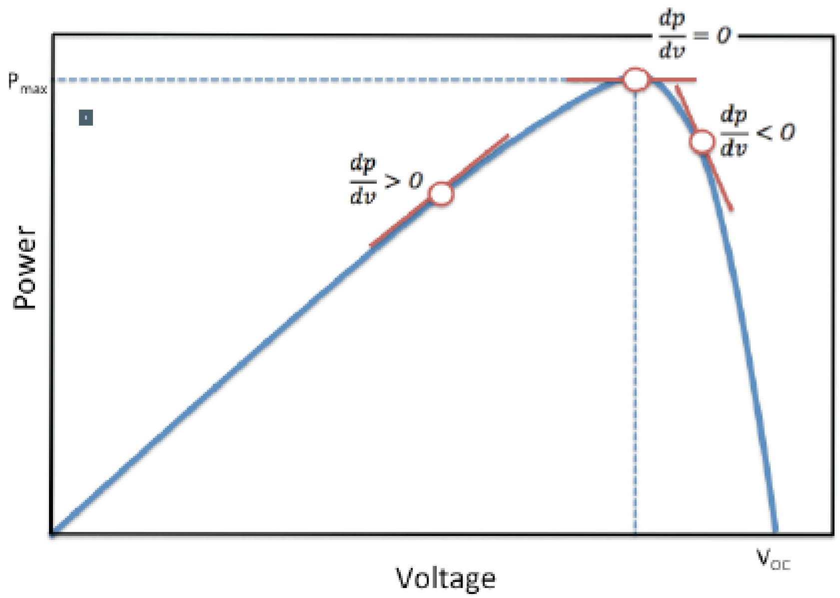


Figure 3.11: MPPT Incremental Conductance Method Permission from American Technical Publishers

The algorithm will know when the maximum power point location has been found when dP/dV=0 [39]. Unlike the perturb and observe method, a discreet value is determined for the maximum power point location in Incremental Conductance method. This system will remain at this point until it undergoes a change in the environmental conditions affecting the power [39]. The big advantage in this method over the perturb and observe method is that the inequality determine from calculating the derivative gives a direction. This will prevent the algorithm from incrementing in the wrong direction.

3.4.3.3 Constant Voltage Method

Constant Voltage Method is the simplest of the three common MPPT algorithms. This algorithm operates as a constant voltage value based of the open circuit voltage. There is a range of accepted approximations for the operating voltage which in between 73% and 80% [39]. Figure 3.12 below illustrated the algorithm at a constant voltage of 76% of the V_{oc}.

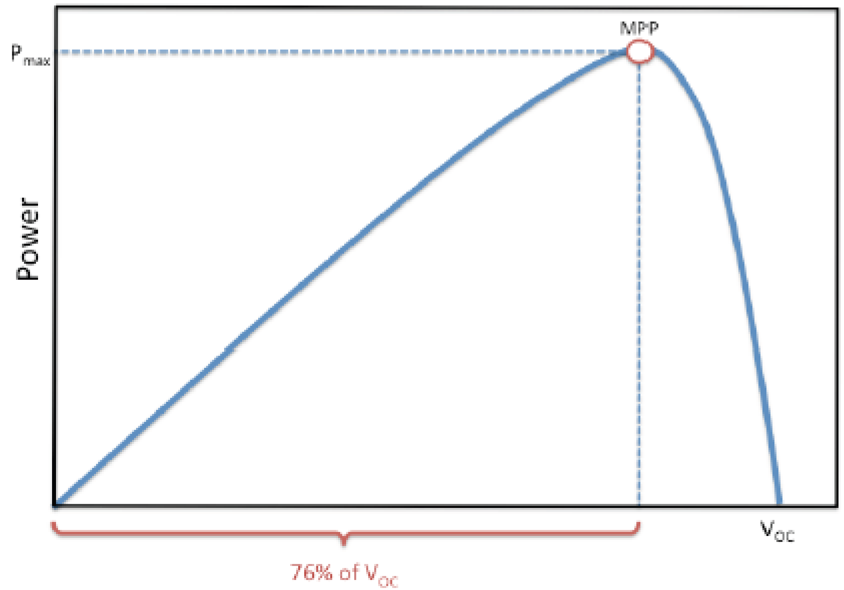


Figure 3.12: MPPT Constant Voltage Method Permission from American Technical Publishers

The constant voltage algorithm will temporarily set the solar panel current to zero to determine the open circuit voltage. The operating voltage is then is then based of the ratio of the constant voltage to that of the open circuit voltage. This is where The system isgin moving. A specified time must be entered into the algorithm to tell the system when to isolate the source and begin the operation again [39]. This method is not as efficient as the perturb and observe or the incremental conductance methods. When the current is set to zero by the system significant losses of efficiency occur because so much energy is wasted. The only advantage to this algorithm is that is much more simple and spends less time on the computations within the system [39].

3.5 Rectifier

Wind generators do not produce DC electricity, so a device called a rectifier is used to convert the turbine's output current to DC. This is the first stage in the battery charger circuit. Some turbines have a rectifier built in. In most cases though, the rectifier is supplied as a separate component that must be installed between the wind turbine and the battery charger. Often, the rectifier is combined with a charge controller into one complete wind turbine control unit

Rectification is the process of converting an alternating (AC) voltage into one that is limited to one polarity. The diode is useful for this function because of its nonlinear characteristics, that is, current exists for one voltage polarity, but is essentially zero for the opposite polarity. Rectification is classified as half-wave or full-wave; with half-wave being the simpler and full-wave is being more efficient.

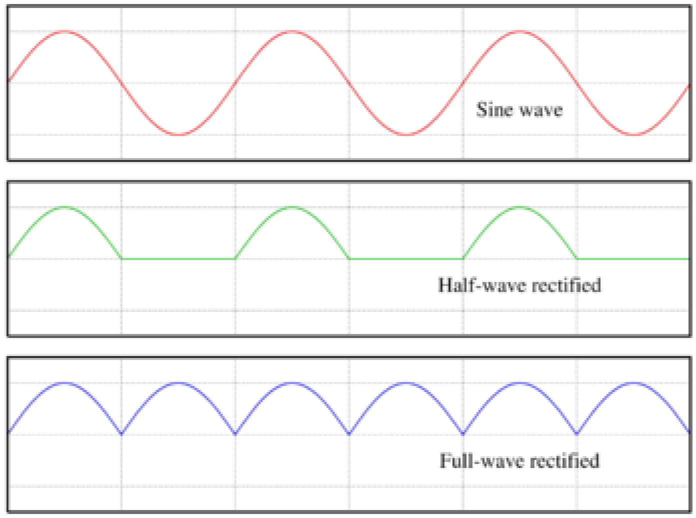


Figure 3.13 Rectified Sine Wave. Permission Pending.

The full-wave rectifier inverts the negative portions of the sine wave so that a unipolar output signal is generated during both halves of the input sinusoid. The input of the rectifier consist of a power transformer, in which the input varies from 0 to 15 volts (rms), and 0 to 60Hz AC signal, and the two outputs are from a center-tapped secondary winding that provides equal voltage. When the input voltage is positive both output signals voltages are also positive.

The input power transformer also provides electrical isolation between the power line circuit and the electronic circuit to be biased by the rectifier. This isolation reduces the risk of electrical shock.

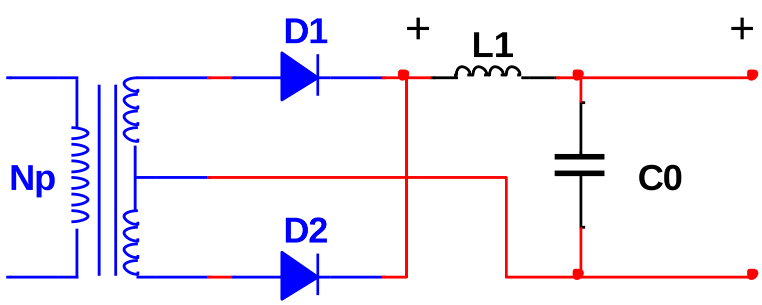


Figure 3.14: Texas Instruments Full-wave rectifier

During the positive half of the input voltage cycle, both output voltages are positive; therefore, diode D1 is forward biased and conducting and D2 is reversed biased and cut off. The current through D1 and the output resistance produce a positive output voltage. During the negative half cycle, D1 is cut off and D2 is forward biased, or “on” and the current through the output resistance again produces a positive output voltage [28].

Another alternative for rectifying input ac signal is the full-wave bridge rectifier. This circuit, which still provides electrical isolation between the input aa powerline and the rectifier output, but does not require a center-tapped secondary winding. However, it does use four diodes, compared to only two for the regular full-wave rectifier circuit. During the positive half of the input voltage cycle, the voltage across the rectifier input is positive, and D1 and D2 are forward biased, D3 and D4 are reversed biased, and the direction of the current is towards D1 and D2. During the negative half-cycle of the input voltage, the voltage across the rectifier input is negative, and D3 and D4 are forward biased. The direction of the current towards D3 and D4 produces the same output voltage polarity as before. Since the full-wave bridge rectifier is more efficient when delivering converted ac power, this will be used for the project.

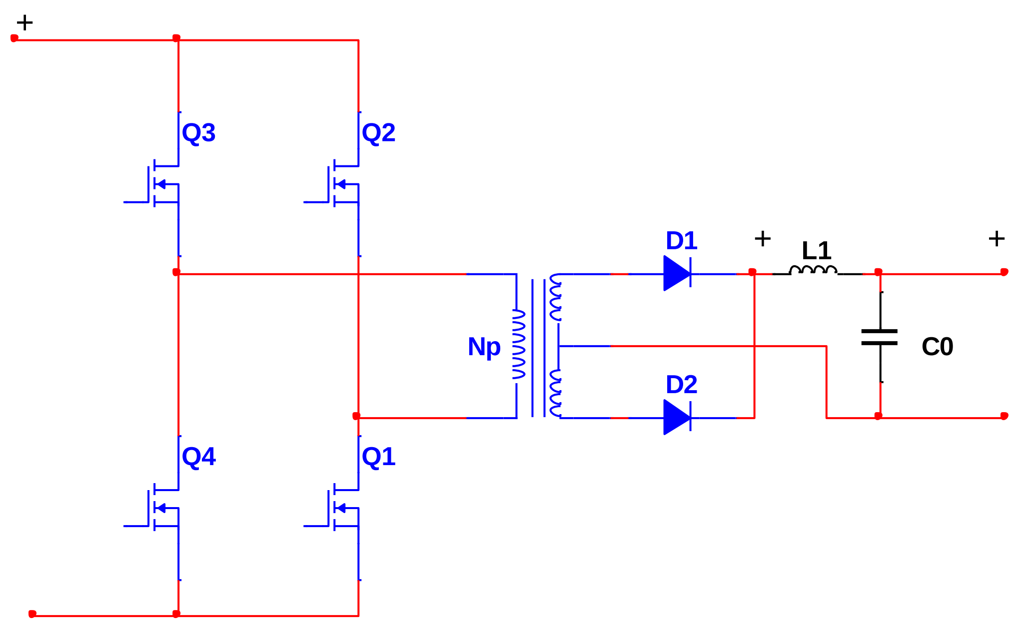


Figure 3.15 Texas Instruments Full Bridge Controller

As the voltage runs through the diodes it becomes a form of DC voltage, along with pulsations of up and downs, which is called as ripple voltage. For this project the charging circuit requires a steady state DC input free from ripple voltage. A RC circuit can be added that soothes out these ripples and improve quality of rectified output.

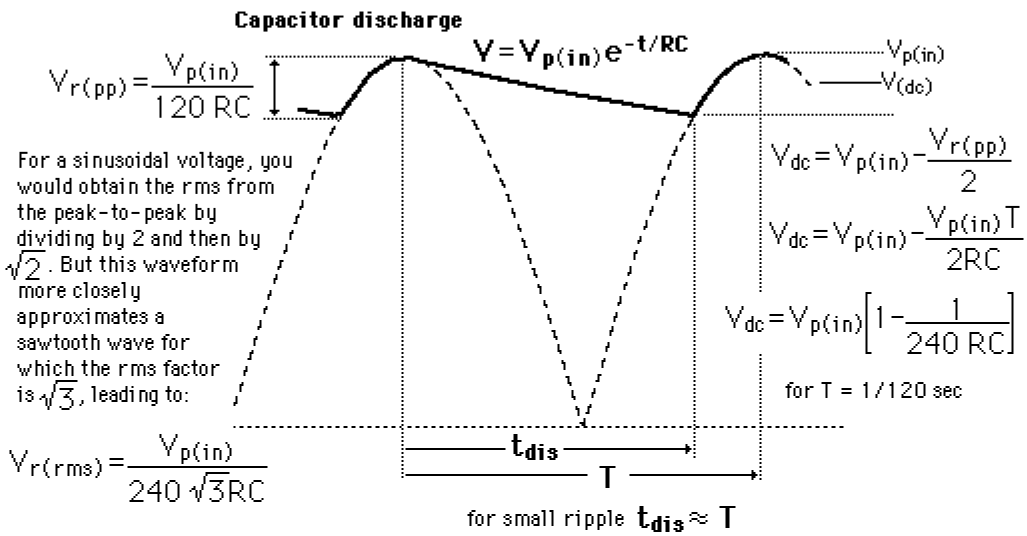


Figure 3.16 RMS Ripple Voltage

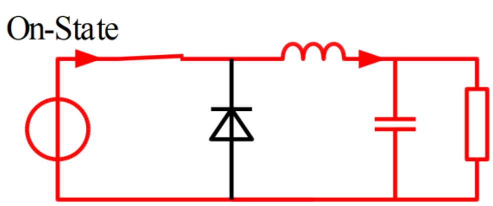
3.6 Voltage Regulator (DC/DC Converter)

Voltage regulators or DC to DC converters are necessary because the DC voltage coming off the solar panels are not a constant throughout the day. Also in order to optimally charge a battery the input voltage must be regulated because the battery voltage will change depending on the load connected to it. These two reasons make the use of a voltage regulator an essential component to this system. For each stage of the battery charge level the voltage will need to be ramped up or down. This is known as a switching regulator where a diode, capacitor, and inductor are usually used to alter the voltage accordingly. Both active and passive switches are used in a switching regulator. A passive switch tends to be just a diode, and an active switch will usually be a MOSFET transistor. The active MOSFET can be an extremely efficient way to switch between the voltage stages because it a digital signal can be used to control the MOSFET. This is accomplished through the use pulse width modulation (PWM) to control the frequency and duty cycle of the MOSFET's on and off switch. This will eliminate the need for a digital to analog converter between the microcontroller and the MOSFET. The digital signal will also be less susceptible to noise which could cause the switch to have an error.

Voltage regulators do not produce any power, they actually consume a little bit of the input power accordingly to their efficiency rating. Since the DC to DC converter consumes some input power, this research will be mostly on switched converters instead of linear converters. This is because the switched converter tends to be around 80% efficiency which is much higher than linear converters [27]. The goal is to keep the power level from moving as much as possible; therefore the current will also be affected by the voltage changes since they are proportional to the power level. Some examples of the different modes of a voltage regulator are: In buck mode the voltage decreases as the current increases, and boost mode the voltage is increased as the current decreases. This way the power level will remain the same as it passes through the voltage regulator. Some types of DC to DC converters that will be discussed in this research paper are: Buck Converters, Boost Converters, Inverting Buck-Boost Converter, and Non-inverting Buck-Boost Converter.

3.6.1 Buck Converter

The Buck converter or step down converter is a very popular switch mode regulator. The Buck converter can operate in three different stages. The first stage the switch is on and the diode is off. During this stage the inductor is acquiring energy because the source voltage is greater than the output voltage. This causes the current to rise in the inductor and the capacitor to charge. The figure below illustrates this stage of the Buck converter and has the equations which dictate the behavior of the circuit.

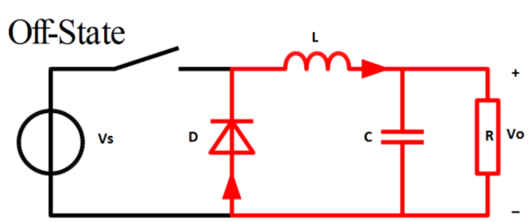


$$\frac{dV_O}{dt} = \frac{i_L - \frac{V_O}{R}}{C}$$

$$\frac{di_L}{dt} = \frac{V_s - V_O}{L}$$

Figure 3.17: On-State of a Buck Converter with permission from Creative Commons

During the second stage of the Buck converter the switch is off and the diode is on. The current in the inductor freely flows through the diode and the energy in the inductor is given to the RC network on the output. The current will become zero and tends to reverse, however the diode will prevent conduction in the opposite direction [29]. The inductor will also discharge in this state, a figure of the second state and the equations that govern it can be seen below.

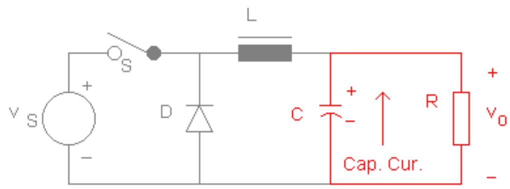


$$\frac{dV_O}{dt} = \frac{i_L - \frac{V_O}{R}}{C}$$

$$\frac{di_L}{dt} = \frac{-V_O}{L}$$

Figure 3.18: Off-State of a Buck Converter with permission from Creative Commons

The third stage of the Buck converter the switch and the diode are both off. The capacitor is discharging and the inductor is at rest with no energy in it. The inductor will not acquire or discharge any energy during this stage [29]. A diagram of this stage and the equation of the voltage behavior can be seen below.



$$\frac{dV_O}{dt} = -\frac{\frac{V_O}{R}}{C}$$

Figure 3.19: 3rd State of a Buck Converter with permission from Creative Commons

There are five basic components to the switched Buck converter: Inductor, capacitor, diode, PWM controller, and a transistor switch [29]. The inductor is placed in series with the load resistor to reduce ripple in the output current. This reduction occurs because the current in the inductor cannot change suddenly. An inductor tends to act like a source when the current level drops. The inductors used in most Buck converters tend to be wound on toroidal cores, and made of ferrite or powdered iron core with distributed air-gap to minimize core losses at high frequencies [29].

The capacitor is installed in parallel with the load resistor to reduce ripple in the output voltage. Switched power regulators usually have high current therefore a capacitor must be chosen to minimize loss. Capacitors experience a loss because of internal series resistance and inductance. A good capacitor for this circuit must have good effective series resistance (ESR) and solid tantalum capacitors are best in this respect [29]. Another way to achieve a low enough ESR is to parallel capacitors.

The diode in a switched Buck converter is also known as a free-wheeling or catch diode. The purpose of this diode is to always ensure that there is a path for the current to flow to the inductor. It is necessary for this diode to be able turn off rapidly; a fast recovery diode would be perfect for this application [29].

To regulate the output with a PWM control an IC will be necessary. The transistor switch will control the power to the load and a power MOSFET is more suited than a BJT [29]. Transistors with fast switching times will need to be implemented to be able to handle the voltage spikes produced by the inductor.

3.6.2 Boost Converter

The boost converter or step up converter is used when the output voltage is greater than the input voltage. Again like the buck converter the boost converter the inductor is used because it resists change in the current. The biggest difference from the Buck converter is that the inductor is on the other side of the switch in series with the input source. The Boost converter has two distinct stages it operates in. Below is a figure of a Boost converter that will be used in the description of the three different stages.

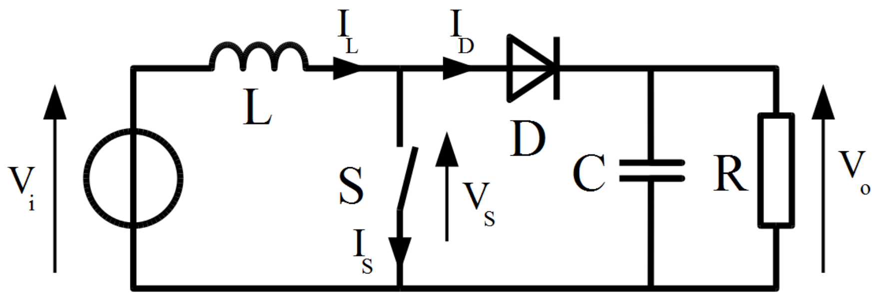


Figure 3.20: Schematic of a General Boost Converter with permission from Creative Commons

The first stage the switch is closed and the diode is off, the current runs in a clockwise direction. During this stage the inductor is charging and acquiring energy. The switch short-circuits and effectively disables the RC part of the circuit. Since the diode is off it will prevent the capacitor from charging [30].

During the second stage the switch opens and the diode turns on. This will make the impedance higher thus causing the current to slow down. The inductor will try to resist this change and it will cause the current to move in the opposite direction. This will cause to act like a source which in turn makes the capacitor charge due to the two sources which are in series (input source and inductor). As a result the output voltage will increase as the current decreases [30].

3.6.3 Inverting Buck-Boost Converter

The inverting Buck-Boost Converter is as the name implies a mixture of both the Buck and Boost topologies. This converter uses the same components as the converters described above. The inductor is placed in parallel with the load capacitor, the switch is in between the source and the inductor, and the diode is placed between the inductor and the load capacitor. A general inverting Buck-Boost convertor can be seen below in figure 3.21.

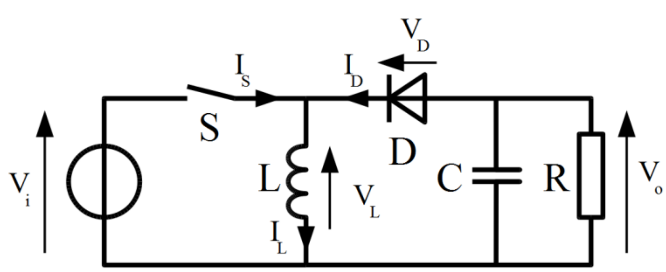


Figure 3.21: Inverting Buck-Boost Converter with Permission from Creative Commons

The Buck-Boost converter runs in two distinct stages. When the converter is operating in the ON-mode the diode will not allow the current to reach the load side of the circuit because it is operating in reverse bias. This is also the mode that the inductor will begin to increase the energy stored in it due to the increase of the current from the input source. During this stage the capacitor will be used to power the load and the circuit as a whole is behaving like a Boost convertor [26]. A diagram illustrating the ON state can be seen below in figure 3.22.

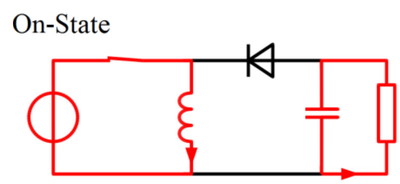


Figure 3.22: Inverting Buck-Boost Converter ON-State

The second state of the inverting Buck-Boost converter is known as the OFF-state. During this state the inductor's energy is used to supply the load side of the circuit. This state is where the inverting Buck-Boost convertor received its name. The current from the inductor will be the opposite polarity of the input voltage causing the output voltage signal to be inverted. The OFF-state diagram of the converter can be seen below in figure 3.23. The biggest advantage to this topology is how little components are needed. This drastically reduces any losses that might occur throughout the circuit. The biggest disadvantage is this circuit can only be used in a system that the polarity of the output does not matter. The other disadvantage is that this circuit will only operate in Buck-Boost mode. If Buck or Boost mode only is needed in the system, this circuit will be of no use.

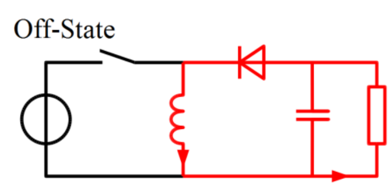


Figure 3.23: Inverting Buck-Boost Converter OFF-State

3.6.4 Non-Inverting Buck-Boost Converter

The non-inverting Buck-Boost converter will not invert the polarity of the output voltage. As a result the circuit topology is much more complex than that of the inverting version. The circuit to be analyzed will use four transistors for the active switches. They will be used to include both the Buck and Boost topologies thus allowing this circuit to perform as; Buck-only, Boost-only, or Buck-Boost converter. The circuit being discussed can be seen in figure 3.20 below. Transistor Q1 is placed in between the input source and Q2. The inductor is placed between Q2 and Q3, while Q4 will be placed in between Q3 and the load capacitor.

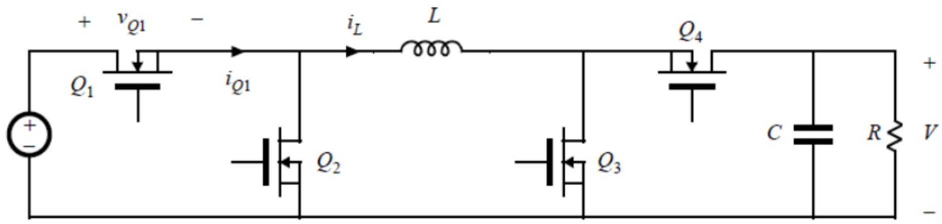


Figure 3.24: Non-Inverting Buck-Boost Converter Topology

In Boost-only mode Q3 is used as a switching MOSFET while Q4 acts as the diode. Q1 is always ON while Q2 is OFF, and Q3 and Q4 form the boost switching leg. In Buck-only mode Q1 is the switching transistor and Q2 will behave as the diode from the Buck topology. Q3 will be OFF and Q4 is always ON, while Q1 and Q2 act as the buck switching leg. In Buck-Boost mode Q1 and Q3 are both ON at the same time during the switching cycle or ON time. Q2 and Q4 will both be ON at the same time during the opposite switching cycle called OFF time. In other words Q1 and Q3 are both ON when the inductor is getting charged while Q2 and Q4 are OFF. When Q2 and Q4 are both ON the inductor is charging the load capacitor while Q1 and Q3 are both OFF [31].

This topology is very advantageous to the system being built because it utilizes all the topologies discussed so far. However the biggest disadvantage to this topology is the relatively large number of components that are required for its design. This will raise production cost and it must be discussed if the advantages outweigh the cost.

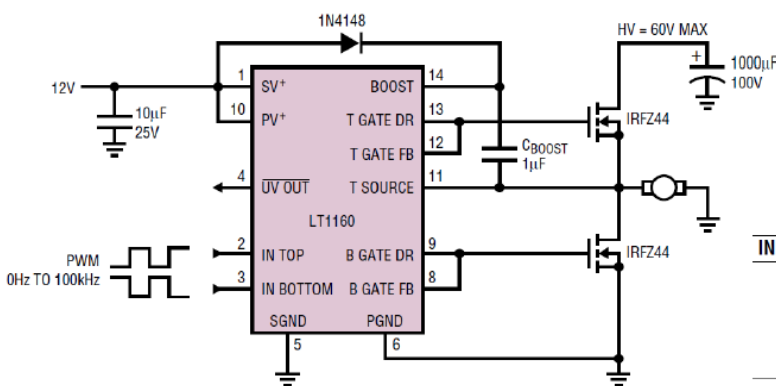
Another disadvantage to this circuit is the large number of switches being used. This will twice as large switching losses than that of the Buck or Boost converters. This is because of the use of four switches instead of two switches. The inductor will also have to be larger in this topology to accommodate for the larger current that must be used in the circuit. Furthermore the load capacitor must have a lower equivalent series resistance. This is due to the fact that the capacitor will carry the full output current during the PWM ON-time and the charge current during the PWM OFF-time.

It seems best to use a four switch DC to DC converter that changes its mode accordingly by observing the input and output voltages. A microcontroller can be programed to make the circuit operate as a Buck converter when the input voltage is greater than the output voltage. Also the microcontroller will make the circuit behave like a Boost converter when the output voltage is greater than the input voltage. The microcontroller should make the circuit operate in a Buck-Boost mode when the input voltage is approximately equal to the output voltage. This will make the inductor create a continuous current because of the direct connection between output and input. This will prevent the high peak current that is experienced in the classic Buck-Boost converter. It also minimizes stress on both of the input and output capacitors as well as reducing ripple voltage [32].

3.6.5 Half-Bridge and Full-Bridge Drivers

Half and Full-Bridge drivers can solve the problem posed at the end of section 3.6.4. These are integrated circuits that can come with a microcontroller that will control a DC to DC converter to act as a non-inverting Buck-Boost converter. The microcontroller will drive the PWM signal to turn on and off the switches which in this case will be N-channel MOSFET transistors. They will be switched at certain frequency and duty cycle. A full-bridge driver could accomplish this by controlling four different MOSFETs. Another way to do this would be to use two identical half-bridge drivers, each one controlling two MOSFETs. This might be the best choice because half-bridge drivers are easier to find.

There are several high voltage half-bridge drivers currently being manufactured. The most suitable one found so far is the LT1160 by Linear Technology. This driver is capable of amplifying a PWM signal with frequencies up to 100 kHz and is capable of switching the MOSFETs. The LT1160 is an IC that has 24 pins; it allows two separate non-synchronous PWM inputs on pins 2 and 3. The MOSFETs are controlled from pins 9 and 13. The IC can handle source voltage between 10V and 15V which is connected to pins 1 and 10. Figure 3.21 shows a typical set up for this half-bridge driver. Two of them will be needed to make a full-bridge driver [33].



IN TOP	IN BOTTOM	T GATE DR	B GATE DR
L	L	L	L
L	H	L	H
H	L	H	L
H	H	L	L

Figure 3.25: LT1160 Half-Bridge Driver. Permission Pending from Linear Technologies

3.6.6 Linear Regulator

Once the AC signal from the wind generator has been rectified to a DC signal, the output voltage from the rectifier still need to be regulated in order to charge the DC battery bank. While a constant DC voltage is a requirement to charge the batteries, other factors such as charging current and voltage must be adhered to. To operate outside these specifications could damage the batteries and reduce their performance and life span. Voltage regulation will also be a necessity for other aspects of this design to include: microcontrollers, LCDs among other components

The simplest way to reduce a DC signal is to use a linear regulator in an integrated circuit (IC) form. The most common types are the T0220 package which is a three terminal IC with the legs protruding from a plastic case with a metal back plate for bolting to a heat sink.

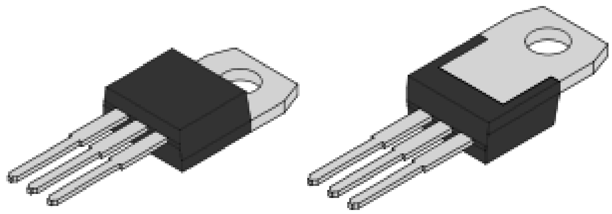


Figure 3.26 TO-220 transistor packages.

3.6.6.1 78XX Three Terminals Linear Regulator

One set of linear regulators that are commonly used is the 78XX three terminal linear regulator families, where XX gives the output voltage of the regulator. Both the input and output voltages of these regulators are positive. For example, a 7805 voltage regulator produces an output voltage +5volts. For negative output voltages, the 79XX regulators are available. By adding additional circuitry, fixed output IC regulators can be made adjustable. Two common ways of doing this is are as follows:

a) Adding a zener diode or resistor between the IC's ground terminal and ground. If the ground current is not constant a resistor should not be used. By switching in different values for the components the output voltage can be made adjustable in a step-wise fashion.

b) By placing a potentiometer in series with the IC's ground the output voltage can be varied. But once again if the ground current is not constant this method will degrade regulation.

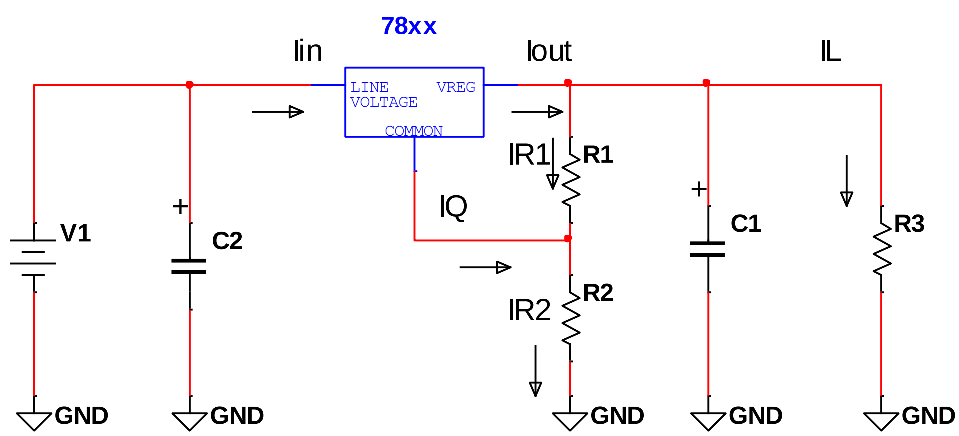


Figure 3.27 A circuit diagram to make linear voltage regulator adjustable. Electronics 2 lab manual

3.6.6.2 Zener Diode Regulator

Another form of linear regulators is the zener diode regulator. In this design a zener diode is placed in parallel with the load and a regulating resistor is placed in series with the diode and source voltage. Once the current is sufficient to take the zener diode into its breakdown region the diode will maintain a constant voltage across itself. Here the output voltage should remain constant even with a varying output load resistance and the ripple input voltage from the rectified AC signal. For proper operation of this circuit, the power dissipation of the diode must not exceed its rated value, meaning when the current in the diode is a minimum, the load current is a maximum, and the source voltage is a minimum. The inverse of this should also hold true. The minimum designed current should be greater than the minimum zener diode current, which can be estimated to be approximately 1/20 the maximum diode safe operating current. With an appropriate zener diode selected for the voltage drop needed for the battery, the remaining parameters for the circuit can be calculated with the following equations with R_i the input resistance, V_s source voltage, V_z zener diode voltage, P_z power of the diode, I_z and I_l diode and load current respectively:

$$R_i = (V_s - V_z)/I_z + I_l$$

$$P_{z\,max} = V_{z\,max} * I_{z\,max}$$

$$I_{z\,max}/20 < I_{z\,min}$$

$$I_{z\,max} = I_{l\,max}(V_{s\,max} - V_z) - I_{l\,min}(V_{s\,min} - V_z)/V_{s\,min} - 0.9V_z - 0.1V_{s\,max}$$

The zener diode regulator can be made to regulate much better by adding an emitter follower stage which forms a simple series voltage regulator. In this circuit the load current is now connected to a transistor whose base is connected to the zener diode. The transistor base current (I_B) now forms the load current for the zener diode and is much smaller than the load current. This forms a very light load on the zener minimizing the effects of variation in the load, it is still however, sensitive to load and supply variation. It is also important to note that the output voltage will always be about 0.6V to 0.7V less than the zener because of the transmitter V_{BE} drop. The circuit is referred to as series because the regulating elements (transistor and diode) are in series with the load. R_i still determines the zener current and can be calculated by the following formula where h_{FEmin} is the minimum acceptable DC current gain for the transistor and K is equal to 1.2 to 2 which ensures R_i is low enough for an adequate I_B:

$$R_i = (V_s - V_z)/I_z + K \cdot I_B$$

$$I_B = I_l/h_{FE\,min}$$

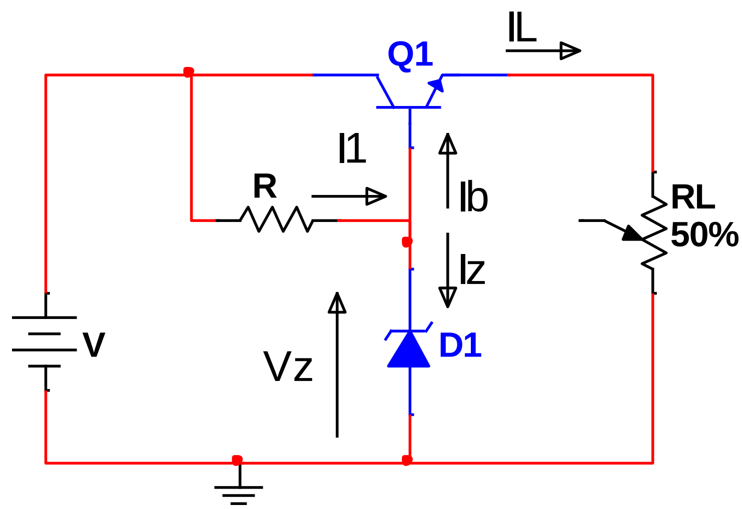


Figure 3.28 Zener Diode Regulator with Emitter Follower

Linear regulators whether in the integrated circuit or diode form are cheap, readily available and reliable. They are also simple to design and implement. There are drawbacks to linear regulators however; they are not very efficient as they waste a lot of energy by heat dissipation. This loss of energy by heat will be very pronounced here because of the high current that will be produced by the alternators. With $P = I^2R$, I^2 being the driving force for the loss in energy by heat, it can be easily seen that the loss will rise exponentially. The compact size of an IC could be a disadvantage because all the heat would be dissipated in a concentrated area. There are also other factors that will disqualify the use of linear regulators for the charging/regulating of the batteries. There will be a large voltage difference between the alternators and the batteries, linear regulator are not usually well suited for this situation and as such they would not be used here. Linear regulators will be used for the micro-controllers and display segments of the design.

3.7 Dump and Diversion Loads

The dump and diversion loads are design to deal with the excess power that is generated from the solar panel and the wind turbine. The solar panels and wind turbines are designed to be under loads when they are operating. The load is usually an electrical load which is drawing electricity that is generated by the solar panel or the wind turbine. There are two most common loads for those to generation systems. They are battery bank and electrical grid. Those electrical loads keep the solar panel and the wind turbine within their designed operation ranges. The wind turbine can be self-destructed under high wind conditions if it operates without loads. For the safety of the operation, it is necessary for a wind turbine and a solar panel to operate under a load.

Generally, since wind turbines are used to charge battery banks or feed an electrical grid, both of the applications need dump loads to consume the excess power. The batteries in a battery bank will be charged until reach fully charged by the wind turbine. Depending on the type of batteries that are used, the full charge voltage could be up to 14 volts for a 12-volt battery bank. Since overcharging of the battery can make permanent damage to the battery itself and may cause safety issues, it is necessary to stop charging the battery bank when it is fully charged. However, the wind turbine needs to operate under at least one electrical load. Thus a diversion load will be implemented to the system for this purpose [34].

The control box will be monitoring the voltage of the battery bank. The battery bank will be disconnected to the wind turbine or the solar panel when the controller senses that its voltage level reaches the predetermined fully charge voltage. Moreover, the control box will then switch the connection to the diversion load to keep the wind turbine or solar panel operating under a constant electrical load. Once the control box sense the voltage of the battery bank drops under a pre-set level, it will switch the connection back to the battery bank. This repeated process is essential for the health of the batteries, the solar panels and the wind turbine since it can keep the battery bank from overcharging and the solar panel, or the wind turbine always operating under an electrical load [34].

3.8 DC/AC Inverter

Many small electronics such as cell phones and I-pods can run adequately off of DC voltage which can be generated from a car's cigarette lighter. However for this project, household type electronics will be powered from the system which tends to require more power. This means that AC voltage of the same quality as an electrical outlet will be required to power these appliances. This will be the final component of the system allowing it to accomplish the ultimate goal of powering electronics from a battery that has been charged with solar and wind power.

The main function of the inverter is take 12V (DC) from the battery and step up the voltage to 120V and convert it to AC voltage which will be delivered through a 3-prong electrical wall outlet. This will require high rated cables due to the high amperage coming from the connections. A DC to AC invertor can easily be built with a transformer, a couple of transistors, and some resistors. However this project is more concentrated on the control aspect of the whole system, so some of the prebuilt DC to AV inverters should be researched. There are four main concerns that one should have when shopping the internet for a good DC/AC invertor and they are:

What type of devices are being powered: This is a major concern because an inverter with the appropriate wattage will be needed to prevent the electronic devices being damaged. The system being built for this project was determined by the group to be able to handle 1200W-1500W maximum. The invertor that will be purchased must have an output that exceeds the maximum wattage needed.

Voltage of the invertor: Two 12V batteries are being used for this system therefore the DC/AC invertor must be rated for 24V. This is an extremely important factor because if the inverter does not meet this requirement, it might get burned up by the input voltage and possibly destroy whatever electronic device is plugged into it.

Surge: The surge rating is the initial amount of power required by a device when it powers up. The initial startup of some equipment can draw much higher energy then when the device is running. Every piece of electronics should have this rating in the manufacturer specs. The DC/AC invertor's wattage threshold needs to be able to handle the surge of whatever type of device that is plugged into the system.

Wave output: When an AC signal comes out of an electrical outlet it will have a perfect sine wave. This is not necessarily true when an AC signal outputs the invertor. When a DC signal is inputted into the invertor it will boost the voltage up and convert it to an AC signal. After this process is done the signal looks more like a square wave than a sine wave. The wave output factor of a commercially purchased DC to AC invertor is the quality of the output sine wave. Since household electronics will be plugged into this systems output, the output voltage will not need to be a perfect sine wave but it cannot be a square wave either. A square wave could damage the appliances that have been plugged in, so a mid-quality invertor will need to be purchased or some filters will be required to clean up the output waveform.

These are the four main factors to consider for purchasing a manufactured DC to AC invertor. Several different brands will be compared later and the most appropriate model that fits the budget will get be picked.

3.8.1 Inverter Efficiency

By efficiency the real meaning is, what percentage of the power that goes into the inverter comes out as usable AC current (nothing is ever 100% efficient; there will always be some losses in the system). This efficiency figure will vary according to how much power is being used at the time, with the efficiency generally being greater when more power is used. Efficiency may vary from something just over 50% when a trickle of power is being used, to something over 90% when the output is approaching the inverters rated output. An inverter will use some power from the batteries even when there is not any component drawing any AC power from it. This results in the low efficiencies at low power levels. A 3Kw inverter may typically draw around 20 watts from the batteries when no AC current is being used. It would then follow that if you are using 20 watts of AC power, the inverter will be drawing 40 watts from the batteries and the efficiency will only be 50%. A small 200W inverter may on the other hand only draw 25 watts from the battery to give an AC output of 20 watts, resulting in an efficiency of 80%. Larger inverters will generally have a facility that could be named a Sleep Mode to increase overall efficiency. This involves a sensor within the inverter sensing if AC power is required. If not, it will effectively switch the inverter off, continuing to sense if power is required. This can usually be adjusted to ensure that simply switching a small light on is sufficient to turn the inverter on. This does of course mean that appliances cannot be left in stand-by mode, and it may be found that some appliances with timers (eg washing machine) reach a point in their cycle where they do not draw enough power to keep the inverter switched on, unless something else, i.e. a light, is on at the same time. Another important factor involves the wave form and inductive loads (i.e. an appliance where an electrical coil is involved, which will include anything with a motor). Any waveform that is not a true sine wave (i.e. is a square, or modified square wave) will be less efficient when powering inductive loads - the appliance may use 20% more power than it would if using a pure sine wave. Together with reducing efficiency, this extra power usage may damage, or shorten the life of the appliance, due to overheating.

3.9 Sensors

3.9.1 Voltage Sensors

For IRPS is crucial to monitor input voltage coming from renewable sources and battery bank to display corresponding values to LCD screen. Microcontroller unit will be constantly receiving voltage and analyzing such reading, processing accordingly and sending it out to external LCD screen. However, if this is just implemented straight out the box, it is going to be discovered that microcontroller could be potentially damaged due to overcoming maximum voltage specification. Most microcontrollers have a more reasonable 5V tolerance and taking voltage directly from sources will peak over microcontroller threshold and cause system to overheat and fail.

In order to manage the voltage reading, a voltage sensor was placed before microcontroller analog input and as it name indicates this sensor will be responsible to calculate and step down maximum voltage to a more reasonable range below 5V. Sensor was placed in parallel with PV panel voltage output acting as a voltage divider to not interfere with reading coming into Voltage Regulator. Complete configuration is two resistors R1 and R2 connected in series and their value is determined based on solar panel maximum power. Essentially, R1 have a higher resistance value to guarantee not having high flows of current passing to microcontroller port. Furthermore, voltage after R2, let’s designated V2, is the safe output voltage to be analyzed by IRPS microcontroller. Having this sensor filtering the voltage before passing over microcontroller port drastically reduce chances of damaging microcontroller. Once sensor emit a safe output voltage ready to be measured, MCU find itself ineffective to receive correct signal without having and analog-to-digital converter (ADC), which it is a requirement to be present when discuss appropriate microcontroller for IRPS.

A second voltage sensor was used for wind turbine, connected on series to corresponding input at Voltage Regulator, and it follows previous configuration and logic, only changing resistors R1 and R2 values based on maximum output voltage specification dictated by project wind turbine. Final output reading for this sensor used a second ADC port from microcontroller, it is processed and displayed to LCD.

A third voltage sensor was placed between batteries and microcontroller in order to be able to check charging level and to display to LCD. Once again resistors values R1 and R2 were altered according battery bank specifications [35].

3.9.2 Current Sensors

Current sensors are very important for this integrated energy harvest design since IRPS implements a detail tracking of maximum power delivered as well as current reading. Voltage measurement was covered by the previous specified voltage sensors, and then the current flow is desired to be captured as well. Both current flows coming from wind turbine and solar panel were analyzed, processed and feed to microcontroller in order to display values on the LCD screen. Research came across with some possible solutions being the first one the Allegro ACS712 current sensor family, MAX4172 from Maxim integrated, and CSLA2CD clamp sensor from Honeywell.

3.9.2.1 ACS712 Current Sensor

The Allegro ACS712 is a practical and very well defined solution to measure AC or DC current in several industrial applications. It is a fully integrated Hall-Effect-Based linear current sensor with a great voltage isolation of 2.1 kVRMS, which it comes very handy to IRPS project specification [36]. The ACS712 comes in a small surface ideally to be mounted on standard free printed circuit board; its breakout is pictured in below Figure 3.29.

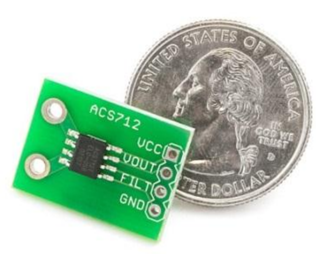


Figure 3.29 ACS712 breakout board.

Previous configuration of ACS712 sensor contains a thick copper conductor and signal traces allowing the sensor handle up to 5 times the overcurrent without tampering against proper functionality. ACS712 is flexible to configure its bandwidth and this is done set via FILTER pin clearly described in above Figure

3.29. Also, this sensor depend upon on a DC 5V in the Vcc in order to function and it should feature some filter capacitors to avoid any noise signals coming from supplied voltage. [37]

The sensor compose a precise low-offset circuit where an applied current flowing through copper conduction path develop a magnetic field which is sensed by the integrated Hall IC and converted into a proportional voltage which would be provided to ADC placed before microcontroller [36].ACS712 features a package of 5 Amp, 20 Amp, and 30 Amp version which guarantee a good variety from where to be chosen based on our project design. Additionally, Allegro specifies that one should expect only having a 1.5% output error at 25 degree C when sensors can fully operates from -40 to 85 degree C and that device is Pb-free being exempt from RoHS. Combining the fact of sensor having an internal resistance of 1.2 mΩ which ensure low power loss with previously explained sensor's versatile, design integration, precision, acquisition price makes the ACS712 current sensor a very good candidate to be used in IRPS. Part specifications which support sensor efficiency are shown in below Table 3.1.

ACS712	
Supply Voltage	4.5V – 5.5V
Operating Temperature	-40°C - 85°C
Bandwidth	80kHz
Output Sensitivity	66 mV/A – 185 mV/A
Output Rise Time	5µs
Internal conductor Resistance	1.2 mΩ

Table 3.1 – ACS712 current sensor key characteristics

3.9.2.2 MAX4172 Current Sensor

MAX4172 is a high-sense current amplifier ideally for systems where battery DC power line controlling is essential. Sensor features a wide bandwidth, ground sensing capability, operates between 3.0V to 32V supply voltage in the Vcc, and is available in a space-saving, 8-pin µMAX® or SO package [38]. In order to gain a high level of flexibility the MAX4172 works with an external sense resistor to establish the load current to be checked. Additionally, Maxim specifies that a user should expect only having a 2% output error at 25 degree C when sensors can fully operates from -40 to 85 degree C .A detailed pin configuration to bring more information about how this current sensor could be integrated with IRPS is shown in below Figure 3.30.

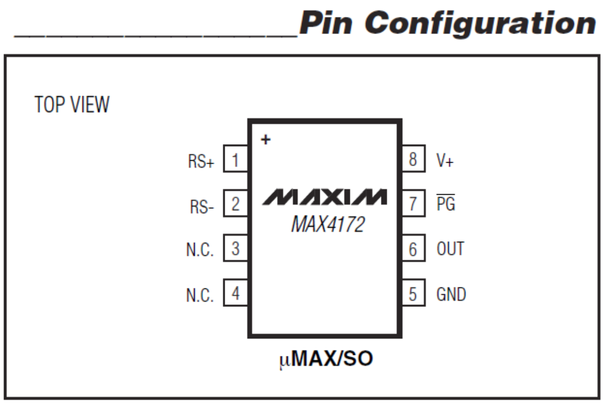


Figure 3.30 MAX4172 pin configuration. (Derived from Maxim Integrated ® MAX4172 Datasheet)

MAX4172 possess some advantages if the system would work with high currents flow. Unfortunately, this sensor only works with DC current limiting the flexibility of using it in all places where current is desired to be measured; however, its potential could be very helpful to be used on specific output where microcontroller is waiting for data to be analyzed/ displayed. Part specifications which support sensor usability are shown in below Table 3.2.

MAX4172	
Supply Voltage	3V – 32V
Operating Temperature	-40°C - 85°C
Bandwidth	800kHz
Output Sensitivity	6.25 mV – 100 mV
Output Rise Time	5µs
Maximum Output Voltage	Iout≤1.5mA

Table 3.2 – MAX4172 current sensor key characteristics

3.9.2.3 CSLA2CD Current Sensor

The CSLA2CD is an AC/DC current sensor made by Honeywell which empowered the advantages of being a Hall Effect current sensor transducer. One of its several advantages for this project is the fact that these types of sensors can be totally isolated from another high voltage electrical component eliminating risk of malfunctioning and help toward safety policies. Previous asseveration is based on sensor functionality core of detecting magnetic field around the wire excepting any electrical contact between components. This is a considerate benefit over current sensor using precision resistors [39]. Second main advantage is that if our signal is weak and this cannot get the desired output, the wire has to be looped as many times as amplification falls into expected range. For the sake of example if our system output signal is 0.05A and the signal needs to be strengthened, then the cable is looped 10 times around sensor clamp and a reading of 0.5A will be obtained; everything is done as previously stated and without having any heat dissipation effect since this types of sensor don't touch electrical element and never get hot. Additionally, Honeywell specifies that a user should expect only having a 2% output error at 25 degree C when sensors can fully operates from -40 to 85 degree C A typical application using this current sensor is shown below in Figure 3.31.

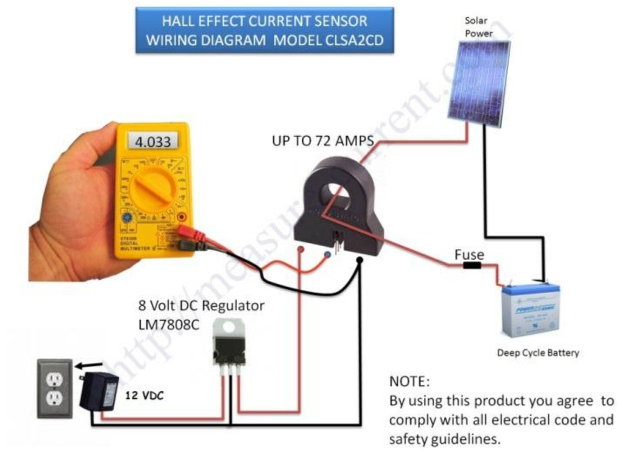


Figure 3.31 Typical application using CSLA2CD Current Sensor.

No everything is bright about this current for our project and some specs must be taken into consideration if it is decided to use this sensor in our circuit. One consideration is the price of the sensor in the market which is tagged as $29 in Amazon as an example; this price is considerably over what our project budgeted to spend in sensors taking into account that more than one would be used. Also, CSLA2CD describes a bulky size taking some considerable space in our pending to be designed board. Part specifications which support sensor usability are shown in below Table 3.3.

CSLA2CD	
Supply Voltage	6V – 12V
Operating Temperature	-25°C - 85°C
Sensed Current(Peak)	72A
Output Sensitivity	32.7 mV N* ±3.0 mV N* @ 8 Vdc
Output Rise Time	3µs
Output Type	Voltage

Table 3.3 – CSLA2CD current sensor key characteristics

3.9.3 Temperature Sensors

In spite of providing IRPS controller the actual temperature of environment where batteries are located, a temperature sensor would be placed on to capture current ambient temperature. The aim of this sensor is to be classified as an inexpensive solution which would be easy to integrate to microcontroller analog input port and delivery an accurate reading of temperature under humid conditions. One desirable aspect of the temperature sensor to have would be the fact to be easily exchangeable in case of malfunctioning.

3.9.3.1 TMP36 Temperature Sensor

These types of sensors are very precise since they implement a voltage drop between base and emitter methodology which is very viable. This approach overcomes other traditional methods using mercury (old thermometers), bimetallic strips (home thermometers), or thermistors (temperature sensitive resistors), and it is very suitable for IRPS proposed design [44]. As a result of not having moving parts, TMP36 is very precise, don't need calibration, never wears out, work under stressful environment, and it is an inexpensive, easy to use, alternative. The structure of sensor is shown in below Figure 3.32.

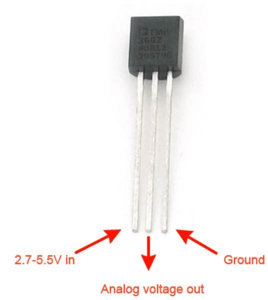


Figure 3.32 TMP36 functioning diagram.

TMP36 measure the temperature using an effortless method where left pin is connected to power (2.7 – 5.5V), right pin to ground and the middle pin will output the analog voltage linearly proportional to the current temperature [44]. In order to obtain the current temperature in Celsius grades, below formula is used:

$$\text{Temp in °C} = [(\text{Vout in mV}) - 500] / 10$$

So as an example if the voltage out is 2V that means that the temperature is ((2000mV-500)/10) =150°C. Taking into account that sensor cost is $2 each at Adafruit store, and IRPS will need two, the total cost of this alternative would be only $4. The only drawback found until here is that two sensors TMP36 will occupied two analog pins in the microcontroller, and it is very critical for IRPS design.

3.9.3.2 DS1624 Temperature Sensor

DS1624 is a Maxim digital thermometer sensor that is very effortless to use as well. DS1624 is well designed to be fully integrated directly with microcontroller without the need of using other external components. This sensor use I^2C bus as method of communication with microcontroller which is a very advantageous feature to have. Briefly, I^2C bus permits multiple devices to be connected to a single bus excluding the situation of having to use multiple analog pins in the microcontroller. However, it is noticed that a maximum of eight DS1624 can be connected to I^2C bus.

In this case the pins serving temperature sensing purpose are Pins 1 and 2, SDA and SCL respectively, which send data back and forth. Serial-Data (SDA) is the actual pin where data associated with temperature is send to the microcontroller once this information has been requested. The microcontroller use previous configuration as it is shown in below Figure 3.33 to make the request for this information through this same pin. The Serial-Clock (SCL) is the pin that is responsible for clocking in and out the data that is sent through the SDA pin [45]. DS1624 device comes with an identifier of 4 bit unique code which describes only this sensor to differentiate from others devices connected to I^2C bus. Moreover, DS1624 have 3 pins (7, 6, 5) which are combined to create a 3 bit unique address assigned to each sensor to be included, range from 000 to 111 giving a total of eight combinations as it was previously explained. Therefore, there is a well-defined structure for microcontroller being able to communicate with different devices connected to I^2C bus, and this case in order to reach each DS1624 sensor, microcontroller sends an address first to identify which sensor is wanted and then sends the request. These sensors have a high temperature tolerance from -55 to +125 °C. Despite of their market price around $9, DS1624 offers an attractive solution to implement using I^2C bus and saving analog inputs for others sensors.

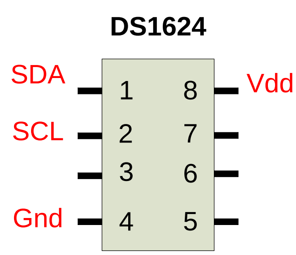


Figure 3.33 DS1624 functioning diagram

3.10 Microcontroller

Microcontroller unit would be the brain of the IRPS since its duties will be monitoring the status of different components and take decision to regulate the safeness of those. Microcontroller will continually execute requests to a variety of sensors in IRPS. Such interaction will allow a continuous monitoring of IRPS performance and possible failures or prevent failures to occur. Chosen microcontroller must be capable to run a fast clock speed, being low power consumption device, having enough appropriate analog and digital I/O ports to interact with sensors and LCD display, and have small size to be integrated on designed board. At this moment, IRPS have identified the need of having 3 voltage sensors ,2 current sensors, and 1 temperature sensors, total to be used could increase or decrease, and also it was identified that some output ports are necessary to display readings to LCD. Since our system will be fed by two renewable sources and some extensive monitoring is desired, it is devised that probably more than one microcontroller will be needed to split the load and gain a close multitasking operation. Decision about if one unit or more are needed will depend on balanced between cost, performance and overall safety; nevertheless, it is aimed that selected microcontroller unit meet the following model:

- Low cost on the unit and desirable on the development board as well
- Low power consumption
- A high level language to be programmed similar to C/C++
- Sufficient memory, +16K of flash memory
- Enough amount of analog I/O ports
- JTAG debugging
- Convenient software, libraries, IDE
- Processor speed exceeding our routines/tasks
- Practical to be integrated with external peripherals (Wireless, data logging, LCD)
- Good community support is not mandatory but desirable
- Good sleep mode when it is not in use

3.10.1 Atmel ATmega328

The option of ATmega328 from Atmel is a microcontroller featuring 14 digitals I/O pins, 6 of them PWM outputs, 6 analog inputs, 32k flash memory, and 16 MHz clock speed. Since the Atmega328 microcontroller could be pre-loaded in the development board Arduino Uno – R3, it can be programmed using the Arduino language which is similar to C [40]. The microcontroller on the board is programmed using the Arduino programming language (based on Wiring) and the Arduino development environment (based on Processing) [41].

The Arduino board can be powered using 5V USB port or an external DC power line (7V-12V) and chip by itself consume 5V DC. At the same time the board is capable to provide 5V and 3.3V DC output to feed sensors or others low power components. Ability of outputting some power is vital to test ATmega328 working in conjunction with sensors during the development phase. Arduino language and IDE are protected under the open source copyright which means if ATmega328 microcontroller is selected, project only have to make budget for the microcontroller, components and development board because all software use to develop the code are free. Moreover, the community has developed very useful libraries to interact with sensors, LCD, communications, and others devices; having previous community support will ease the programming of algorithms and speed up the testing of our complete IRPS. A picture detailing the Arduino Uno R3 board comes with a price of $29.95 which is on our budget range and it is a good guidance to follow at the time of assembling the final controller box design.

3.10.2 Atmel AT91SAM7X512

Microcontroller AT91SAM7X512 from Atmel is featuring a very powerful ARM7 Thumb processor with high performance 32 bit RISC architecture. Also, AT91SAM7X512 performs at 48 MHz clock speed with an expansion of 20 GPIOS with SPI,I^2C, and 4 PWM [42]. An expansion of 14 digital I/O pins and 6 analog inputs leave plenty room to decide if combine all monitoring process into one microcontroller instead having multiple units. In addition, the 512 KB space for code storage and 128 KB SRAM establish a comfortable condition to work with. Since this unit possess I^2C bus communication, it would be perfect if chosen temperature sensors are compatible with I^2C too; this would save analog inputs for others requirements. As its relative but more discrete ATmega328, AT91SAM7X512 could be powered by an enhanced development board named Netduino.

This single board is a derivate version of original Arduino board with the main difference that the Netduino is an open source electronics platform using the .NET Microsoft Framework. Preferred IDE is Visual Studio and language programming is C# which is a very sophisticated modern high language. Even though IDE is proprietary software from Microsoft and license is far from being accessible from IRPS budget, a totally full license is ready to be used from DreamSpark, which is an agreement between Microsoft Corporation and University of Central Florida. For that reason, if AT91SAM7X512 microcontroller is chosen, IDE would be available for no cost and could be easily integrated to Netduino development board. Some members of IRPS carry a good expertise on the .Net framework from Microsoft, and having this alternative, which could be very suitable, was attractive enough to be considered. Netduino board is a couple of dollars expensive than its predecessor coming at $34.95 yet is on the budget range.

3.10.3 Texas Instruments® MSP430

The MSP430 is a well-known low cost microcontroller from Texas Instrument; this unit has been familiar to every member of this group through academic courses. Texas Instrument has exposed several renewable energy harvesting projects based on the technology of this microcontroller based on its characteristics: Low operating voltage, 16 bit architecture, integrated ADC for measurements, and low standby current when idle. Combining this microcontroller with a RF system on chip the system will obtain a result of CC430 family alternative for our project. CC430 features a 32k flash memory, 4k of ram, 12 bit A/D converter, 16 ADC channels, and integrated LCD driver for up to 160 segments, and a very small size to integrate into our PCB. The microcontroller itself is a very cheap solution but the downside here is that evaluation debugging board can reach the $100 and IDE to load the code has to be purchased as well for about $400, however, free open source alternative software is available but not really the best option. Furthermore, Texas Instruments proprietary IDE has a free version with full capability but bears a limitation of 16 KB of total code.

Despites price to be invested on the software, this MCU is considered as a good alternative because its features and low power consumption.

3.10.4 PIC24 from Microchip ®

Last alternative for microcontroller is the Pic24 family under a 16 – bit architecture. This family of microcontroller is compatible with high language C/C++ and also could be accessible on assembly too. The low power PIC24F performance at 3.3V and has from 64k to 96k of flash memory varying based on the version but either one leave plenty of room for algorithm code and necessary libraries. The chip itself is very affordable for a few dollars and a point up to a very good 28 ADC inputs of 10- bit channels, and despite his large pin size Pic24F comes with an efficient XLP technology to sleep when current is at low as 20nA [42].

Research over this microcontroller family yielded that Microchip offers a vast package of documentation, libraries, examples, tutorial, datasheet, and diagrams about how to use and interact with this microcontroller. Having those elements at hand will ease any development that could take effect over PIC24F. Downside of previous advantages is that a complete development board along with MPLAB IDE comes to the price around $70 based on Microchip website. Even though IDE itself is given at free charge by Microchip, this IDE is completely based on some proprietary C compiler which license must be purchased. Final price is not discouraging the possible decision of using PIC24 family because microcontroller comes with a good variety of ports, speed, and desirable characteristics and not to mention that is flexible to integrate in a PCB solution.

3.11 LCD Display

Our integrated energy harvested system would ease the output reading if only one LCD display is used to combine all metrics there. Therefore, our aim regarding output display is targeting toward having a low cost, low power consumption LCD device capable of showing all reading in one place, including the batteries status. In order to do so, our searching will be focus to acquire a LCD with more than 4 lines and suited to hold up to 20 characters per line; that space would be enough to exposure all sensors reading plus battery checking. In total there will be the following parameters:

- Solar – Power, voltage, current
- Wind turbine – Power, voltage , current
- Battery 1 – Status, level of charge, voltage
- Battery 2 – Status, level of charge, voltage
- Any custom message displaying system status
- Alerts

In addition, it is highly desired that chosen LCD will be compatible with microcontroller unit to make process smoothly integrated and at the same time to have its own light to make it visible even at dark places. Backlight feature seems to be necessary based on the projection that our controller box should be under roof to avoid get the components wet or damage by inclemency of weather, then a little enhancement to make the LCD readable at any time is deemed to be necessary even at the cost or increase LCD power consumption.

Two types of LCD being considered are the alphanumeric and Dot matrix. Alphanumeric type is very simple to interact with as well as it comes with many symbols to be used. Downside part of this version is the limitation of information to be displayed since any data not complying with existing symbols cannot be interpreted, then the flexibility at the time of representing the output is not the strong argument on alphanumeric LCD. On the other hand, dot matrix LCD possess the capability of receiving a wider range of characters and to choose where to positioning them in the matrix coordinate [row, column]. Dot matrix version increase the degree of freedom when programing against the LCD at the time of accommodating; it increases the success of compacting all output reading in one LCD screen. One possible disadvantage for both types is not having the potential to show images, icons or create custom graphics interface [39]. Last parameter to be analyzed over which LCD would be appropriate to use is the preference of having a monochrome or color screen. Widely known is the fact that color screens are more expensive that their relative monochrome family then is almost certain that a monochrome version will be more suitable.

A third type of LCD being excluded by default because not complying with our targeting goals are the ones classified as "Graphical LCD." Even though this option is not being considered, it is mentioned due to the fact that graphical LCD is greatly used nowadays on a large variety of user output information screen. Graphical LCD has to use more layers of cell to bring the rich appearance of colors, which is equal to more power devoured from our harvested renewable energy. Regardless of our project aim to maintain power consumption at the lowest, it is given the credit that having a graphic LCD as user screen will potentially enhance user experience when interpreting the data shown; not even limiting that making such LCD touchscreen capable will catapult application interaction to the next level. Despite not being considered as an option, it is leaving as a viable alternative to the design phase to decide whether it should be included on the integrated control.

3.12 Analyzing Source Threshold Algorithm

Integrate two different renewable energy sources in one solution would be always challenging at the time of designing the platform due to incomparable sources impedances, in this case wind turbine and solar panel. In order to implement such feature in this project, study has been conducted to not only integrate both sources but also to maximize the charging system. Research to be conducted for proper threshold analysis will be enduring and extending article study "The Integrated Operation of a Renewable Power System" by Mu-Kuen Chen presented to "IEEE Canada Electrical Power Conference" in 2007. Chen's work demonstrated through theoretical analysis and field experiment that traditional method couldn't be used to charge batteries from wind power and solar energy if used at the same time [1]. The truthful study by Chen was conducted almost five years ago giving time to this implementation being settled, then current research will pick from there and look towards an enhanced microcontroller based solution.

Due to large output fluctuation on both sources based on weather condition and itself efficiency, it is debatable whether the best solution would be to combine both existent sources alternating charging cycles or to create two separate bank of batteries, one dedicate to solar collection and the second one to wind energy collection. Wind turbine output voltage is defined as Vo_{wind} and solar panel as Vo_{solar} for a better understanding of below explanation.

First alternative, being an apparent union of two renewable energy sources to charge one bank of batteries will need a switch system to control charging cycle. It is a fact that both sources output cannot coexist as one unique voltage combined cause of intrinsic nature of energy. Then, the correct approach here would be to adjust the charging duty cycle ratio of two energy sources to obtain a maximum input to battery bank [1]. Notice that no microcontroller unit would be needed to make this alternative works, a clear sketch is picture in below Figure 3.34.

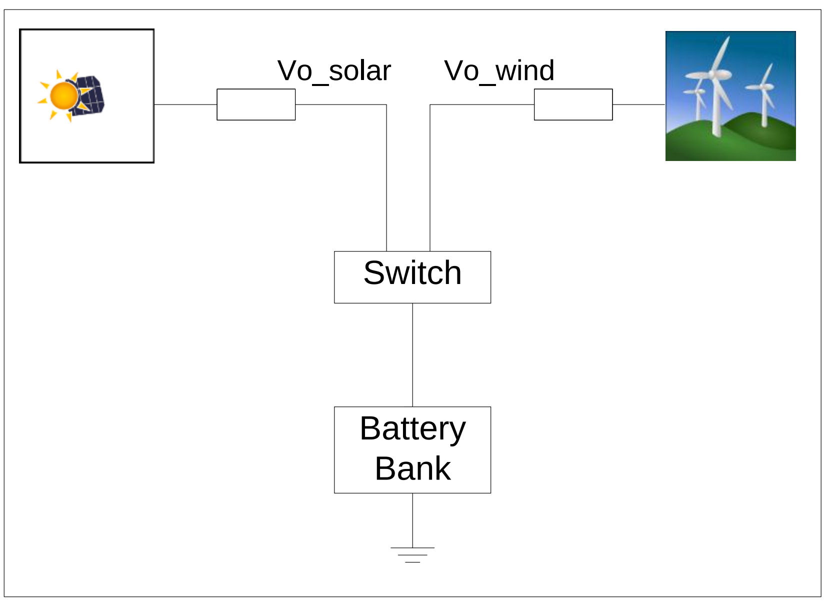


Figure 3.34 Alternating sources using switch

This approach will definitely works based on the solid basis that switch will timely alternate sources allowing batteries being charged through solar panels or wind turbine; however the lack of decision making, the structure as unchangeable methodology, and the drawback of an inefficient performance would lead to not a really competent system and a big waste of possible energy harvested.

Second alternative under consideration would be based on Mu-Kuen Chen proposal where previous charging methodology will be redesigned removing switch component and adding a microcontroller. Microcontroller unit selected will analyze both available sources to determine what would be the charging procedure at that moment; such algorithm will be implemented with the aid of sensors to detect spontaneous discrepancy and to maximize battery bank charging. This time, two separate banks of batteries would be implemented, first one named $\mathrm{E_{solar}}$ and second $\mathrm{E_{wind}}$; for the sake of simplicity this project would use one battery representing each sub group. The system would run under two main categories: *independent* and *integrated*.

Integrated mode would be if sensor reports that only one source is available at the moment, then microcontroller would analyze the data and send the proper signal to open corresponding circuit switches to charge both $\mathrm{E_{solar}}$ and $\mathrm{E_{wind}}$using one energy source. *Independent* mode would be if sensors report that both sources are available and wind turbine is working under threshold limit, then microcontroller sends appropriate signal to open corresponding switches allowing bank $\mathrm{E_{solar}}$ being charged with solar panel output and $\mathrm{E_{wind}}$ being charged with wind turbine output. A third mode, an extension of independent, is the "wind-enhanced" mode which is not falling into a new category but rather improving it. This special case is depicted as heritance from independent mode conditions with the addition of having wind turbine running beyond threshold limit. Furthermore, the intention of this scenario would be solar panel charge $\mathrm{E_{solar}}$ bank and wind turbine output charge $\mathrm{E_{wind}}$ and also $\mathrm{E_{solar}}$ bank; energy sources are maximized and fluctuations in the wind power generating are decreased [1]. Second alternative is sketched in below Figure 3.35 where it can be observed how the microcontroller will be in the middle of the charge decision making. In addition, there is a completed and resumed scenario situations depicted in below Table 3.4.

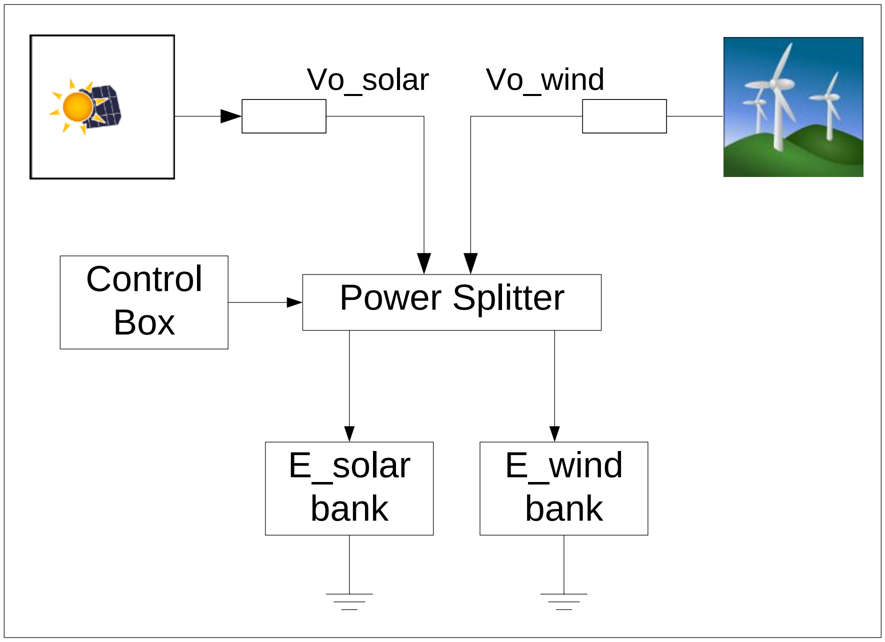


Figure 3.35 Microcontroller Alternative to Maximize Efficiency

Energy Source	E_{wind}	E_{solar}
Solar Energy		
Win Energy		
Solar and Wind Energy(low wind speed)		
Solar and Wind Energy(high wind speed)		

Table 3.4 - Microcontroller Alternative Charging Modes

3.13 Batteries

Battery is the most popular and technologically matured energy storage option. It is very important to adapt batteries within the stand-alone IRP system, especially hybrid solar and wind power generation system. The battery bank balances the energy within the IRP system. It also improves the overall efficiency and consistency of the system by ensuring that there is sufficient supply for the load.

3.13.1 Types of Battery

Cell batteries are the most commonly used form of energy storage. There are various forms and types of cell batteries. Based on the material, cell batteries categorized to the following:

- Lead Acid Batteries: They are the cheapest and most popular. The tolerance of depth of discharge is 75%, and the life span on this depth of charge is 1000 to 2000 cycles.
- Lithium Ion (Li Ion) Batteries: They have a very high efficiency of 100%, more cycles of life span, 3000 cycles, and greater depth of discharge, 80%. They have negligible self-discharge. However, they are very expansive.
- Sodium Sulphur (NaS) Batteries: They are very efficient in the use of daily charge and discharge. They also have negligible self-discharge. However, they must be kept at 300 ˚C. This increases the difficulty of maintaining the system.
- Nickel Cadmium (NiCd): They have a very large capacity which can be up to 27 MW of power. In addition, they have more life span cycles and greater depth of discharge then the Lead Acid Batteries. Nevertheless, they are expansive and toxic, and their self-discharge is high.
- Zinc Bromine (ZnBr) Batteries: They have high power and energy density, but the technology is less matures then the others. They are also toxic.

Therefore, in the IRPS, the best option will be Lead Acid Batteries comparing with other battery types considering the combination of performance and cost. A summarized battery characteristics table is shown below [48].

Attributes	Lead Acid	Li Ion	NaS	Ni-Cd	Zn-Br
Depth of Discharge	75%	80%	100%	100%	100%
Cost	Low	Very High	High and auxiliary heating systems needed	High	High
Lifespan (Cycles)	1000	3000	2500	3000	2000
Efficiency	72-78%	100%	89%	72-78%	75%
Self-discharge	Average	Negligible	Negligible	High	Negligible
Maturity of Technology	Mature	Immature	Mature	Mature	Immature

Table 3.5 Key Battery Attributes Comparison [48].

3.13.2 Lead-Acid Battery

Lead-Acid batteries are the most commonly used form of batteries among all of the rechargeable batteries in power application. Nevertheless, there are still some limiting factors that affect the power efficiency in a stand-alone power generation.

3.13.2.1 Limitation

The limitations are the following:

- Due to the limited power density of the Lead-Acid batteries, the time that will take the battery to be charged is considerable. Furthermore, the amount of energy will be able to deliver to the system is significant.
- Lead-Acid batteries have a life span of 1000 to 2000 cycles on its depth of discharge of 75%. It is relatively shorter comparing to the other four forms of batteries. As a consequence, Lead-Acid batteries need to be replaced regularly [48].
- Lead-Acid batteries are large in size relative to the other forms of batteries. They have a very low energy-to-weight ratio and a low energy-to-volume ratio.

3.13.2.2 Advantages

Despite the limiting factors of Lead-Acid batteries, their advantages over other types of batteries still make Lead-Acid batteries the most popular form in stand-alone power generation at present. The advantages are the following:

- Low cost. The price of a 12-volts Lead-Acid battery can be as low as 15 dollars while the average price of a Lithium Ion battery is over one hundred dollars [49].
- Lead-acid batteries have the most matured battery technology [50]. They are well developed and studied.
- Because of the ability to supply high surge currents, lead-acid batteries are able to uphold a relative large power-to-weight ratio. Thus, it is more efficient among all of the battery forms.

3.13.2.3 Types of Lead-Acid Battery

There are two basic types of lead-acid batteries: starting and deep-cycle battery. The starting lead-acid is designed to start a car and typically used in starting automotive engines. They are lighter in weight comparing to deep-cycle batteries. This type of batteries achieves low resistance and high surface area by adding many thin lead plates in parallel. This allows the batteries to have a maximum high current output. The starting lead-acid batteries are useful for applications that need a high current, such as several hundred amperes, to boost in relatively short period of time. However, it cannot be deep cycled. The battery will be damaged if it is repeatedly deep discharged, and it will lose its capacity as well. Continuous float charge will also damage the battery in premature failure. On the other hand, the deep-cycle lead-acid battery will allow batteries to be periodically charge and discharge. They are normally used for photovoltaic systems and electrical vehicles. They are also widely used as continuous power supplies. This type of batteries is designed to have large capacity and high cycle count, but the batteries have a relative low current output [49]. Therefore, deep-cycle battery is preferred for this project.

Thus, even though there are many rechargeable batteries can be found in the market, deep-cycle lead-acid battery will be used in this project because of the combination of cost and performance.

3.13.3 Lithium Ion Battery

Lithium ion batteries are one of the commonly used batteries in consumer electronics. They are also one of the most popular among the rechargeable batteries, especially for portable electrical equipment. Moreover, the Li-ion batteries are used in military, electric vehicles, and aerospace applications. This type of batteries has advantages over other batteries as well as some disadvantages.

3.13.3.1 Limitation

The limitations are the following:

- Li-ion batteries are much more expensive than the lead acid batteries. They tend to have one of the highest cost-per-watt-hour ratios.
- There is also more safety requirements need to be concerned for li-ion batteries. They are quite sensitive to the temperature. Overheating or overcharging may cause the battery to suffer thermal runaway and cell rupture [47]. What is worse, combustion can also occur by some extreme conditions. It may lead to unsafe circumstances when the cell is short-circuited by deep discharging.

3.13.3.2 Advantage

Despite the cost and safety requirements, Li-ion batteries have a lot of advantages over other types of batteries.

- They have the best energy density which makes them have a very high efficiency of almost 100%
- Self-discharge rate for a li-ion battery is negligible. It is approximately 5 to 10 percent per month.
- The li-ion batteries also have advantages on weight and size. They are much lighter than other rechargeable batteries, and have a wide variety of shapes and sizes which makes them fit in a large range of electronic devices.
- The components of the battery are environmental friendly since the li-ion battery will not release lithium metal [48].

3.13.4 Battery Charging Algorithm

There are various charging methods for lead-acid batteries. The battery charging process will be terminated when certain responses occur based on closed loop techniques that communicate with the battery.

Lead-acid battery charging adopts a voltage-based charging algorithm. The charge time for lead-acid batteries vary. For sealed large stationary lead-acid battery, the charge time is 12 to16 hours. It can be up to 36 to 48 hours. However, the charge time can be downgraded to 10 hours or less if the higher charge currents and multi-stage charge methods are applied, but the completion of the topping charge may sacrificed. Lead-acid batteries cannot be charged as fast as other types of batteries due to their lethargic nature.

There are three charge stages implemented by lead-acid batteries. They are *constant current charge*, *topping charge* and *float charge*. The first stage is the constant current charge stage, also called the *bulk charging* stage. This stage uses up approximately half of the required charge time. The only requirement for this stage is that the charging voltage must be set to exceed the battery's current voltage. The function of this stage is to discharge battery to around up to 70% of its capacity in about 5 to 8 hours. The batteries that will be used in IRPS have 12V nominal battery voltage. When the battery discharges below roughly 10.5V, it can be permanently damaged. Therefore, it is important for the charge controller to monitor the status of the battery especially in this stage [49].

The second stage is the topping stage. This stage is important for the health of the battery. The battery will lose its ability of being fully charged eventually if proper cares are not taken. It begins when the voltage of the battery reaches a predetermined level, and charges the remaining 30% of the battery in around 7 to 10 hours. During the topping stage, the battery at a lower current and the voltage saturates on a constant value. The current decreases during the process because the internal resistance increases as the battery charges up fully charged [49].

The third stage is the float charging stage. The charging voltage is constant for this stage as well. However, the charging voltage is lower than the voltage level in the topping stage. The loss of power caused by self-discharge is compensated in this stage [49]. Figure 3.36 illustrates the voltage and current level in each charging stage.

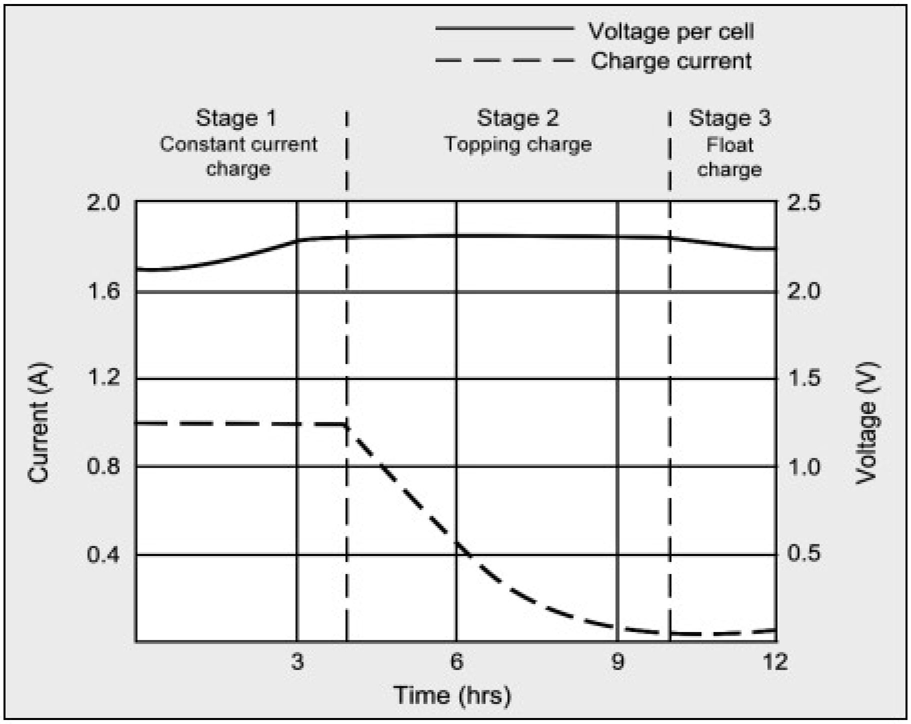


Figure 3.36 Voltage and Current in the three charging Stages. Permission Pending.

It is shown in the figure that the transition between the first and second charging stage are seamless. This transition occurs when the voltage of the battery reaches the pre-determined level. However, the switch point of the current in between the first two stages is very clear. The current decreases rapidly to three percent level of the rated current of the battery.

It is essential to set the correct charge voltage. Compromises need to be made when setting the threshold voltage. This is because it is desired for the battery to be fully charged to its maximum capacity in order to avoid sulfation while this may cause grid corrosion on the positive plate and induce gassing. Moreover, the battery voltage varies with temperature. Marginally lower voltage thresholds are required in warmer surroundings; vice versa, a higher threshold lever is needed for a cold environment. Lower voltage threshold is preferred for safety reasons. However, to optimize the charge efficiency, temperature sensors should be included to the chargers to adjust the charge voltage when the chargers are exposed to temperature fluctuations [49]. Table 3.5 shows the advantages and disadvantages of different voltage threshold settings.

	2.30V to 2.35V/cell	2.40V to 2.45V/cell
Advantages	Maximum service life; battery stays cool; charge temperature can exceed 30°C (86°F).	Faster charge times; higher and more consistent capacity readings; less sulfation.
Disadvantages	Slow charge time; capacity readings may be inconsistent and declining with each cycle. Sulfation may occur without equalizing charge.	Subject to corrosion and gassing. Needs constant water. Not suitable for charging at high room temperatures, causing severe overcharge.

Table 3.6 Effects of charge voltage on a small lead acid battery (SLA). [49]

The sealed batteries have lower ability to tolerate overcharge than the flooded type. Therefore, it is crucial for this type of batteries not to stay at the topping voltage for more than 48 hours and reduce to the float voltage level. For large stationary lead-acid batteries, it is recommended to set the float voltage between 2.25V per cell at 25°C. Lower float charge voltage should be set when the battery is at temperatures above 29°C, which is temperature in Florida most time of the year and will be used in the IRPS.

When the battery is full, the hysteresis charge will disconnect the float current in order to reduce stress. Batteries should be topping charged every six months so that the voltage level will not be under 2.10V per cell and cause sulfation.

Open circuit voltage (OCV) method can provide indication of the battery's state-of-charge. A battery that has 90 percent voltage level at room temperature only needs a brief full charge before use. If the voltage drops below 90 percent of charge, the battery must be charged to prevent damage. The storage temperature is also necessary to be monitored. A warm battery highers the voltage slightly and a cold one lowers it. It works best to estimate the state-of-charge to use the OCV method when the battery has been resting for a few hours. This is because the battery will be agitated by the charge or discharge resulting in distorting the voltage.

Chapter 4 Project Hardware and Software Design Details

4.1 Initial Design Architectures and Related Diagrams

In the overall system, the initial design architecture is shown in Figure 4.1. The wind turbine and solar panels collects powers, and the charge controller then adjusts the current and voltage going to the batteries to prevent overcharging or over discharging. Voltage sensors are placed between the sources, efficiency optimizer and batteries. When each of the battery is fully charged, the power will go to a diversion load to dissipate the exceeding power. The voltage sensors are also used to monitor the voltage level of the batteries so that the charging can take place automatically when it is needed. All of the signals from the voltage sensors are sent to the controller box which monitors the charging process of the battery bank. Electricity can be drawn from the battery bank for power consumptions. It goes through a DC/AC converter and a transformer to the power outlet.

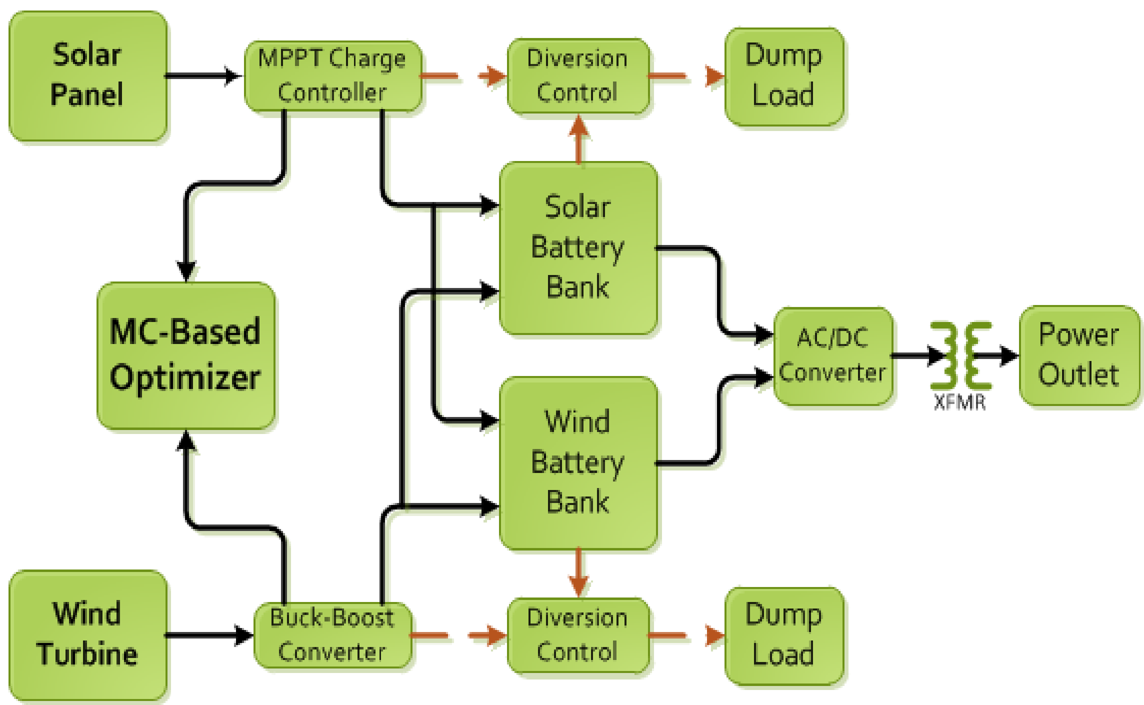


Figure 4.1 Block Diagram of the Overall System

4.2 Solar Panel

There are so many different types of solar panels in today's market, but after much time spent looking the choice that is best for this project is a polycrystalline silicon panel. The mono-crystalline silicon panels are more efficient; however the poly-crystalline silicon panels are not that much less efficient. Also the mono-crystalline panels are too expensive for our budget and the extra bit of efficiency does not seem worth the extra money. The thin film and amorphous silicon technology has not matured enough yet and has terrible efficiency compared to the silicon panels. Although GaAs panels have excellent efficiency they have also been ruled out due to price and lack of availability. SunWize is the company that builds a solar panel that best suites the needs of this project. Table 4.1 below shows the specs of SunWize's SW polycrystalline silicon panels. The SW-S85P model is the model that has been selected for this system. This model is within our budget and it has close to the 100W output that was originally desired. The best price that has been found online is at solarhome.org at $249.85 which is much cheaper than the $375.00 price at the manufacturer's website.

Model	Rated Power (W)	Rated Voltage (Vmp)	Rated Current (Imp)	Open Circuit Voltage (Voc)	Short Circuit Current (Isc)	Weight (lbs)
SW-S55P	55	17.4V	3.15A	22.0V	3.3A	14.0
SW-S65P	65	17.4V	3.7A	22.0V	4.1A	14.1
SW-S85P	85	17.4V	4.9A	22.0V	5.4A	18.0
SW-S110P	110	17.4V	6.3A	22.0 V	6.6A	21.4
SW-S130P	130	17.4V	7.4A	22.0V	8.1A	25.4

Table 4.1: SunWize SW Series Polycrystalline Silicon Panels [47]

As discussed in chapter 3.3.4 temperature can be a large negative factor in the solar panel as far as voltage loss is concerned. The electrical and thermal parameters for the SW-S85P solar panel must be kept in mind if the system starts to show signs of voltage loss due to the Florida temperatures. The SunWize panel was chosen because it was believed to be a good model for dealing with the climate here in Florida. The electrical and thermal parameters from the manufacturer's specs can be seen on table 4.2 below.

Max System Voltage	**600Vdc**
Series Fuse Rating	10A
Voltage Temperature Coefficient	-0.35%/C
Current Temperature Coefficient	0.065%/C
Power Temperature Coefficient	-0.5%/C
Peak Power Tolerance	±5%

Table 4.2: Electrical and Thermal Parameters of SW-S85P [47]

4.2.1 Mounting

Solar panels tend to be fragile and can easily be damaged if not properly secured. One main reason the SunWize SW series was chosen is because of the mount holes premade on the perimeter of the panel. Trying to drill holes into the panel could very easily destroy the panel, so this was a good selling point on this particular solar panel. The design for this project needs a ground based mounting bracket that can have the angle adjustable on the vertical axis. Since this system is being built here in Central Florida which is the Northern Hemisphere, the panel should face due south and have an optimal vertical angle. This allows the optimal amount of sun light for energy use. Below is a table of these angles by month of the year for Orlando Florida [48].

Month	Jan	Feb	Mar	Apr	May	June
	46°	54°	62°	70°	78°	86°
Month	Jul	Aug	Sept	Oct	Nov	Dec
	78°	70°	62°	54°	46°	38°

Table 4.3 Angle of Vertical Axis on Mounting Bracket for Orlando FL [48].

These angles could be controlled by a solar tracking system and would not have to be set manually. This would require an electric motor which would need to be powered. Since the main goal of this project is to charge the batteries as quickly as possible, the group decided the solar tracking system would use too much of the power being produced. Every month the solar panel’s angle will have to be set manually.

The mounting bracket could not only increase the amount of sunlight reaching the solar panel, but it can also protect the panel from high winds. Since Florida is an area of the country that tends to have hurricanes this will be necessary to protect the panel. There are many different universal solar panel ground mounts and after some research it was determined that one can be acquired for around $50.00.

4.3 Wind Power Generation

Three main options fit the requirements and specifications of this project.

1st option: ***THE WORKHORSE 250 watt $129***

The first option is a low budget wind generator that delivers 250 Watts. It is sold widely on eBay by various vendors. The price for this unit is $129. It includes rotor, blades, tail, protective diode, generator and screws. This unit can be purchased in case our budget gets reduced. This unit is designed to charge a 12 volt dc auto or marine style battery in low wind areas with very little installation time or experience. A 15 mph wind will give 15 volts, which is enough to begin charging your batteries. The higher the wind - the faster your batteries will charge. The unit has a tail section which simply screws together with the body and then the blades bolt onto the hub. A 10 amp diode is included with the unit, which keeps the motor from draining your battery when the wind is not blowing. The assembled wing span of the blades with the hub is 33" to install the unit, simply run your charging wires up a 1" i.e. pipe or conduit and connects the turbine's 2 wire output to your charging wires. It produces 6v – 120vdc 2450 rpm produces 120vdc direct drive Stall at 120v draws 3.21 A . 200 RPM produces over 12VDC.

The main drawback of this unit is that requires winds higher than 9 miles per hour to start generating power. This factor is very important for the project because when both input sources work at least at %60 of its capacity the system needs to be tested. If at least half of its capacity is not achieved, the batteries will not get charged.

Figure 4.2 THE WORKHORSE 250 watt. Permission Granted from WORKHORSE.

2nd option: ***Apollo 550W 12V DC (3 Blades) $438.00***

http://www.greenergystar.com/shop/

This wind generator meets the needs for the project. The price for this unit is $438. It starts producing energy at 8 mph, which is perfect for Orlando whose average wind speed is about 9.2 mph. According to the vendor, GreenergyStar's Apollo Wind Turbine is the most mechanically advanced generator in the market today. It features many upgrades that solve performance issues that our competitors struggle with. The following list will summarize its major features:

- With 49" swept area when mounted on a 5" Hub
- Incorporates highly efficient, true airfoil
- Quiet performance with minimal vibration
- Can generate 800 watts or more depending on PMA efficiency
- Manufactured using a precision injection molding process that produces blades of exceptional consistency
- Made with new thermoplastic to increase durability
- Smoother and more durable than any blades you can find in the market
- Adjustable blade degree with included degree adjusters / shims (see picture below)
- High resistance to bending (over 150 degrees)

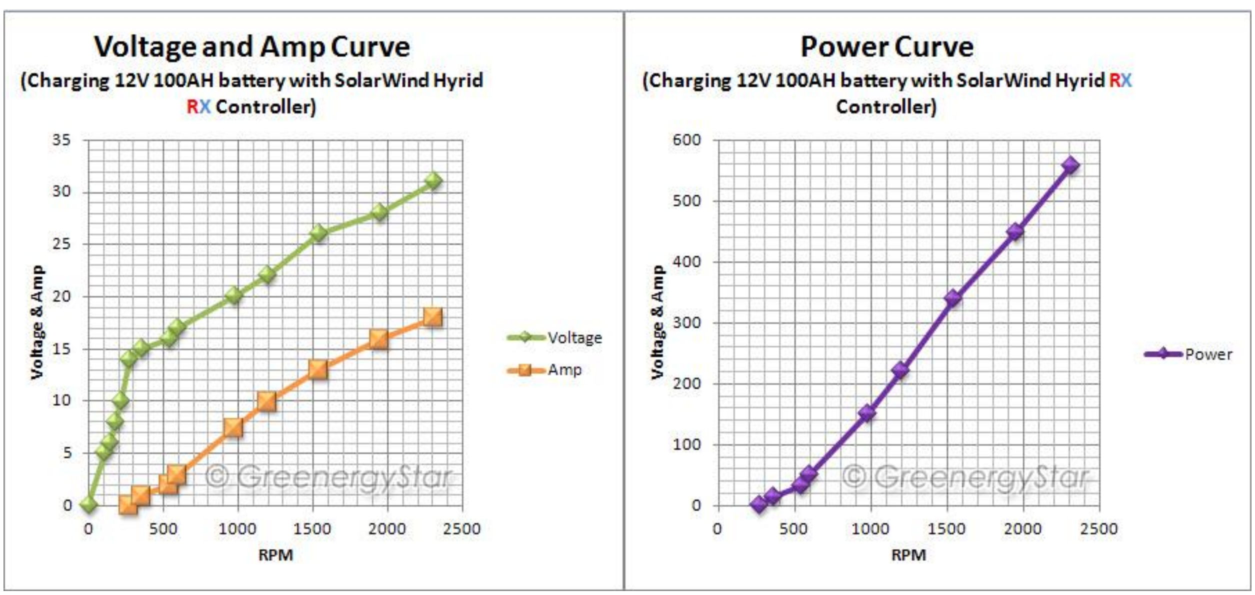


Figure 4.3 Voltage & Amp vs RPM. P

Generator Specification:

Body Material	Aluminum
Rotor Diameter	124.5cm (49 inches)
Starting Wind Speed	3.5m/s (8 mph)
Rated Wind Speed	13m/s
Survival Wind Speed	45m/s
Voltage	12 VAC
Rated Power	450W
Maximum Power	550W
Weight	7.88kg (17.39 lb)
Mount	1.5 in schedule 40

Table 4.4 Apollo 550W 12V D Specification

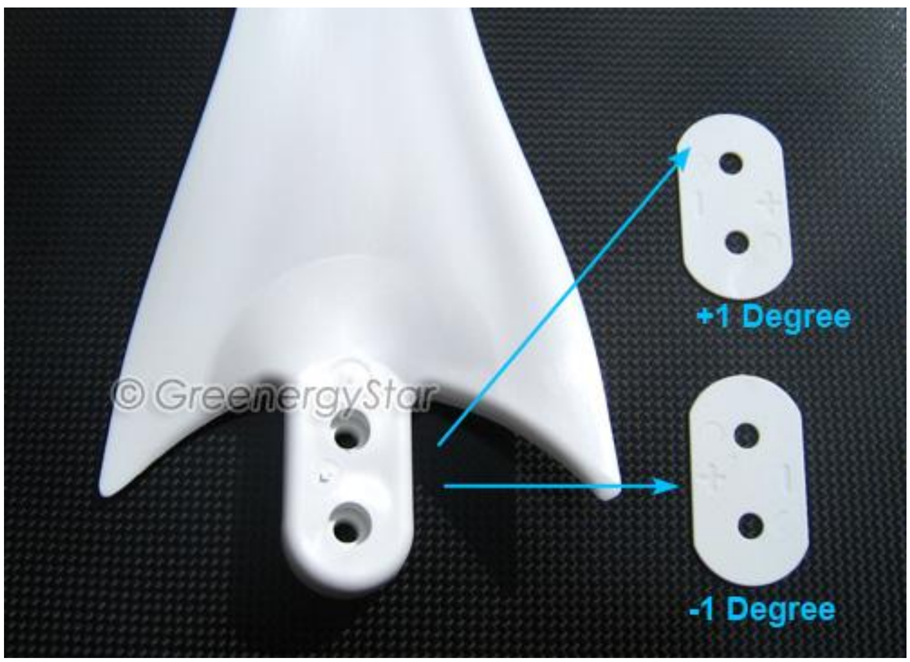


Figure 4.4 Apollo 550W 12V DC blade configuration. Permission pending.

Body Specification:

Material	Aluminum
Length	62 cm
Tail Height	33 cm
Tail surface	225 cm^2
Upgradable	Yes
Blades	6

Table 4.5 Apollo 550W 12V D Blades specifications. Permission pending.

4.4 Controller Box

Controller box is the IRPS concept for the encapsulation of some components and functionalities. IRPS performs some actions directly related to microcontroller both in the input and output direction. However, it is important to highlight that the reason of having some components forming part of controller box concept doesn't mean that they are physical located next to microcontroller in the prototype implementation. Rather, controller box encapsulate them as grouping similar actions to easily explain most of IRPS actions. Being controller box one important part of IRPS circuitry but not the whole board, several electrical components are left out of its design and they are detailed in their own design section. Controller box concept encompassed the microcontroller, voltage sensors, temperature sensor, LCD display, USB interface, and User Monitoring Report. An overall design of controller box is described in below Figure 4.5.

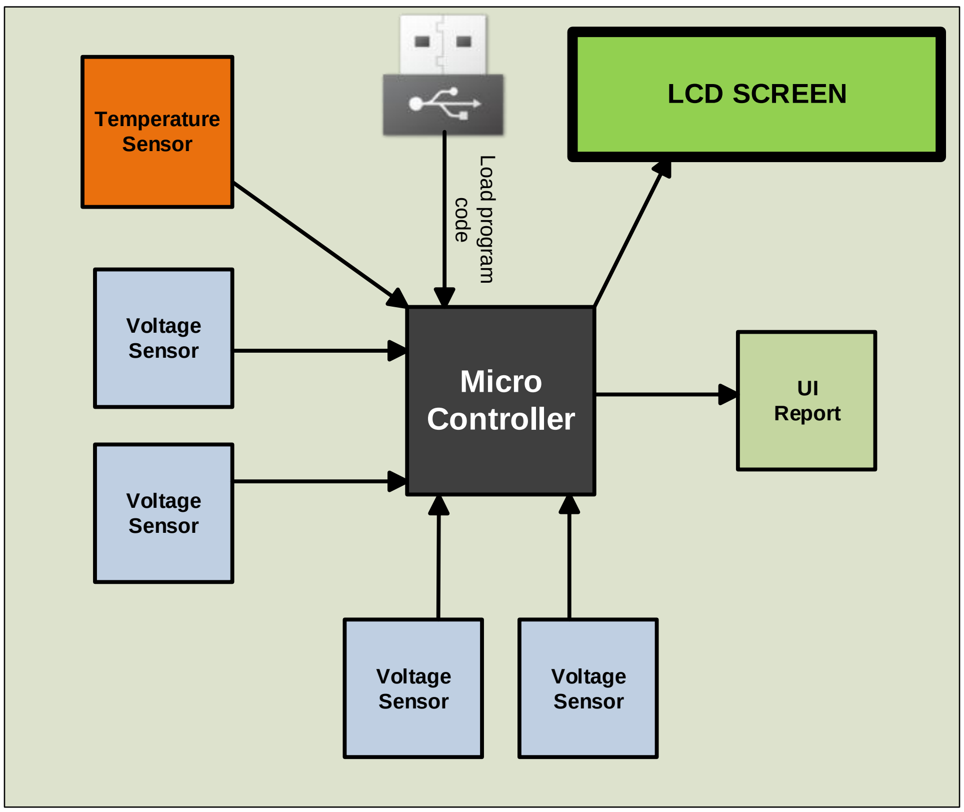


Figure 4.5 Overall Controller Box Diagram.

First and more important component as core of controller box is the microcontroller depicted as the dark grey box in the middle of Figure 4.5; microcontroller chosen was the Atmel AT91SAM7X512 with Netduino boot loader. Orange box at the top left of diagram is describing the temperature sensor used in the IRPS; temperature sensor chosen was DS1624 and uses microcontroller I^2C bus to provide actual readings. Light blue boxes are referring to voltage sensors in IRPS where each one of them consumes one analog input of microcontroller. Light green box is a USB-Serial connection between microcontroller and monitoring software running in a remote pc which provides a variety of analytical reports. Dark green rectangle is representing the LCD display which display every important reading produced from microcontroller and any last time message or alert. LCD screen communicates with microcontroller through serial communication or more specific TX and RX microcontroller pins. Lastly, an USB interface interacts with microcontroller allowing updating program code; USB interface is represented by a USB-to-TTL integrated circuit.

Controller box possess a pre-defined block diagram of how logically will perform as a whole. Previous statement allows project development to be more transparent and accessible to follow. An overall controller box block diagram is described in below Figure 4.6.

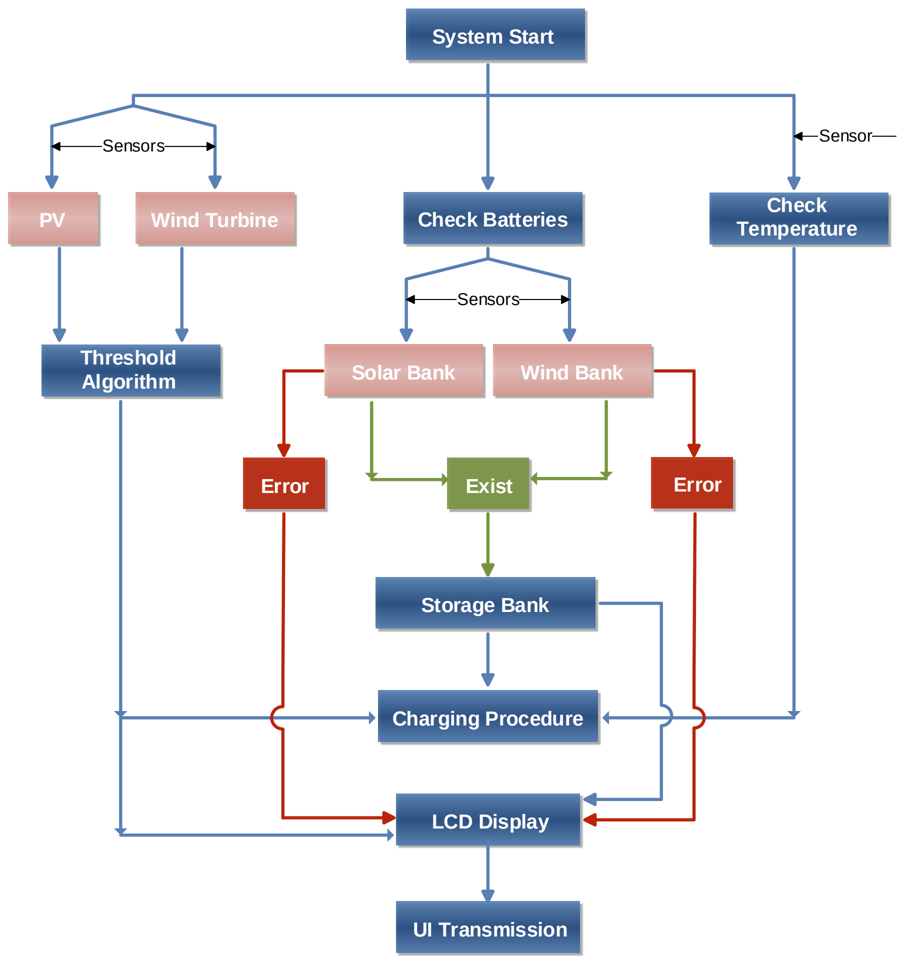


Figure 4.6 Controller Box Block Functionality Diagram

Controller box functionality diagram is shown in above Figure 4.6 and it is divided by using symbolical colors. Blue boxes and arrows means logical stages and system direction flow. Light oranges boxes are used to describe physical components which interact with some stages. Red boxes and arrows are specially used to denote critical system errors status and action to take upon it.

Finally, green boxes and arrows are meant to define successful checking of some components correct availability.

Once system is ready to be functional, it reaches the symbolic step of "System Start". After this point, controller box begin its pre-defined flow checking all required sensors. As first stage, controller box will enter in "Check Batteries" mode where a single request is made to each battery bank voltage sensor; an existent battery bank status is taken into account. At the same time, both "PV" and "Wind Turbine" voltage sensor are requested to measure actual energy sources output. In the same line, controller box request the value of environment temperature sensor on "Check Temperature" mode. If controller box fails on getting previous value into the system, then predefined constant is established by default to not stop IRPS flow.

Second stage is composed of two main modes: "Threshold Algorithm" and "Storage Bank". Threshold algorithm mode takes both "PV" and "Wind Turbine" voltage sensor values and evaluate the strength of both results to determine if actual IRPS threshold status is classified as *Integrated*, *Independent*, or *Independent – Wind enhanced*. Previous statement is indeed asseverating that IRPS uses Mu-Kuen Chen proposal where charging methodology is designed using a microcontroller. Therefore, result is established as No_source, Integrated_source, Independent_source, and IndependentWE_source. Second mode implemented is "Storage Bank" where controller box states what bank of batteries is available to be charged up. IRPS prototype implements one battery representing each sub-bank but it is deemed that production version will have more than battery in each sub-bank. In the current mode, if one or more sub-bank follows the green arrows then it means that controller box will have at least one sub-bank to look up at further stages. Results are established as All_banks if two are present, Wind_bank if only wind sub-bank is available, and Solar_bank if only solar sub-bank is available. Whichever is the result, it is marked to be displayer later. Contradictory, if any of the sub-banks is observed in error state due to complete discharge, overcharge, damage, sensor not working properly, or only connection missing then status is marked to be displayed as alert and status SBank_error or WBank_error will be set. Moreover, if both sub-banks are found to be in error status, then "Storage Bank" will output a No_bank status and an alert will be marked to be displayed later.

Third stage or "Charging Procedure" is the most complex in the functionality diagram. In this mode, controller box checks that *Storage Bank* is not at the status of No_bank because if this status is present then it means that both sub-banks are found as unavailable. Therefore, controller box will emit the appropriate signal to close charging circuit to each bank and start deviating voltage coming to respective dissipative load. If this check is successfully passed then next step is to check if *Threshold Algorithm* is not at No_source status because there will be not voltage coming to the system. Being at that state means that even though *Storage Bank* is at some accepted status, controller box have to emit appropriate signal to close charging circuit to sub-bank batteries to avoid losing any voltage coming out from batteries back to the source. In the expected scenario where *Threshold Algorithm* is different that No_source status and *Storage Bank* is different that No_bank status, then “Charging Procedure” begin the valid logic of the stage. First, voltage value coming in from *Threshold Algorithm* is be compared with each sub-bank voltage presented in *Storage Bank* and in case that first one is greater than any one on the second set, then controller box is setup to start charging procedure to respective sub-bank, otherwise controller box will deviate coming voltage not going to specific sub-bank and not allowing inappropriate discharging. Second, in this phase controller box knows what sub-bank is needed of charging, what charging mode has been set, and voltage coming is greater that sub-bank current voltage. At this point controller box sends appropriate signal to switching circuit informing at what charging mode he will operate. Also, controller box will stop any voltage deviation to dissipative load.

Fourth stage or “LCD Display” wraps around any variable value or alert to make a custom format message and interact with LCD device to display final outcome. Values presented are current PV power, wind turbine voltage, current charging mode, each sub-bank status or charge level, and controller box temperature. Notice that if any malfunctioning raises an emergent alert, no standard format message would be displayed rather the emergency itself.

Fifth stage or “UI Transmission” is where microcontroller establishes a direct connection with a computer where report software is running. Such software possesses a background thread always listening incoming transmission from microcontroller and saving it into system database. Saved information is later used to populate a variety of useful reports to final user.

4.5 Monitoring System Design

4.5.1 Microcontrollers Units

The Atmel AT91SAM7X512 microcontroller was used in IRPS pre-loaded with the preference of Netduino boot loader. This microcontroller contains the adequate hardware and software for all design goals, providing enough digital and analog pins to handle all sensors, LCD, and battery charging check, meanwhile at the same time being able to control the IRPS circuitry using pulse-width modulation (PWM) outputs. A list of specifications for the AT91SAM7X512 is given below: [40]

- 32-bit microcontroller
- 48 MHZ clock speed
- 512 KB flash memory
- 128 KB SRAM
- Two pins UART
- 14 digital I/O pins
- 6 analog inputs pins

- 4 PWM channels
- SPI Interface
- I2C bus communication
- Input power 7.5 – 12 V DC
- Output power 5 V DC

The six analog pins were utilized in IRPS. In order to enable I^2C communication in this microcontroller, analog pins 4 and 5 were used. Occupying two analog inputs will reduce the available number of analog inputs to four. Four analog voltage sensors take up the leftover four analog input pins. Every I^2C device carries a unique address to allow a precise identification on the bus and up to 127 unique peripherals may be contained on a single I^2C bus. Hence, if any extra device needs to interact with microcontroller, I^2C compatible parts would be highly recommendable over analog devices. In case that only analog device can be further implemented due to certain limitations, then it is deemed necessary to include analog-to-digital converter in order to be in harmony with I^2C bus.

In the microcontroller output pins implementation, most of the pins were assigned to specific functions. First, it is attributed the digital pins 2 and 3 to the LCD since it uses serial transmission; such pins are better described as TX and RX and are part of the UART. Microcontroller has another two UART pins located in digital pins 0 and 1, named debug UART, and they were used as interface between microcontroller and external computer. Finally, the two PWM output located at pins 5 and 6 controls the circuitry logic focused in the charge controllers to implement the right stage of charging, the addressing of voltage flow to batteries or dump, the threshold energy source charging mechanism, and all others function in the IRPS; PWM pins 9 and 10 were left unused.

The Atmel AT91SAM7X512 microcontroller was a perfect election for IRPS since contain all hardware required and leave plenty room of processing and memory to add future expansions. The natural choice with this microcontroller would be using AVR's IDE (AVR Studio) and programming language; in this case code would be implemented in either a C-like or in assembly language. The principal deficiency with this alternative is the fact an external programmer is needed to load new code to the chip flash memory. IRPS would use an enclosed chassis design to protect components then the situation of physically accessing to microcontroller every time that an update must be implemented it is highly inapplicable. On top of previous disadvantage, it is certainty that removing microcontroller can incur in further damage to board causing bending pins, electrostatic discharge every time the chip is removed from a socket. All combined result an impractical deployment of IRPS controller box to a final scenario such as small location, then the current approach is discarded as the best method to implement AT91SAM7X512 microcontroller.

Instead, the Netduino development board procedure was chosen to implement algorithms in AT91SAM7X512. Netduino boot loader permits direct programming using USB interface, removing the demand of a separate hardware to implement an update. In consideration of this implementation, a USB interface was included in PCB design such as a USB-to-TTL integrated circuit (IC) allowing updating code in microcontroller after every component is integrated in IRPS PCB board. A handy alternative was to use one ATmega8U2, reprogrammed as a USB-to-Serial converter, to communicate AT91SAM7X512 microcontroller and IDE where was programmed the chip. Second major fact supporting the Netduino method as microcontroller implementation was the available IDE and programming language. The commodity of having the C# language at hand to implement microcontroller was a plus taking into consideration existent familiarity with language. The language is both easy to use and robust, sustaining all the functionality needed for interfacing with analog sensors, I^2C components, and TTL serial peripherals among others. Also, Visual Studio as IDE chosen is proprietary software but full license is available and ready to be used, which will take the topic off the discussion. The community support for microcontroller implementations using Netduino development board is very large and consistently updated shorting the learning curve at time of implement dedicated algorithms needed for IRPS. There are several built libraries concerning sensors, motors, LEDs, communication tutorials, etc. readily available on the Netduino website. Finally, IDE software was Microsoft Visual Studio 2010, and .NET Micro Framework SDK 4.1 was downloaded from Netduino website in order to override the AT91SAM7X512 to load and interpret the C# code compiled.

4.5.2 Algorithm Implementation

Microcontroller is to execute specific algorithms performing IRPS core functions. Algorithm order was established based on priority criteria of those components which were more critical if occur a malfunctioning and can propagate a system error if they are not taken care at the right step. In below Figure 4.7 is depicted a sequential flow diagram referring to main algorithms or methods implemented in the microcontroller.

Algorithm Sequence

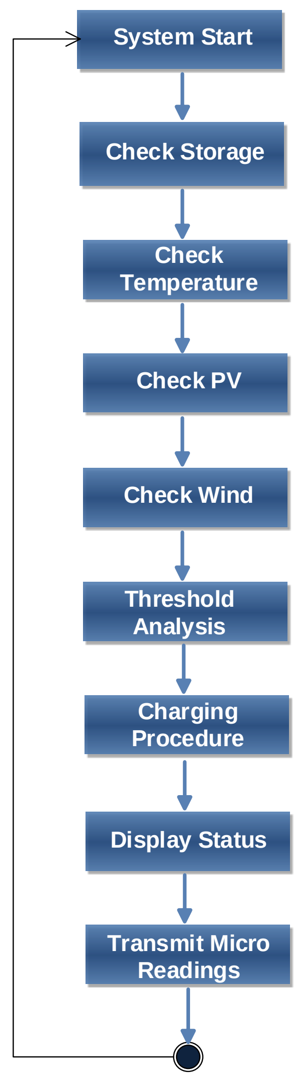


Figure 4.7 Algorithm Implementation Flow

Microcontroller continuously executes the sequence above and loop over it at same cycle time which is defined by the best execution model. Above Figure 4.7 enumerate the main logical methods describing consequent steps implemented; however, those main methods use others sub-methods serving as helpers. Necessary sub-methods are not presented in flow diagram to avoid confusion and to obtain a better understanding from main algorithm logic. Currently, methods describe in above Figure 4.7 performed the following logic:

- System Start: It is defined as the beginning of sequential flow, it is represented by an infinite cycle such as instruction “while (true)” and embrace the rest of the methods. Also, initial variables were declared and initialized here.

- Check Storage: This method check both battery banks status using the voltage sensors. It uses two sub methods to check each corresponding battery (Solar, Wind). After both batteries status are retrieved, all results are be saved in different “battery objects” belonging to *battery class*. Some attributes recorded are current charge level, current charge stage, and if need more charging.
- Check Temperature: This method interacts with temperature sensor linked to IRPS output to retrieve current controller box temperature. Result is saved in one variable to be further.
- Check PV: This method interacts with voltage sensor linked to solar panel output to retrieve the current voltage status. Result is saved in variables to further use.
- Check Wind: This method interacts with voltage sensor linked to wind turbine output to retrieve the current voltage status. Result is saved in variables to further use.
- Threshold Analysis: In this step microcontroller uses previous two steps results to analyze at what mode IRPS should operate (Integrated Solar, Integrated Wind, Independent, and Independent Wind Enhanced). Current mode is set at one variable for later use.
- Charging Procedure: This step is critical and hold a high degree of importance to maintain IRPS circuit stability and avoid board physical damage. At this stage, method determines what source should be used and how. It reads previously created *battery objects* and combining with decided threshold mode, it will act upon the correct charging procedure. Furthermore, as an example if battery solar object need charge and it is at *bulk charging stage*, battery wind object indicate full charge, and threshold method define that IRPS should operate at *Integrated solar mode,* then microcontroller sends the signal to switching circuit stating bulk charging mode to be effectuated and it will deviate energy to not charge the wind battery to avoid overcharging. As protective trigger, IRPS could be at any charging mode but if both batteries are full or unreachable for system to know current status, then microcontroller begin to deviate the coming voltage to *Dump Load*.
- Display Status: This method compiles all previous necessary variables and builds a custom friendly message to be displayed in the LCD. Important variables are current PV power, wind turbine voltage, current charging mode, each sub-bank status or charge level, and controller box temperature. After this step, microcontroller can be either put to idle mode for some period of time or directly jump to “System Start” flag.
- Transmit Micro Reading: This method create a secondary thread on charge of compiling system current variables, build a custom message and transmitting it to an external computer where it is parsing and save it into a database.

4.5.3 LCD Display

As an important design requirement of the IRPS board is that the elements included should use as little power as possible, as not to detract from the power available for charging the battery. ARM microcontroller selected draws more energy that some smaller alternative but also reduce the chance of having to use two units instead of one and further complicate the logic of IRPS design. Then, it was decided to do some saving in energy consumed from others devices to be integrated; therefore, the graphical display was opted out. On details, a graphical display might consume hundreds of mA while a character LCD would consume less than 100 mA when fully backlit. Additionally, graphic LCD would introduce more complexity on interaction since it requires not only more programming and testing to make it work but also more I/O pins from microcontroller. IRPS is not gaining big enhancements from incorporating this element and it was decided to better go to other type of LCD. However, it is noticed that opting out from graphical LCD will bring as constraint that no touchscreen capability will be offered from IRPS.

The power consumption was the main reason not to select the graphical LCD however even though the segmented/alphanumeric LCD consumes the least amount of power, it does a poor flexibility for IRPS and is therefore eliminated as well. The 14-segment characters are generally very large per character and do not allow the system to display detailed messages, which was very desirable for IRPS performance feedback. The segmented LCD option was deemed inefficient because it could not display several status values such as current and voltage simultaneously.

With not so many discussed alternatives left, it was clear that a character LCD screen would be the more suitable solution for IRPS. It provided the adequate balance of power consumption and image size/quality making it the most viable option. As it was discussed on the research portion, backlighting is still a necessary feature to be part of the LCD so that the status could be read in any lighting situation. Backlighting makes the screen more versatile and allows the user to quickly and easily view the text in varying conditions.

Taking into account the arrived conclusion, 20x4 characters LCD was chosen for implementation into the IRPS design. This provided enough room to display several quantitative values as well as any custom message or alert that need to be displayed. The display model selected was the serial enabled LCD-09568 from vendor SparkFun Electronics. The actual LCD is 87.3 x 41.8 mm while the PCB footprint measures 105 x 59.9 mm. This display is monochrome (black on green) and has adjustable backlighting. Serial type LCD was selected over parallel similar models cause of their simplification of use and reduction in the number of pins that they use. Parallel LCD device can be acquired at lower price but its added complexity at programming and the greater amount of microcontroller pins needed, won’t make up the money saving worth.

4.5.4 Sensor Implementation

4.5.4.1 Voltage Sensor

Voltage sensors used in IRPS system were voltage divider implementation and a low pass filter shielded final signal to avoid voltage spikes. AT91SAM7X512 has a 5V tolerance and taking voltage directly from sources will peak over microcontroller threshold and cause system to overheat and fail. Overall sensor design is described in below Figure 4.8.

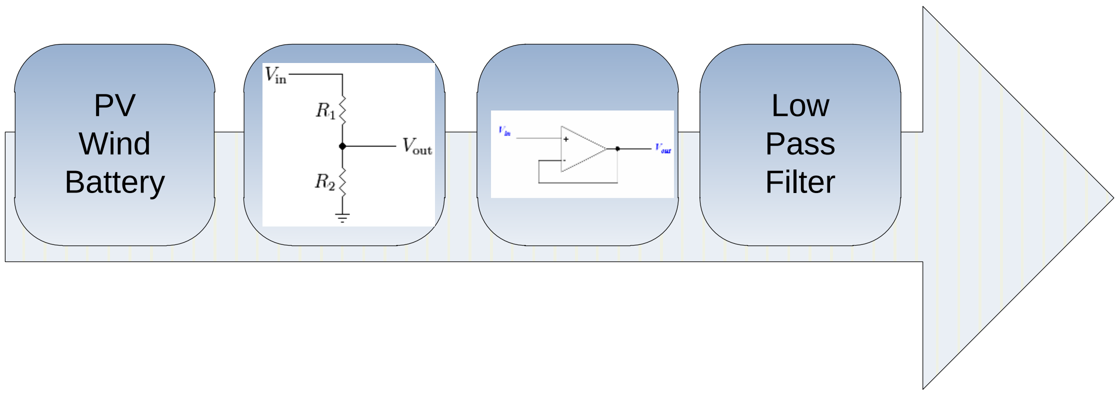


Figure 4.8 Voltage Sensor Operational Flow

The voltage across resistor R2 is the voltage that is monitored and measured for the IRPS; consequently it will work with electrical specifications of the Solar PV Panel and the microcontroller to prevent any damage or malfunctioning of the system. The appropriate resistor values are calculated as following given the conditions:

$$R_1 = 1M\Omega$$

$$V_2 = \frac{R_2}{R_1 + R_2} V_p \ (1)$$

In above formula V_2 represents the voltage drop across R_2 as a function depending of V_p which represents the voltage generated by the solar panel. Solar panel maximum output voltage is 22.0V; that number would be taken into account in below formula to find the value of R_2. V_2 is the important result here since would be the reading provided to microcontroller, and design shown above will enforce that V_2 value won't be ever greater than 5V. Taking above formula 1 and maximum voltage value assigned to V_2, it is calculated the necessary resistor R_2 value to finish the custom voltage divider circuit.

$$5V = \frac{R_2}{1M\Omega + R_2} 22V$$

$$R_2 \cong 340k\Omega$$

Even though the value of R_2 was calculated to be 340kΩ, it was determined through experimentation that 180kΩ was a better value for R_2. This value still offers the same protection to the micro-controller but gives a more useful input range due to the fact that the micro-controller may only input 0V to 3.3V for accurate voltage sensing. Having set resistors values, voltage divider circuit was prepared to deliver no more than 5V output to microcontroller under current solar panel specs. Output from voltage divider is fed into a voltage follower which is a safety net to separate components in the voltage sensor circuit to avoid interference between them. Next, voltage value would be fed to chosen capacitor with the only function of attenuate the fluctuation and regulate possible spikes before provide output voltage to microcontroller.

In below Figure 4.9 voltage sensor circuit was simulated using Multisim as proof of previous explanations and calculations. A maximum power of 22V has been set in the simulation to act like maximum voltage output to sensor circuit. First voltmeter in the simulation display voltage across R_2 as of 3.355 V confirming that circuit first step is stepping down voltage below AT91SAM7X512 maximum voltage tolerance of 5V. Second and third voltmeters display the filtered voltages and it is observed that difference is only just 5 mV after the voltage follower.

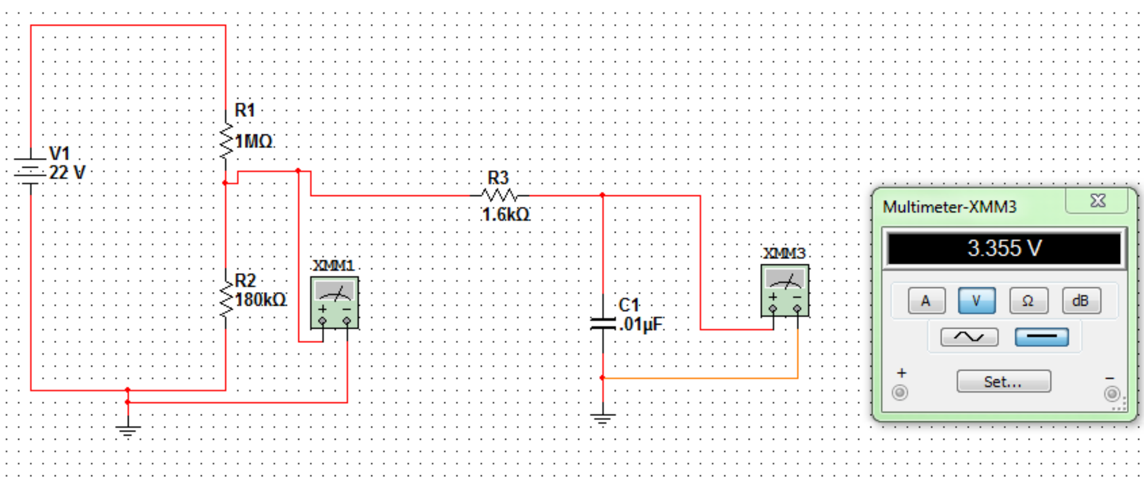


Figure 4.9 Voltage sensor circuit worst case simulation

Simulated components validate that IRPS worst scenario to be experienced would count to a total of 3.355 V and it is demonstrated that circuit last part or Low-pass filter is not affecting voltage value but attenuating the final signal. Furthermore, it is expected to have a slight different output voltage once sensor is implemented with real components due to internal elements variations; however, voltage can never exceed the 5 V thresholds, otherwise R_2 has to be revised and changed to a different value to obtain a simulated small voltage than 3.35 V taking into account the physicals components signal offset.

Implementation starting at above formula (1) was repeated when measuring voltage in the wind turbine and batteries. R_2 value will change for both cases since V_p is different depending on their specs, then formula (1) must be re-calculated entering each set of values and simulation similar to above Figure 4.9 has to be implemented for both cases to ensure that no more than 5 V is coming out from particular case sensor.

4.5.4.2 Current Sensor

Being able to sense current for IRPS is essential for two reasons. The first reason is that the SunWize PV panel outputs voltage even when the sun is not present. When the sun sets the PV's current will drop to zero thus making the power equal to zero. Without the current sensor IRPS will not be able to determine if a useable solar source is present. The second reason is that IRPS will be able to determine if the batteries are being charged or not. If current is flowing towards the battery which will be a positive value then the batteries are charging. If the current is flowing away from the batteries which will be a negative value, then the batteries are discharging. The priority task of IRPS is to charge the batteries a quickly as possible, this is one reason the system will be unable to use premade current sensors. Current sensors that are available in today's market tend to be ICs that require at least 5V to operate. It will be beneficial to figure out a passive way to detect current that will not use any of the precious power that should be directed towards charging the battery. The shunt resistor technique was chosen for IRPS as the current sensor. Figure 4.10 below depicts the shunt resistor technique.

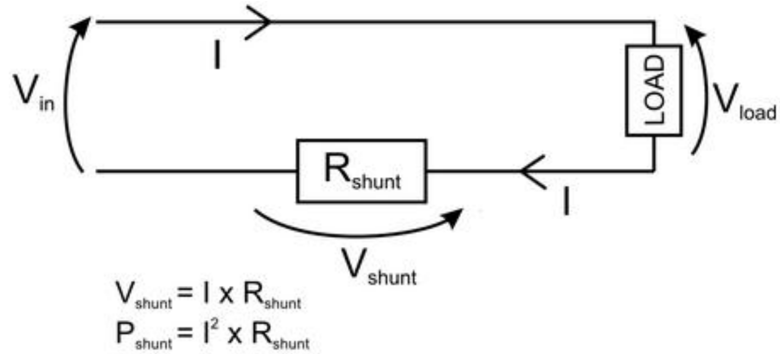


Figure 4.10 Shunt Resistor technique used for IRPS current sensors

IRPS used the system itself as the shunt resistor in the current sensor. First the resistance of the system will need to be determined. Using the voltage sensors from the source and the appropriate battery IRPS was able to calculate the voltage drop. Next a current meter was placed in series from the solar charger to the battery determining the current allowing the resistance to be calculated using Ohm's law. The resistance of the IRPS system was determined to be 1.6667Ω. This value was entered into the software as a constant allowing the micro-controller to use Ohm's law to not only determine the value of the current, but also which direction it is flowing as well. This information was used to determine if the batteries were being charged and how much power in watts was being produced by the PV panel.

4.5.4.3 Temperature Sensor

The DS1624 Thermometer from Maxim is a digital temperature sensor that fits all of the desire characteristics that are needed in IRPS. DS1624 is well designed to be fully integrated directly with microcontroller without the need of using other external components. The main features important for IRPS design are:

- Communication type: I2C Bus
- VDD of 2.7 to 5.5 V input power
- Range of temperature is of -55°C to +125°C
- The temperature is read as 13-bit value
- 8- pin DIP

The ample temperature range where sensor operates brings the advantage to be exposed to high temperatures and still providing accurate readings. Since sensor use I^2C bus for communications, enable the possibility to implement this channel and have the advantage of having already set if more I^2C devices compatible.

As it was discussed on DS1624 research chapter and referring to below Table 4.6, DS1624 pins are configured on the best interest of IRPS design. Pin 1 and 2 are in charge of the communication so they are connected directly with the microcontroller I^2C bus. Pin 3 is a pin that is not used therefore is left unconnected. Pin 4 and 8 are responsible for powering the chip and grounding the chip respectively. The voltage applied at the VDD should be between 2.7 to 5.5 volts. Finally pins 5, 6 and 7 were used to assign different address to the DS1624 sensors so there will be not identification misdirect between sensor and microcontroller request.

Pin	Symbol	Reference
1	SDA	Data input/output
2	SCL	Clock input/output
3	NC	No connect
4	GND	Ground
5	A2	Address input pin
6	A1	Address input pin
7	A0	Address input pin
8	VDD	Supply voltage

Table 4.6 Temperature sensor DS1624 pin description

4.5.5 Switching Circuit

The main idea behind IRPS is to integrate solar and wind power to charge a system of batteries. It was determined by the group to utilize a micro-controller based switching system to integrate the two sources. Therefor the switching system is the heart of IRPS and cannot function without it. Each source was hardwired to its own battery but the switching circuit will allow each source to “share” its power to the other sources battery. This was accomplished with the circuit in Figure 4.11 below.

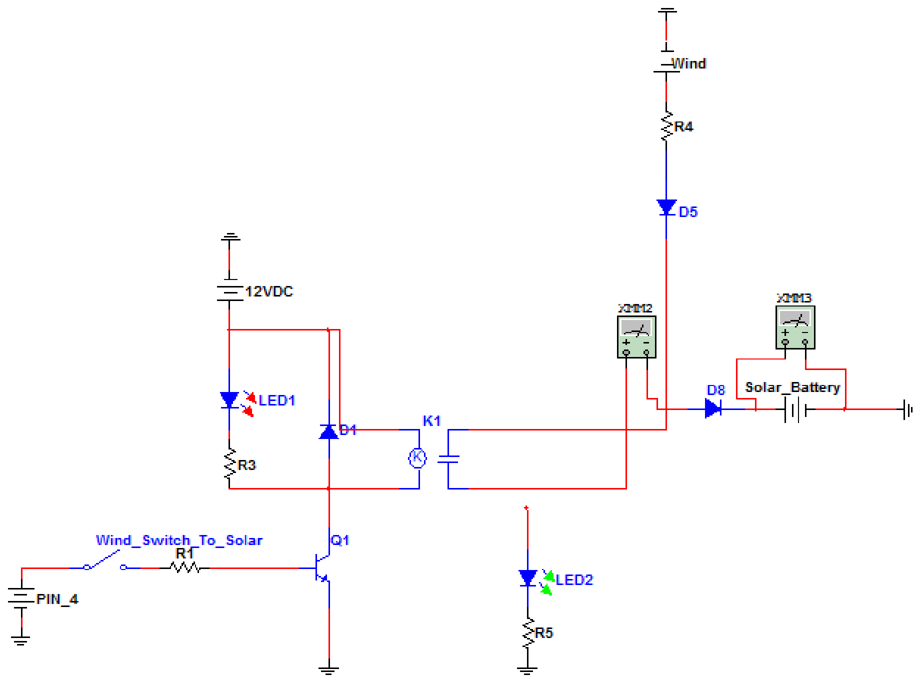


Figure 4.11 Switching Circuit of the Wind Turbine sharing power to Solar Battery

Two of the circuits depicted in Figure 4.11 were used so that each source could be integrated to the others battery. When the micro-controller determines that one source needs to be shared to the other’s battery it will output 3.3V from one of its analog output pins. This 3.3V will turn on transistor Q1 which will allow the 12V from the battery to flow from diode D1 to the relay K1. LED1 will also turn on giving a visual confirmation that a source has entered into integrated mode and is sharing its power. Diodes D5 and D8 are to ensure that current only flow towards the battery and not back towards the source.

4.6 Battery Bank

Energy storage must be optimized to ensure the most effective sizing of each of the system components. When choosing a battery type for the integrated renewable energy applications, there are many factors must be taken into account. Those important comparison criteria are possible depth of discharge of the battery, cost, number of charge or discharge cycles the battery can tolerate, efficiency, self-discharge, energy density, cost, size, weight and technology maturity. It is found in the research that lead-acid and lithium-ion chemistries are the most popular types of batteries for renewable energy systems. Therefore, a comparison of these two types of batteries is break down into the above criterion in the table below.

Attributes	Deep-Cycle Lead-Acid	Lithium-ion
Depth of Discharge	75%	80%
Cost	Low	Very High
Lifespan (Cycles)	1000	3000
Efficiency	72-78%	100%
Self-discharge	Average	Negligible
Energy Density (Wh/kg)	30-50	100-200
Charge Time (hr)	12-16	1-4
Maturity of Technology	Mature	Immature

Table 4.7 Lead-Acid vs. Li-Ion Batteries

Currently, the most popular type of batteries leading the battery market is the lithium-ion batteries. They are mostly used within portable electrical devices, such as laptops, cell phones and music players. This is because they have very high efficiency of close to 100 percent and they have a very high energy density which stores a lot of energy for a small amount of weight. In addition, they have a lifespan of 3000 cycles at a depth of discharge of 80 percent. Nevertheless, they are very expensive; therefore, they are not currently considered for larger energy storage applications. On the other hand, lead-acid batteries are the cheapest and most technological matured type of batteries. Comparing to the li-ion batteries, they fit much better in the IRPS project in an economical manner. Hence, deep-cycle lead-acid batteries are used in the project design.

Among the deep-cycle lead-acid batteries, flooded, gel-electrolyte, and absorbed glass mat (AGM) batteries are the most commonly used ones. While flooded lead-acid batteries are the cheapest type, they require maintenance and special shipping methods in transporting due to the risk of acid leakage. Gelled electrolyte batteries eliminate the potential of acid leaking, but they must be charged at a slower rate (C/20) to prevent excess gas from damaging the cells. Another disadvantage of this type of batteries is that they must be charged at a lower voltage than the other two types.

In this IRPS project, AGM batteries will be used for energy storage. AGM is a newer type of sealed batteries. This type of batteries possesses all of the advantages of the gelled electrolyte batteries, but they are much durable. They cannot spill, even if broken. As a result, they can be transported using normal shipping methods. This will lead to a lower shipping cost. In addition, they can practically resist damage from freezing since there is no liquid to freeze. Water loss is also negligible because hydrogen and oxygen are recombined back to water inside the battery while charging at a very efficient rate. There is no need to adjust the charging voltage. Due to the extremely low internal resistance, there will be almost no heating of the battery even under heavy charge and discharge current. The only short coming of the AGM batteries is that they cost almost two to three time higher than the flooded batteries.

The battery chosen for IRPS is the Universal Power Group (UPG) UB12180 D5745 Sealed AGM-type Lead-Acid Battery shown in figure 4.12. The batteries are purchased from Amazon.com for $35.75. The battery is rated for nominal 12 volts and 18Ah capacity at a 20 hour (0.90A) charge rate. The battery has an internal resistance of 18 mille-ohms, and should be charged under constant voltage. For cycle, at 25˚C, the set point of the voltage level should be 2.45V per cell, and the maximum charge current should within 0.30˚C. For standby, at 25˚C, the set point of the voltage level should be 2.30V per cell, and the allowable range is between 2.27 to 2.30 volts. The final discharge voltage per cell is 1.75 volts. The battery has the dimensions 7.13 x 3.01 x 6.50 cubic inches and weighs 11.9 lbs. This battery has an average battery life of four years. It can be used in security, medical mobility, solar, emergency lighting, uninterruptible power supplies, electric gates or fences, garage door backup battery, and portable medical devices. The battery will not leak even if it is broken, and it can withstand freezing temperatures. Moreover, the battery also features small self-discharge of 3 to 6 percent per month, and no need for additional water. It is efficient and reliable energy storage for this project. [49]

Figure 4.12: Universal Power Group (UPG) UB12180 D5745 Sealed AGM-type Lead-Acid Battery. Permission requested pending.

The charging algorithm used for this type of battery specified by the Universal Power Group is similar to the lead-acid charging algorithm reached in chapter 3.

Three stages will be included. The bulk charging stage will use up approximately half of the charge time, and charge up to 70 percent of the capacity. When the voltage of the battery reaches the predetermined voltage lever, which is set to be between 14.5 to 14.9 volts varying with the temperature, the second stage, topping stage begins. During this stage, the remaining 30 percent of the battery will be charged in around 7 hours. When the current of the battery has dropped to 0.3 ampere, the battery is considered fully charged. Then the third charging stage, floating charge, begins. The voltage is dropped to between 13.6 to 13.8 volts. The purpose of this stage is to offset the loss due to self-discharge. The specifications of the UPG UB12180 D5745 AGM lead-acid battery is summarized in table 4.7.

Battery Bank Specification	Value
Nominal Voltage	12V
Nominal Capacity	25˚C
20-hr. (0.90A)	18Ah
10-hr. (1.67A)	16.74Ah
5-hr. (3.06A)	15.30Ah
1-hr. (10.80A)	10.80Ah
Approximate Weight	11.9 lbs (5.4kgs)
Internal Resistance (approx..)	18mΩ
Shelf Life	3-6%
Cycle Use	
Initial Current	≤5A
Control Voltage	14.5-14.9V
Float Use	
Control Voltage	13.6-13.8V

Table 4.8: UPG UB12180 D5745 Sealed AGM-type Lead-Acid Battery Specification

4.7 PCB Design

One of the most important issues that come into constructing our Renewable Source Controlling System box is the printed circuit board design. Printed circuit boards are necessary because it allows all of our integrated circuit chips as well as the Display screens, resistors, capacitors, memory devices and other electronic circuits to be soldered by surface mount technology directly to the PCB. Without the surface mounting process, everything would have to be manually connected to the board by a soldering iron and the process would take too much time. Nowadays PCB's are assembled step by step using computer based programs. The software used for these computer programs are great to utilize because they allow for flexibility in board design layout as well as editing in case you make a mistake.

Sunstone Circuits are chosen to get all the design sources to print our circuit board process http://www.sunstone.com. The Sunstone's PCB Design Software

PCB123 was downloaded. When comparing this software to other existing software available out there, this one best suite our needs. The software acts as a prototype for the Renewable Source Controlling System so it can refer to it often in case for it needs help. Once the detailed design specifications are filled in for the PCB it can be directly ordered from the PCB software. Procedure for designing a new printed circuit board using Sunstone's PCB Design Software PCB123 V3 for our Renewable Source Controlling System:

1) Call the board any name that you want.
2) Make a net list file for your printed circuit board. A net list file will tell the manufacturer in an organized fashion all of the listed individual components, their numbered terminal ports, and where they should be placed on the board.
3) Next step is to define your board size in terms of width and height of the printed circuit board. Make sure to choose a good width and height so that 102 you give yourself enough workspace to add more electronic components if necessary.
4) After that the PCB designer must select the number of layers that he wants for his design. The designer can choose from 2 layers, 4 layers, or 6 layers. 2 layers are mostly used for simple designs, 4 layers is preferably applied for medium-density designs, and 6 layers mainly works for high density or complex designs.
5) If the user/designer determines that he would like to select either 4 layers or 6 layer PCB board then they have option for adding additional plane layers. Plane layers are sheets of copper material.
6) Subsequently the board has additional features such as coating for the PCB. The designer can decide whether he would want a solder mask or a silkscreen. Our best bet when designing our PCB is to use solder mask, which is a green coating on the circuit board.
7) Then there is an option of choosing which thickness is desired. On the PCB123 software, you can select either 0.031 inches or 0.062 inches. For our design which should use 0.062 inches as it is most recommended.
8) And the copper weight is the next factor in the development of the printed circuit board. There are two alternatives to select from for the type of copper weight that you want: the 1 – oz or the 2.5 oz. The Renewable Source Controlling System will want a 1-oz to make the finished product for our PCB. [62]

The common standard that is referred to for the design of PCB’s is IPC-2221A. IPC stands for the Institute for Interconnecting and Packaging Electronic Circuits which is the authoritative figure that controls every aspect of PCB design, manufacturing, and testing. The key document that describes PCB design is IPC - 2221 which is specifically titled “Generic Standard on Printed Board Design.” When fabricating the PCB, the rules that must be considered when making the foundation for every component being surface mounted on entails board size (tracks), trace width and spacing, pad sizes, holes sizes, and hole spacing. You may ask yourself, what are the factors that involve picking an accurate board size (track) for your PCB? These parameters depend upon the electrical requirements of the Renewable Source Controlling System design, the routing clearance and space available, and your own preference. Standard board spacing for routing is 0.3 inches with an additional 1 to 2 inch border on the board for processing. Larger track width is preferred more because they have low direct current resistance and relatively small inductance. Lower limit of the track width will depend upon the track resolution that the manufacturer for the printed circuit board is capable of producing. Also the size of the board will have a particular amount of resistance given off. Finally, the thickness of the copper substrate will have a huge effect on the printed circuit board when soldered upon.103 Pads are defined as a portion of a pattern on PCB‟s that are selected for the purpose of surface mounting electrical components.

The important topics concerning pads involve their sizes, shapes, and dimensions. Pads heavily rely upon the manufacturing process used to make the printed circuit board as well as a person’s solder ability. Another factor that is used to evaluate pads on a PCB is known as the pad or hole ratio. More generally the pad or hole ratio is referring to the pad size to hole size. The rule of thumb for the pad on the PCB should be 1.8 times the diameter of the hole because it will let the alignment tolerances on the drill. Using the PCB 123 software, the manufacturer has the option of choosing which whole sizes he prefers best to implement on the printed circuit board. Make sure to notice that when picking a hole size the plate-through will directly result in making a hole narrow. These plate-through thickness of the holes range from 0.001 inches to 0.003 inches. Another design rule to consider when making a PCB is trace width and spacing. The trace width of the PCB depends upon the maximum temperature rise of current and as well as the impedance tolerance. The least width of trace and spacing are factored upon the x/y rules. X stands for the least trace width and y is the least trace spacing. Tracing spacing is an important parameter to discuss when trying to make a PCB. It will tell the designer how to layout the traces width and spacing between the holes. When a manufacturer makes a PCB he has to make sure that you are given adequate spacing, so if the traces are adjacent to the holes there is a possibility that they will be shorted and therefore the board will be no longer good to use. To calculate the spacing requirements one must determine the peak voltage and then plug it into the formula described below.

$$\text{Spacing (mm)} = 0.6 + V_{peak} \times 0.005$$

$$V_{peak} = V_{rms} * (2)^{1/2} \text{ (in Volts)}$$

Often when setting a workspace for the development of the PCB, people must lay your board on a fixed grid, called a “snap grid.”This will function in order to make all the components on the PCB snap into their permanent positions on the grid. Another grid to question whether a developer would want to use is a visible grid. A visible grid consist of an on-screen grid of solid lines or dots. Here are some facts to bear in mind when working on grids for the design of PCB’s. [63]

- A snap grid is crucial because the workspace for the PCB will allow the parts being placed on the board to be neat and well organized.
- Another aspect about a snap grid is that it will make editing, movement of tracks, and components easier to do because the board will eventually expand in size.
- There are two types of grids in a PCB package that a developer in electronics can choose from: a visible grid or a snap grid.

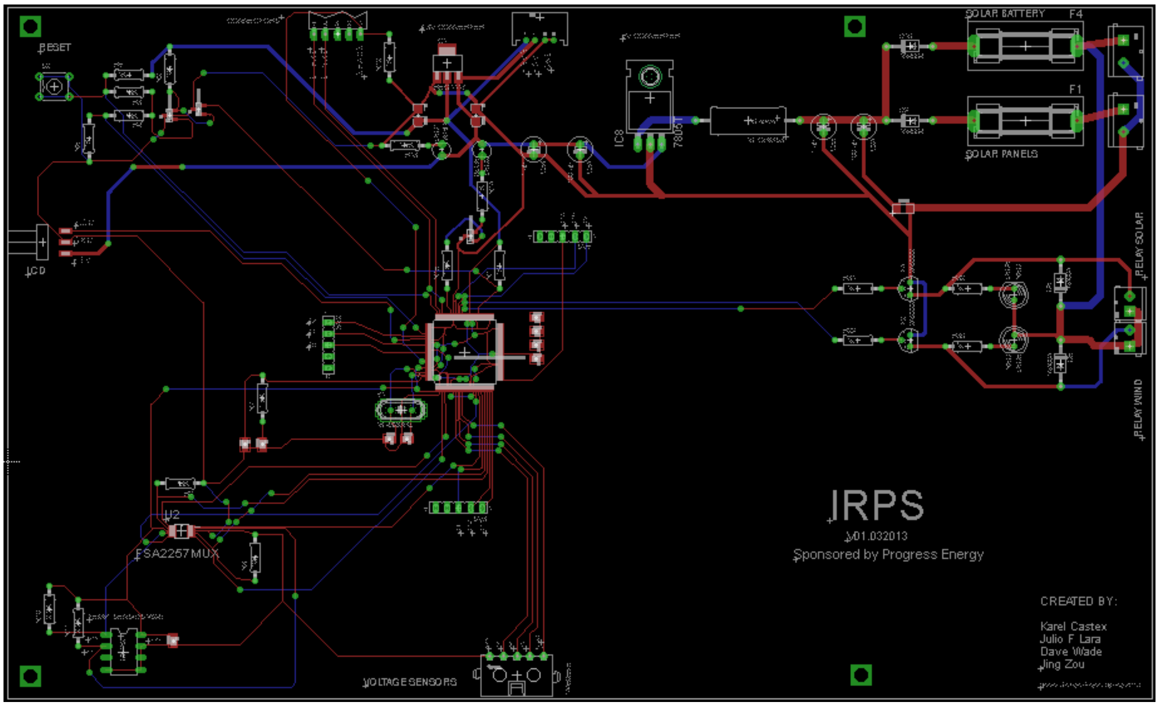


Figure 4.13: PCB Layout of the Efficiency Optimizer

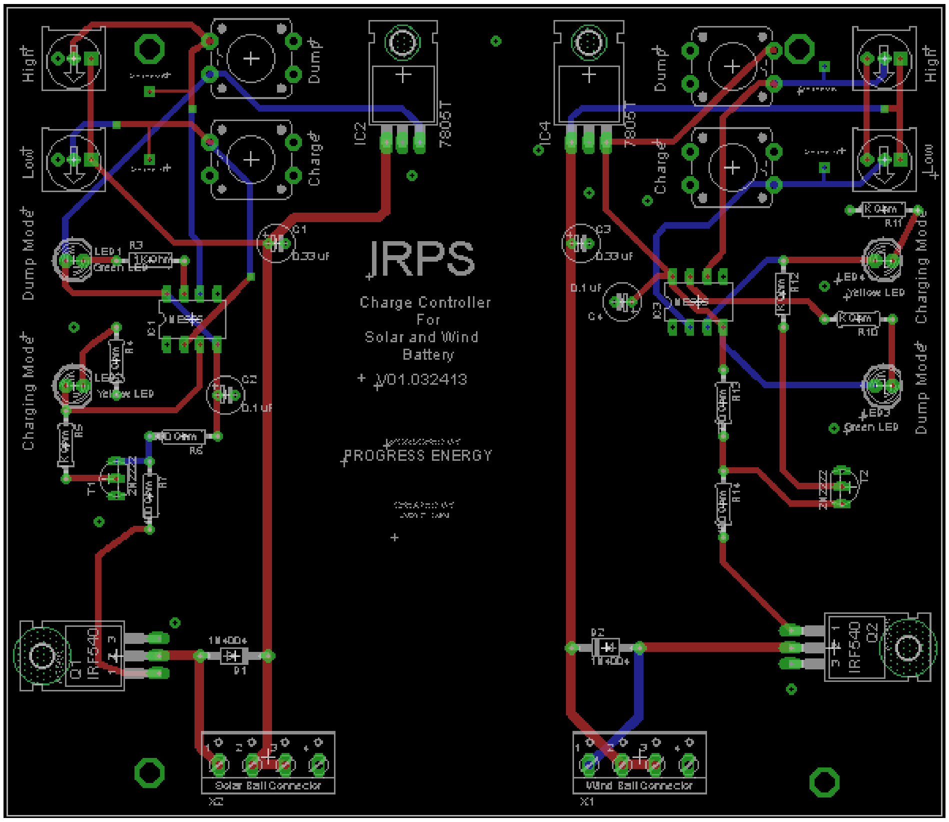


Figure 14: PCB Layout of Battery Charge Controller and Diversion Load Circuit

4.7.1 Design Equations for Printed Circuit Boards

The first design factor for printed circuit boards to discuss about is the conductor capacitance. The conductor capacitance is necessary because it will tell the designer how much electrical energy is stored for a given potential. Finding the capacitance is easy to figure out once you are given the thickness of the conductor, the conductor width, and the distance between conductors. To attain the value of the dielectric constant for the substrate that can be looked up in a table with other materials.

Conductor Capacitance

d = distance between conductors (inches)

b = conductor width (inches)

C= Q/V

k = substrate dielectric constant

a = thickness of the conductor (inches)

Another concept that is prevalent in printed circuit board design for manufacturers is conductor resistance. Conductor resistance is affected by the thickness of a wire, length, temperature, and the conductivity of the base material being used. The thickness of the wire is basically the cross sectional area of the substance being fabricated. Area in this case is length of the material times the width of the material. In order to determine the conductor resistance the only specification that a designer needs to take into consideration is the conductor width.

Conductor Resistance

W = conductor width (inch)

The characteristic impedance of an electric structure is the ratio of amplitudes of voltage and current waves moving along an infinitely long line. Characteristic impedance comes into view as resistance due to them having the same SI units. The power of the infinitely long line is accounted for since it is being generated on one end of the line and transmitted through the line as well. For a printed circuit board this is the formula used to determine the characteristic impedance of an infinitely long line.

Characteristic Impedance

C = capacitance (F)

L = inductance (H)

Zo = impedance (Ω)

R = resistance (Ω)

G = conductivity per unit length of line (Ω ^-1)

A microstrip is an electric medium that can be made using a PCB. The cross sectional surface representation of a microstrip can be divided up into 4 components. These components are the conductor, the upper dielectric, dielectric substrate, and the ground plane. Some drawbacks to the microstrip are that they have minimal power handling capacity and high losses.

A is known as the top conductor, B is the upper dielectric medium, C is defined as the dielectric substrate or level between the dielectric and the conductor, D is referred to as the ground plane Illustrated below is the method to calculate the characteristic impedance of a microstrip line. The impedance of the microstrip line is altered with the frequency of the material being used. The quasi-static characteristic impedance can affect how the frequency rises or falls for the substrate.[64]

$$Z_{\text{microstrip}} = \frac{Z_0}{2\pi\sqrt{2(1+\varepsilon_r)}} \ln\left(1 + \frac{4h}{w_{\text{eff}}}\left(\frac{14+\frac{8}{\varepsilon_r}}{11}\frac{4h}{w_{\text{eff}}} + \sqrt{\left(\frac{14+\frac{8}{\varepsilon_r}}{11}\frac{4h}{w_{\text{eff}}}\right)^2 + \pi^2\frac{1+\frac{1}{\varepsilon_r}}{2}}\right)\right)$$

h = dielectric thickness

W = microstrip width

Er = substrates dielectric constant

4.8 DC/AC Inverters

There are basically three kinds of dc-ac inverters: square wave, modified sine wave, and pure sine wave. The square wave is the simplest and the least expensive type, but nowadays it is practically not used commercially because of low quality of power. The modified sine wave topologies (which are actually modified square waves) produce square waves with some dead spots between positive and negative half-cycles. They are suitable for many electronic loads and are the most popular low-cost inverters on the consumer market today. Pure sine-wave inverters produce AC voltage with low total harmonic distortion (typically below 3%). They are used when there is a need for clean sine-wave outputs for some sensitive devices such as medical equipment, laser printers, stereos, etc. [50]

A basic inverter design includes a transformer and a switch. A DC current is driven through the center of the primary winding and the switch rapidly switches back and forth, as the inductor charges and discharges, allowing the current to go back to the DC source. The inverting current direction produces alternating current. Recent inverter designs use pulse width modulation to produce a pulsed waveform that can be filtered easily to achieve a good approximation to a sine wave. The advantage of PWM is that the switching techniques result in high efficiency. Significant control circuitry and high-speed switching are required to make the pulse width vary according to the amplitude of a sine wave. This is because the PWM signal has to be filtered out effectively so the frequency of the PWM has to be much higher than the frequency of the sine wave to be synthesized. Filtering for the modified sine wave inverter can be further augmented to produce a more approximate sine wave by assimilating another waveform to remove the unwanted harmonics. The switching stage could be implemented with a combination of bridge and half bridge components. Some DC-AC inverters are also designed using the popular 555 Timer IC. The 555 inverter in Figure xx connects the IC in mono-stable mode and uses it as a low frequency oscillator. It has a tunable frequency range of 50-60Hz using the potentiometer. It feeds output through two transistors to the transformer. The circuit suggests that it produces a virtual sine wave due to the fact that the capacitor and coil filter the input.

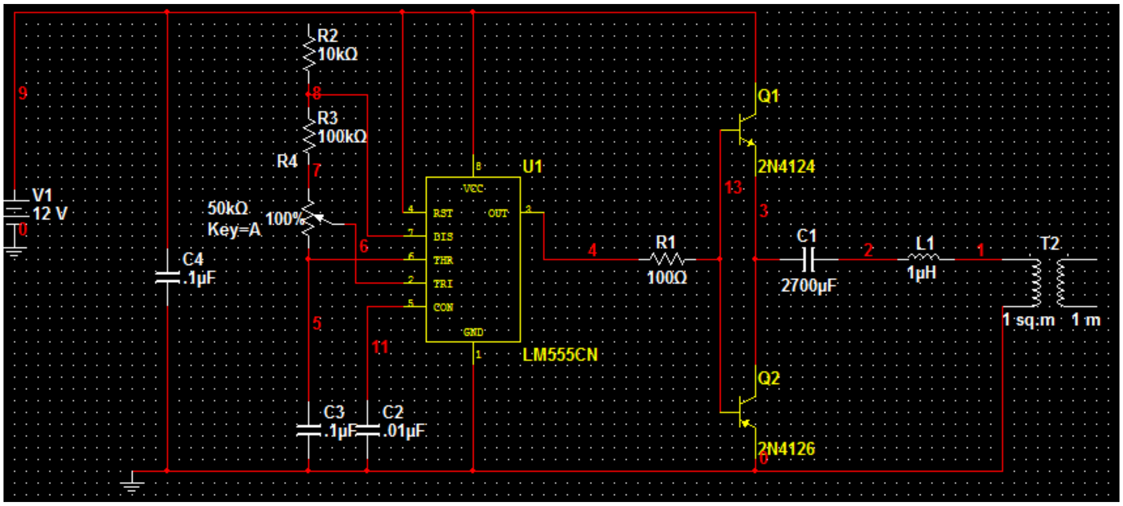


Figure 4.15 Inverter circuit with a LM555 timer

4.9 Battery Charge and Diversion Controller Circuit

The main reason a system needs a diversion charge controller is to protect the battery bank from overcharge and over discharge. Systems that have small, predictable, and continuous loads may be able to operate without a charge controller. However solar and wind power are nowhere near being predictable or continuous so the design will need to implement charge controllers to help our batteries charge efficiently and without damaging them. The charge controller circuit design is based on a 555 timer IC chip. This circuit will use a 40 amp SPDT relay switch changing and dumping modes.

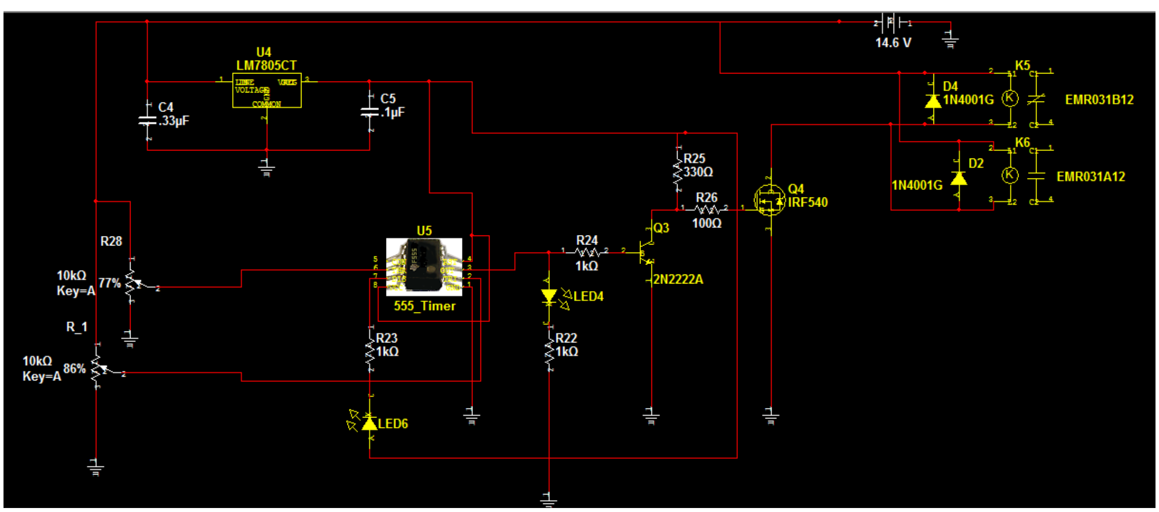


Figure 4.16: Diversion Charge Controller Schematic Circuit

The circuit needs to be calibrated for a charging window. 11.9V and 14.9V are set as low and high set points for the controller. These are the points where it switches from sending power to the batteries to dumping power into a dump load, and vice versa (a dump load is only needed if a wind turbine is used, if using only solar panels, the dump load line can be left open).

The relay configuration will be set differently for each source. For the wind generator the relay pin 30 will be the input from the source and the relay pin 87a will be connected to the positive terminal of the battery. The relay pin 87 will be connected to the dump load. For the solar panel the relay pin 87a will be connected to the input of the solar panel. The relay pin 30 will be connected to the positive terminal of the battery. Pin 87 is left open with no connections.

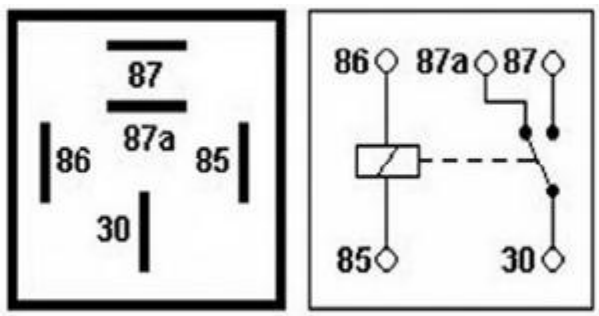


Figure 4.17: Relay

4.10 Dump and Diversion Loads

Two questions should be kept in mind to determine the size of the dump loads. First, what the voltage of the generation system will be. Second, what current at maximum power the wind turbine will produce. Once this information is known, the calculation can take place.

Ohm’s Law is applied to the calculation. The dump load system needs to be able to dissipate the maximum power of the wind turbine and solar panels used. Ohm’s law states that the power dissipated is equal to the product of the voltage and the current shown in equation 4.1. The voltage of the batteries charged by the wind turbine and the solar panels will be 12-volt batteries. The current at the maximum power is approximately to be 30 amperes. In this occasion, the voltage of the system is the battery bank voltage, which is approximately 14 volt for a fully charged 12-volt battery, and the currents of the wind turbine and solar panels are approximately 32 amperes and 5 amperes.

Equation4.1: Power = Voltage x Current

Therefore, according to the datasheet of the wind turbine and solar panel, the maximum power that will be dumped by the diversion load to be 448 watts for the wind turbine and 70 watts for the solar panels is obtained. 12-volt dump load resistors are used in this project. The resistors have an internal resistance rating of 0.73 ohms. Therefore, the amount of power the resistor will consume can be calculated by applying Ohm’s Law one more time. By manipulating Ohm’s Law equation, equation 4.2 is derived as below.

Equation 4.2: Current = Voltage / Resistance

Current = Battery Bank Voltage / Resistor's resistance

Plug in the values into equation 4.2, the current is then calculated to be 19.18 amperes. Hence, 268 watts power is possible flowing through one of the WindyNation 12 volt dump load resistors. It is important to make sure that the dump load are going to be used has the capacity of 268 watts at continuous duty to avoid dangerous fire hazard. The WindyNation 12 volt dump loads have the ability to hold up to 312 watts of power continuously. Therefore, they can be used in this project.

As recalled, the capacity of the dump load system is calculated to be 448 watts. To use a 268 watt dump load resistor, one way is to wire multiple 268 watt resistors in parallel. Then the wattage of the dump load is the sum of each load. Consequently, the equation below can be derived.

Equation 4.3: Total Watts of the dump load system need to consume = (268 watts) x (the number of 0.73 ohm resistors in parallel)

448 watts = (268 watts) x (number of 0.73 Ohm resistors needed in parallel)

Solve the equation above by using simple algebra, the number of 2.9 Ohm resistors needed in parallel is calculated to be

(# of 2.9 Ohm resistors needed in parallel) = 1.67

Since the resistors only come in whole units, 1.67 resistors have to round up to two sets of dump load resistors for consuming 448 watts of power. Two of the WindyNation 0.73 ohm resistors wired in parallel give a total dump load capacity of 536 watts. According to the user manual, to protect the expensive wind generator, battery bank and alternative energy system from potential destruction, it is necessary to choose a dump load that exceeds the maximum output of your complete system by at least 20 percent. Use the equation below to calculate the exceed power percentage, two parallel WindyNation 0.73 ohm resistors can consume about 19.6 percent more power than the maximum output of the complete system [51].

Equation 4.4: (power consumed by the dump load – maximum output of the complete system) / (maximum output of the complete system)

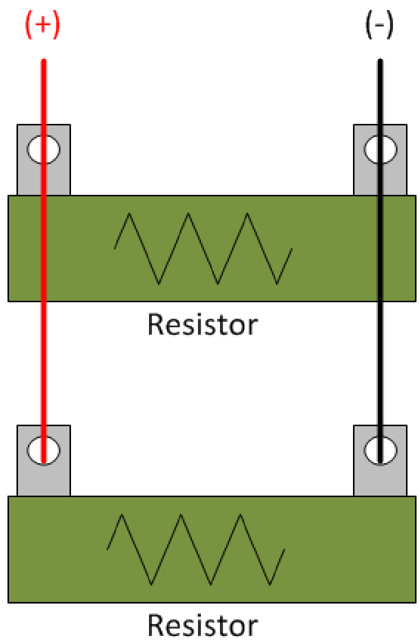


Figure 4.18: Two Dump Load Resistors Connected in Parallel

Similarly, the same process can be applied to calculate the dump load for the solar system. Since the 0.73 ohm dump load resistors can consume 268 watts of power, and the capacity of the dump load needed is only 70 watts, one WindyNation 0.73 ohm resistors are sufficient for the design.

4.11 Monitoring-Reporting Software

IRPS is built with a monitoring user friendly application, granting a live status condition of control box system. Application possesses a background thread always listening to controller box data to be sent through a serial USB-TTL cable. The intention of IRPS with such application is to take the data collected to a different level of usefulness for the final user. Data is being transmitted using debug UART port from microcontroller to the PC at a baud rate of 9600 bits per second and it is continuously time stamped and saved to selected storage engine.

Application was developed in Windows Presentation foundation platform (WPF) using Microsoft Visual Studio as IDE and C# as language. Both microcontroller and user application were programmed using same language and IDE bringing a completely integration when comes to data codification, synchronization, and communication strength. Application is powered by SQL Server Compact database which is widely used in the industry and allow this user interface not only being informative but also having an excellent performance when running analytics reports. Figure 4.19 shows a view of main screen where it can be observed live data monitor, system current status, current weather, three analytical reports and system settings configuration.

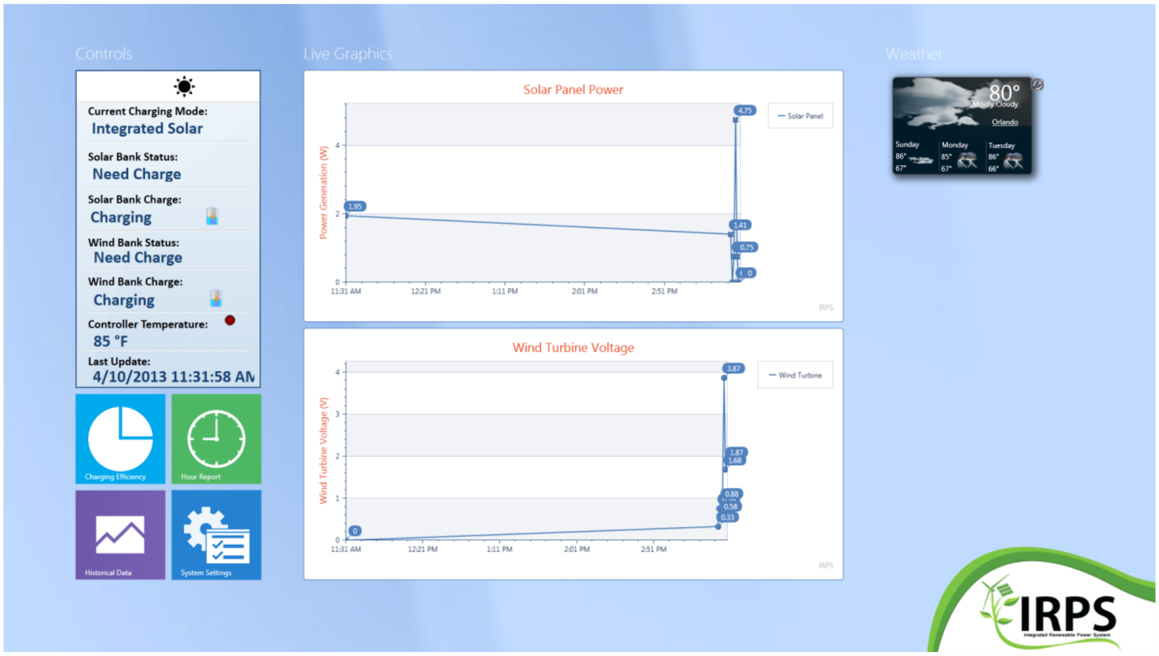


Figure 4.19 User Monitoring Main Screen

Chapter 5 Design Summary of Hardware and Software

5.1 Hardware Summary

To summarize the hardware design of the Renewable Source Controlling System it is first described the essential elements that generate power. As input power source that was used 12VDC 85W PV panels, and 15VAC 450W wind generators. Since the battery charging system only uses VDC, the ac signal produced by the wind generator has to be rectified. To achieve this goal, an AC/DC rectifier was added to the ac line to produce a rippled dc signal. Although, system can technically use this rectified dc signal, it is still needed to regulate it in case that wind generator produces more power that is expected to. In order to maintain VDC at a voltage suitable to charge the batteries without over passing the max battery voltage, a voltage regulator was added to the rectifier output line; this voltage regulator circuit maintains the voltage at a maximum of 15VDC.

Once IRPS have the refined DC from the wind generator, it is connected both PV panels and wind generator to the efficiency optimizer controller box. Within this box the microcontroller, voltage sensors, current sensor, temperature sensor, LCD display, and USB interface are located. The microcontroller determines which input source is the most productive when both sources are in operation, to do this it is placed voltage sensors in each source line to determine which input is the higher. This helps the charging system to choose the input source with greater power to maximize the charging system. Once the batteries are fully charged or the input voltage to the battery is too high or too low, the diversion controller will have to divert the excess power to a dump load to protect the batteries from overcharging or over discharging. The load is usually an electrical load which is drawing electricity that is generated by the solar panel or the wind turbine.

The final stage of IRPS is the output. When a load is connected to the system the microcontroller sends the power stored to the supply the load. However, since most appliances use ac power, the system has to invert the batteries VDC to VAC. The main function of the inverter is to take 12V (DC) from the battery and step up the voltage to 120V and convert it to AC voltage The output of the system should reach between 110 and 120 Volts in AC power for the user to plug in electronic devices and use them. The outlet should be safe for both the users and the electronic devices.

5.2 Software Summary

Controller box is the IRPS concept for the encapsulation of some components and functionalities. IRPS performs some actions directly related to microcontroller both in the input and output direction. Controller box concept encompassed the microcontroller, voltage sensors, temperature sensor, LCD display, USB interface, and User Interface Report. An overall design of controller box is described in below Figure 5.1.

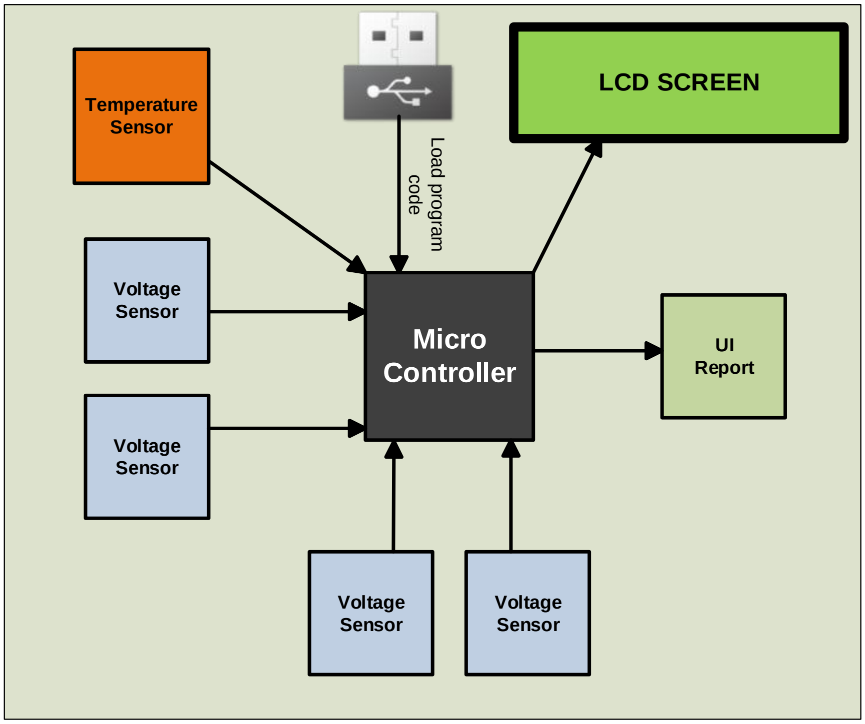


Figure 5.1 Overall Controller Box Diagram.

Depicted as the dark grey box in the middle of Figure 5.1 is the microcontroller chosen, which was the Atmel AT91SAM7X512 with Netduino boot loader. Orange box at the top left of diagram is describing the temperature sensor used in the IRPS; temperature sensor chosen was DS1624 and use microcontroller I^2C bus to provide actual readings. Light blue boxes are referring to voltage sensors in IRPS where each one of them consumes one analog input of microcontroller. Light green box is a USB-Serial connection between microcontroller and report software running in a remote pc which provides a variety of analytical reports. Dark green rectangle is representing the LCD display which display every important reading produced from microcontroller and any last time message or alert. LCD screen communicates with microcontroller through serial communication or more specific TX and RX microcontroller pins. Controller box possess a pre-defined block diagram of how logically will perform as a whole. An overall controller box block diagram is described in below Figure 5.2.

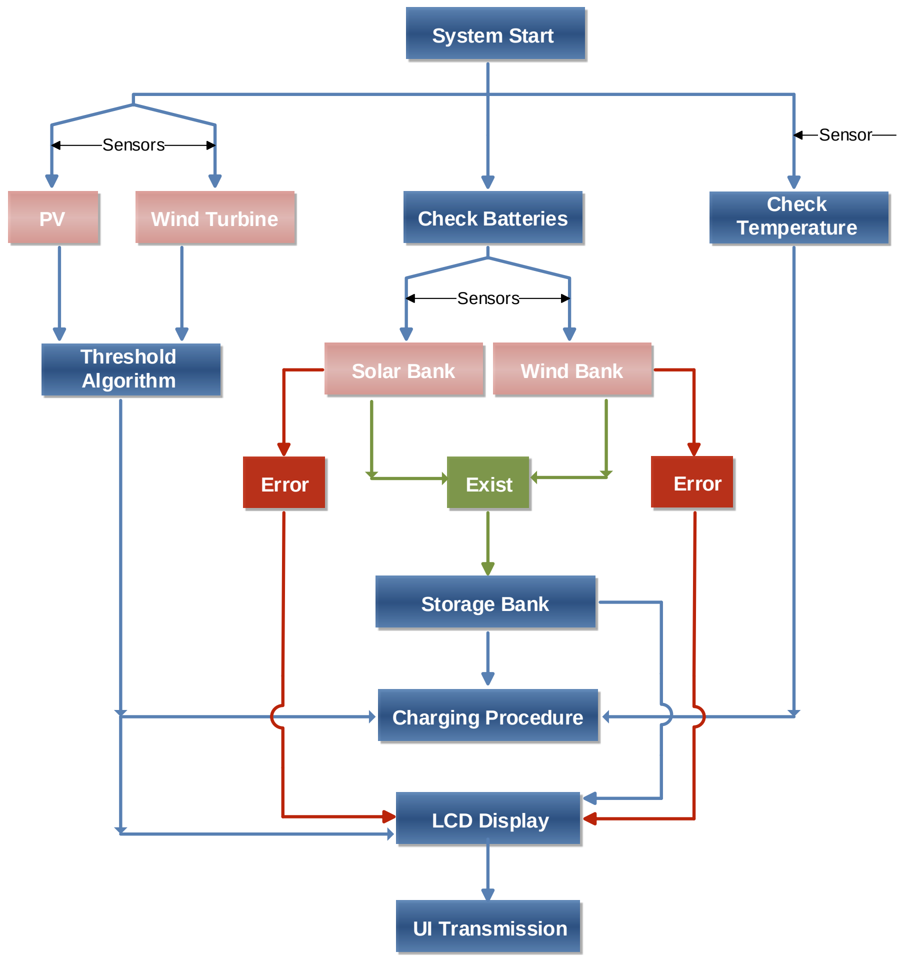


Figure 5.2 Controller Box Block Functionality Diagram

Controller box functionality diagram is shown in above Figure 5.2 and it is divided by using symbolical colors. Blue boxes and arrows means logical stages and system direction flow. Light oranges boxes are used to describe physical components which interact with some stages. Red boxes and arrows are specially used to denote critical system errors status and action to take upon it. Finally, green boxes and arrows are meant to define successful checking of some components correct availability.

Controller box performs five main stages and each one of them includes more than one mode or procedure. First stage is composed by “Check Batteries” mode, “Check Temperature” mode, and “System Output” mode. Second stage is composed of two main modes: “Threshold Algorithm” and “Storage Bank”. Third stage or “Charging Procedure” is the most complex in the functionality diagram. Fourth stage or “LCD Display” wrapped around any variable value or alert to make a custom format message and interacted with LCD device to display final outcome. Finally, fifth stage is the communication between microcontroller and user monitoring user running in remote computer.

As it was mentioned previously, the Atmel AT91SAM7X512 microcontroller was used in IRPS, pre-loaded with the preference of Netduino boot loader. This microcontroller contains the adequate hardware and software for all design goals, providing enough digital and analog pins to handle all sensors, LCD, and battery charging check, meanwhile at the same time being able to control the IRPS circuitry using pulse-width modulation (PWM) outputs.

LCD chosen was 20x4 characters LCD-09568 from vendor SparkFun Electronics. The actual LCD is 87.3 x 41.8 mm while the PCB footprint measures 105 x 59.9 mm. This display is monochrome (black on green) and has adjustable backlighting which is desired in the system to enhance final user experience.

Using a voltage divider configuration circuit as a voltage sensor in the design was extremely convenient. The resistor values used in the circuit were relatively easy to calculate, which makes the overall implementation of the circuit easy to modify and/or adjust as required if needed in the future.

On the temperature sensor side, the DS1624 Thermometer from Maxim is a digital temperature sensor that fits all of the desire characteristics that are needed. DS1624 is well designed to be fully integrated directly with microcontroller without the need of using other external components. This sensor has the capacity to be assigned a digital address which allows up to eight temperature sensors to be use in the design and they can all be accessed from the microcontroller through the same I2C bus line.

Microcontroller executes specific algorithms perform IRPS core functions. Algorithm order is established based on priority criteria of those components which are more critical if occur a malfunctioning and can propagate a system. Below Figure 5.3 pictures the flow diagram of main methods to be executed.

Algorithm Sequence

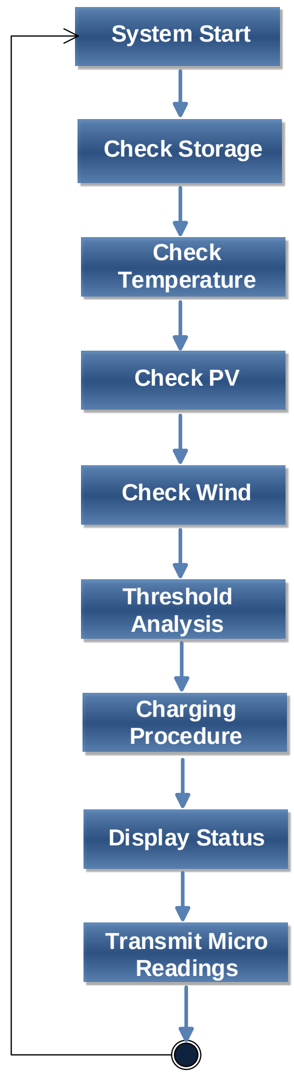


Figure 5.3 Algorithm Implementation Flow Diagram

Microcontroller continuously executes the sequence above and loop over it at same cycle time which is defined by the best execution model. Above Figure 5.3 enumerate the main logical methods describing consequent steps implemented; however, those main methods use others sub-methods serving as helpers. Necessary sub-methods are not presented in flow diagram to avoid confusion and to obtain a better understanding from main algorithm logic.

Chapter 6 Project Prototype Construction Plan

All of the components are placed on printed circuit boards and since the price of the printed circuit boards is dependent on the size, the design is as space efficient as possible. In order to keep the PCB as small as possible, the smallest parts available that meets our criteria were chosen. The plan was to surface mounting as many of the components as possible, so when there are options, the product that is made to be surface mounted was selected. It has been decided that this design should go with as many surface mount products as possible. This is because they are generally smaller than their through-hole counterparts and more cost effective. The main microcontroller is small and only account for a small percentage of the overall layout of the main control unit printed circuit board design. All of the PCB hardware is purchased from 4PCB.com. 4PBC.com offers reasonable prices for the needs of this project. Among their good offers, two offers match the requirements for this design.

The first one is the 2-Layer Printed Circuit Board Designs for $33 each. The specifications are shown in table 6.1. The maximum size is 60 square inches, and the minimum line space and size of the hole are 0.006 inch and 0.015 inch respectively. There are maximum 35 drilled holes on a square inch.

Min. qty. 4 Boards	White Legend (1 or 2 sides)
Lead Time 5 Days	1 Part Number Per Order (extra 50 charge for multiple parts or step & repeat)
2-Layersm FR-4, 0.062’’, 1 oz. cu. Plate	Max. size 60 sq. inches
Lead FREE Solder Finish	No slots (or overlapping drill hits)
Min. 0.006’’ line/space	No Internal routing (cutouts)
Min. 0.015’’ hole size	No scoring, tab rout or drilled hole board separation
All Holes Plated	Routed to Overall Dimensions
Green LPI Mask	Max. 35 drilled holes per sq. inch
Credit Card Order Only	

Table 6.1: 2-Layer Printed Circuit Board Specification.

The second type is the 4-Layer Designs which is $66 each. The specifications are shown in Table 6.2 below. Comparing to the 2-layer PCB, the 4-layer one has a maximum size of 30 square inches. The minimum line space, size of the hole, and maximum drilled holes per square inch are the same as the 2-lay board.

Min. Qty. 4 Boards	White Legend (1 or 2 sides)
Lead Time 5 Days	1 Part Number per Order (extra $50 charge for multiple parts or step & repeat)
Lead Time 5 Days	Max. Size 30 sq. inches
Lead Free Solder Finish	No Slots (or overlapping drill hits)
Min. 0.006’’ line/space	No Internal Routing (cutouts)
Min 0.015’’ hole size	No Scoring, tab rout, or drilled hole board separations
All Holes Plated	Routed to Overall Dimensions
Max. 35 drilled holes per sq. inch	Green LPI Mask
Credit Card Orders Only	Does not include Blind/Buried Vias

Table 6.2 4-Layer Printed Circuit Board Specification

Chapter 7 Project Prototype Testing

7.1 Solar Testing

The group spent time on the UCF campus testing the solar panel outside the Engineering building. It was important for the group to understand how the purchased solar panel reacts to different daylight hours and weather situations. This can be observed by the output voltage of the panel during those different times of the day. This allowed the group to become familiar with the fluctuations in the output voltage.

A direct power source from the senior design laboratory was used to test the solar power circuits which include the power charger and voltage regulators. This way the group can observe how the circuits were reacting to different types of controlled input voltages. This allowed for more knowledge of how the circuits react to the non-linear output voltage from the solar panel. Once this was understood, these circuits were attached to the solar panel and tested outside on the UCF campus when the weather permitted.

The solar panel needs to be tested to make sure that it has not been damaged in the delivery, and that it is close to the manufacturers specs listed in the datasheet. The first specification to be tested was the open circuit voltage (Voc). According to the model's datasheet the SunWize SW-S85P should have 22.0V for the Voc. This can be tested by putting a voltmeter to the terminals on the back of the solar panel. This is where some precaution needs to be taken. A solar panel is always active when sunlight is present. Therefore there is voltage running through the panel and it is enough to severely injure a person. With this is mind the solar panel should be turned to a southern direction. Make sure the voltmeter is on DC voltage and the probes are in the voltmeter inputs. Put the probes on the voltage out terminals on the panel and take a reading. While the voltmeter is reading the output voltage tilt the solar panel to the optimal angle with the sun [52]. This should give a reading that is close to 22.0V for this panel.

Next the short circuit current (Isc) should be tested. This was tested again with the multi-meter. The multi-meter should be set to DC amps and the probes moved to the amperage input. Turn the panel in a northern direction and attach the probes to the output of the solar panel. While the probes are attached slowly turn the solar panel to the south and tilt it to the optimal angle with the sun. The multi-meter should show the amperage increasing until it reaches the value from the spec sheets [52]. According to the manufacturer this value should be near 5.4A for the SunWize SW-S85P.

These steps should properly ensure that the solar panel was not damaged in the delivery. This also gave the group a good idea of the average open circuit voltage and short circuit current of the SunWize SW-S85P. With these figures known the circuits used on the solar side of the system can be more accurately simulated inside the lab.

7.2 Wind Testing

The wind generator was tested so it can be measured the power curves advertised by the vendors. This power curves can be found in the manufacture's website, magazines where the manufacture publish their product or in the manuals that come with the hardware. Power curve is a graph indicating how much power (in watts or kilowatts) a wind generator produces at any given wind speed. Power is presented on the vertical axis; wind speed on the horizontal axis. Wind generators reach their rated or nominal power at their rated wind speed in mph or meters per second (m/s). Rated power is not synonymous with peak power, though they are occasionally the same. Rated power and peak power are just two points on a power curve. Typically the peak power of a small wind generator is greater than its rated power. For example, the rated power of THE WORKHORSE 250 is 250 watts at 15 mph. Yet its peak power is nearly 400 watts at 33 mph. Similarly, the Apollo 550W 12V DC is rated at 550 watts, but the manufacturer says it will produce up to 800 watts.

To measure the wind speed, an anemometer was used, which was placed below the wind generator. If the anemometer is in the wake of the tower, the anemometer will see less wind than the wind generator. This will tend to boost the relative performance of the wind generator in the manufacturer's favor. For example, if the anemometer sees 9 mph, but 10 mph winds strike the rotor, the wind generator will produce proportionally more electricity than it would at 9 mph. The recording system will log production from actual winds of 10 mph in the loggers 9 mph register. The power curve appeared better than it really is. Standard test procedures call for erecting an anemometer mast separate from and upwind of the wind generator. The intent is to place the anemometer in the free stream just upwind of the wind generator's rotor. The American Wind Energy Associations or as well known as AWEA has a standard to place the anemometers to measure wind generator's speed. Their standard is to place the anemometer 1.5 to 6 rotor diameters upwind of the wind generator rotor's centerline [53].

Air density has a significant effect on wind generator performance. The power available in the wind is directly proportional to air density. As air density increases the power available also increases. Air density is a function of air pressure and temperature. Published power curves are typically presented for standard conditions of temperature and pressure so they are readily comparable with one another. At a standard temperature of 288 degrees Kelvin (273.15 degrees K plus 15 degrees Celsius) and pressure of 760 mm Hg or 1013.25 mb, air density is 1.225 kg/m3 in SI units. Standard conditions in the English system occur at a temperature of 59 degrees Fahrenheit and 29.92 in Hg. Both temperature and pressure decrease with increasing elevation. Consequently changes in elevation produce a profound effect on air density.

While changes in barometric pressure affect air density slightly, temperature has a more discernible effect. Air density decreases with increasing temperature.

During the winter months average daytime temperatures in Orlando may average 70 degrees Fahrenheit (21 degrees C) or more. This can reduce air density by some 2% relative to standard conditions. Consequently it's important to account for temperature as well elevation during power curve measurements.

There are several ways to measure power: separately measuring voltage and current (volts x amps = watts), or measuring voltage and current together with a power (or watt) transducer. AWEA's standard recommends (though it doesn't require), using a watt transducer. Hall-effect sensors and their signal amplifiers are found in clamp-on ammeters. They are easy to use. The conductor being measured was passed through the sensor doughnut. The objective is to measure the generator's power after all internal losses, so that only power delivered to the load was measured according to AWEA's performance standard. In a battery charging wind system this occurs between the charge controller and the batteries as it is more recommendable. In a real world application what is crucial is the energy saved to batteries, not what's being produced at the top of the tower.

In a typical application, battery storage is finite. When batteries are fully charged, wind generator charge controllers switch off the load to avoid overcharging and damaging the batteries. Clearly it's futile to try and measure the wind generator's performance when the charge controller has stopped charging and unloaded the wind generator. Consequently there must be sufficient load on the batteries so they never become fully charged during the test period. This often entails a diversion controller and a diversion load.

Voltage is a good state-of-charge indicator for lead-acid batteries. Voltage decreases as batteries become discharged, and increases as they are charged. In a typical renewable energy system, battery voltage constantly fluctuates with the state-of-charge.

Unfortunately, the performance of battery-charging wind generator is partly a function of battery voltage. Scoraig Electric's Hugh Piggott notes that a wind generator's low wind performance improves as voltage decreases. He says that permanent-magnet alternators need to reach a certain speed to produce the necessary voltage to begin charging the batteries. When battery voltage is low the alternator speed at which charging begins is accordingly lower and the wind generator's "cut-in" wind speed is lower. In high winds, Piggott says, losses depend on current and you can get more power out of a given current when voltage is high because power is the product of voltage and current [53]. In addition, on the battery charge controller side the losses are proportional to the type of material (copper has less resistance than aluminum), diameter (thick cable has less resistance than thin cable) and distance to the batteries (short cables have less resistance than long cables). These resistive losses are reflected in the voltage drop between the wind generator and the batteries. The length, diameter, and material used in the cables connecting the wind generator to the batteries determine the resistive losses between the wind generator and the batteries. Manufacturers specify the cable size and material for a range of distances between the wind generator and the batteries that will allow their wind generator to perform as designed.

7.3 Microcontrollers and PCB Testing

Microcontroller and LCD test plan was encompassed together based on the need of verifying data processed or calculated and the displaying of the same. Current scenario allows constantly debugging algorithm performance and correcting output. Microcontroller test plan was based on steps, expected result and current status wanted from algorithm flow diagram. Meanwhile, same criteria would be applied to LCD test plan in order to assure the device functionality correctness. In below Table 7.1 and Table 7.2 we can observe a detailed test plan for microcontroller, consequently Table 7.3 will describe test plan for LCD unit.

Step	Procedure	Expected Result	Actual Result
Microcontroller (AT91SAM7X512) Part 1			
1	Netduino development board correctly functioning with necessary libraries	Proper functioning and programing code uploading	Done
2	Check Storage (Hard code)	Algorithm take correct decision based on value captured	Done
3	Check Temperature (Hard code)	Algorithm save entered value or default one is assumed	Done
4	Check PV (Hard code)	Algorithm save entered value or default one is assumed	Done
5	Check Wind (Hard code)	Algorithm save entered value or default one is assumed	Done
6	Threshold Analysis	Algorithm will determine the correct charging mode	Done
7	Charging Procedure	Algorithm will use previous values to determine different charging states	Done
8	System Output (Hard code)	Algorithm save entered value to be displayed	Done
9	Display Status	Algorithm conform correct custom message to be displayed	Done

Table 7.1 Microcontroller Testing Plan Part 1

Step	Procedure	Expected Result	Actual Result
Microcontroller (AT91SAM7X512) Part 2			
10	Repeat Steps 2-5, 8 using corresponding sensors	Each sensor should deliver some reading and algorithms will perform same result as 2-5, 8	Done
11	Repeat step 6 using step 10 result	Algorithm will determine the correct charging mode	Done
12	Repeat step 7 using step 10-11 result	Microcontroller will correctly interact with circuitry to set correct charging state	Done
13	Repeat step 9 using 10-12 result	Identical result as step 9	Done
Development phase	PCB microcontroller integration phase		

Table 7.2 Microcontroller Testing Plan Part 2

Step	Procedure	Expected Result	Actual Result
LCD			
1	LCD connected to microcontroller	LCD and microcontroller should communicate effectively	Done
2	Hard-code values forming a custom message	Text displayed on LCD	Done
3	Conform alert message	Text displayed on LCD	Done

Table 7.3 LCD Testing Plan

7.4 Sensor Testing

7.4.1 Voltage Sensor Testing

The voltage sensors are crucial to IRPS because it allows the micro-controller to know which source is available and the voltage sensors are also used indirectly to sense current. The voltage sensor is basically a voltage divider that will allow the micro-controller to input a smaller voltage and the software will use a multiplier constant to give an accurate reading. Testing is needed to find this constant value for each of the four voltage sensors. The table below shows the wind turbine's voltage sensor values recorded.

Input (V)	Output (V)	Ratio
9.8	1.50	6.533
10.2	1.50	6.8
10.5	1.55	6.77
10.7	1.61	6.65
11.3	1.68	6.73
12.7	1.87	6.79
13.0	1.91	6.8

Table 7.4 Voltage Sensor I/O values at Wind Turbine

A table was constructed for each of the four voltage sensors and the input and output voltages were recorded. From these values a ratio was determined and inserted as a constant into the software so the microcontroller has a realistic idea of the voltage levels.

7.4.2 Current Sensor Testing

The current sensing capabilities of IRPS are a secondary function of the voltage sensors. Since the shunt resistor technique was used the resistance of the whole system was needed to be able to apply Ohm’s law. A current meter was needed for this test and two of the voltage sensors to test the voltage drop of the system. Once these readings were acquired the equation below was used.

$$R = \frac{V_{PV} - V_{S.Battery}}{i}$$

The resistance of the system R was determined to be 1.6667Ω and was plugged in as a constant into the software. Once this value was determined IRPS was able to accurately calculate the current solving for i in the equation above.

7.5 Integrating Solar and Wind Generation Testing

This was the test that proved if the system as a whole is working or not. As the system was designed there are four distinct modes of operation. These modes of operation can be seen below in Table 7.7. The batteries are labeled E_{solar} for the solar bank and E_{wind} for the wind bank. In the first mode only the solar panel is generating voltage so the microcontroller will switch the solar voltage to charge both E_{solar} and E_{wind} banks. The second mode is wind only and the voltage from the turbine will charge both E_{solar} and E_{wind} banks. In the third mode the solar panel and the wind turbine are generating voltage however the wind speed is low which will be less than 3 m/s. In this mode E_{solar} and E_{wind} banks will be charged by their respective source. The fourth and final mode is the same as mode three, but the wind speed is high which will be above 3 m/s. In this case the E_{wind} will be charged by the turbine while E_{solar} will be charged by both the solar panel and the wind turbine.

Energy Source	E_{wind}	E_{solar}
Solar Energy		
Wind Energy		
Solar and Wind Energy(low wind speed)		
Solar and Wind Energy(high wind speed)		

Table 7.5: Microcontroller Alternative Charging Modes

All four of the modes reviewed above were tested to make sure that they were not only working, but working efficiently. Two voltage meters and one current meter were used to generate the data that can be seen in Figures 7.1 through 7.2 below. The first mode was tested outside on a sunny day with the wind turbine not connected. The multi-meters will give accurate reading for the charging current and voltages to both E_{solar} and E_{wind} to make sure they are both being charged by the solar panel. The second mode was done at night or when the solar panel was disconnected. In Central Florida it is hard sometimes to get a good flow of wind. Therefore a drill was used to control the speed of the wind and keep it constant for the duration of tests utilizing the wind turbine. Once the wind turbine is the only source running the multi-meters recorded the charging current and voltage. The third and fourth modes were tested the same only the wind speed will be increased. The most interesting aspect of mode four is to check if E_{solar} charge current and voltage significantly increase. This will indicate that the microcontroller is in fact charging this battery with both the wind turbine and the solar panel. However this was difficult to get accurate results because the wind turbine is so uncontrolled with the current going up and down. This made the reading of E_{solar} wild and unpredictable.

The first data collected was for integrated solar mode where the PV panel charged both E_{solar} and E_{wind}. As can be seen in Figure 7.1 below, the voltage being delivered to both batteries increases over time.

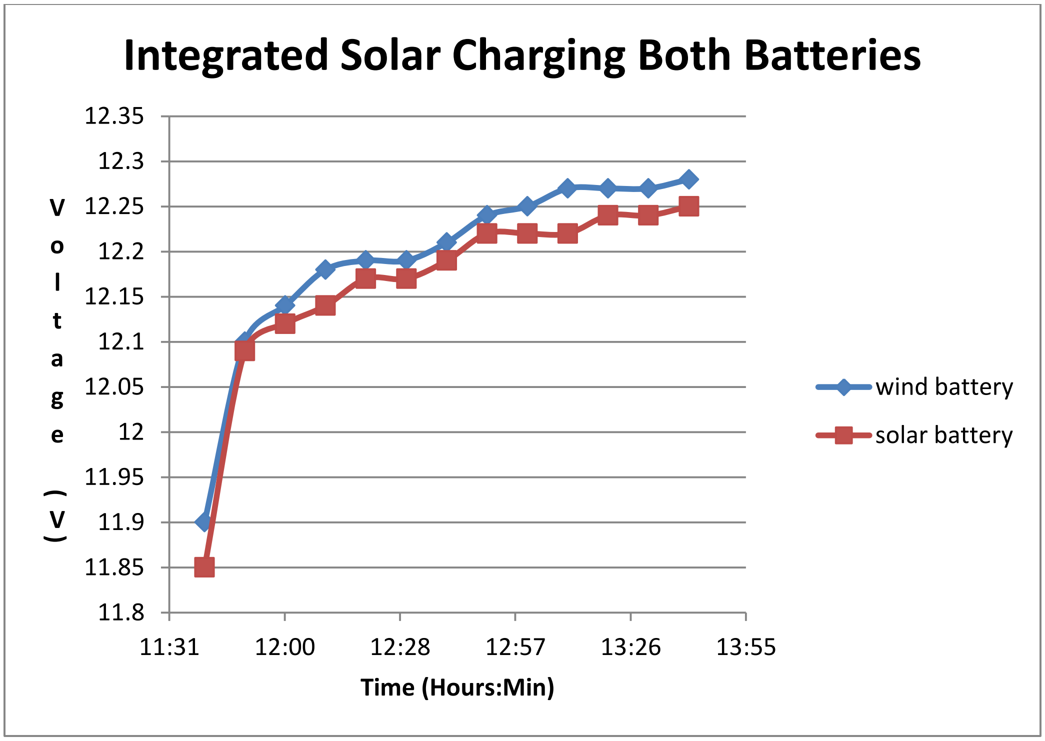


Figure7.1 Integrated Solar Mode Voltage Vs Time

Notice how the voltage being delivered to the batteries follow each other within 50mV of each other. This is the expected result of monitoring voltage to the batteries and it shows that micro-controller has indeed put both batteries into parallel with the PV panel. It also proves that the PV panel is charging both batteries simultaneously.

It is difficult to tell the batteries are charging without monitoring current as well. Unfortunately the wind turbine is too uncontrollable to get a consistent current reading, but the MPPT charge controller will allow for the team to get the current reading required. Figure 7.2 and 7.3 below show the current being delivered to the batteries by the PV panel during the integrated solar mode.

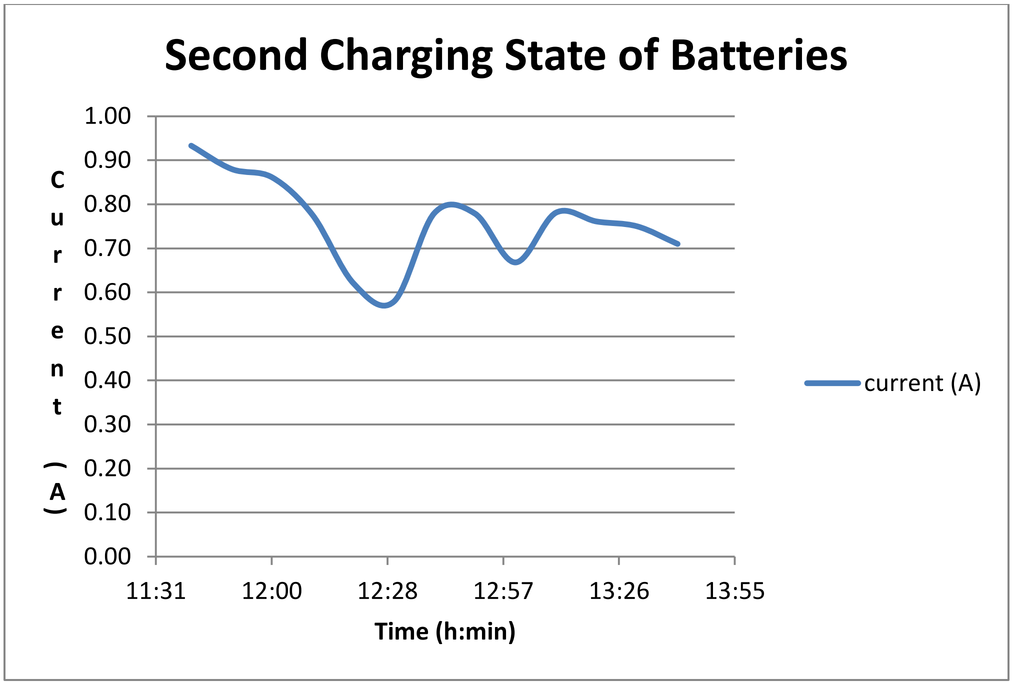


Figure 7.2 Integrated Solar Mode Current vs. Time with battery in second charging state

The interesting fact discovered from testing IRPS is the fact that the current reading will give you the battery charging state and the voltage will not. Figure 7.2 above shows the batteries in their second charging state with the current being around 1A. As the current being delivered drops the voltage increases, and the battery becomes more fully charged. The final charging stage of the batteries happens when the PV panel is outputting around 500mA. This can be seen in Figure 7.3 below.

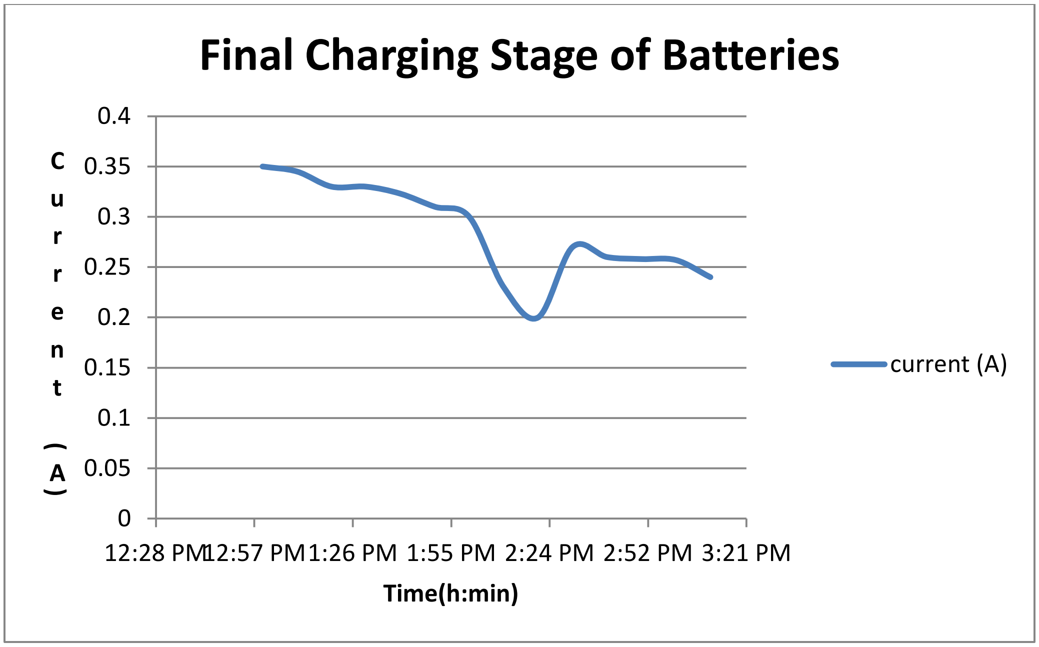


Figure 7.3 Integrated Solar Mode Current vs. Time with battery in final charging state

As was mentioned above the wind turbine is an uncontrolled source and that means that the turbine does not put out a constant current. Once the turbine sends around 2.5A the battery will enter charge mode until the wind turbine stops producing voltage. Because of this situation the only testing that could be recorded for the integrated wind mode is the voltage vs. time graph seen below in Figure 7.4.

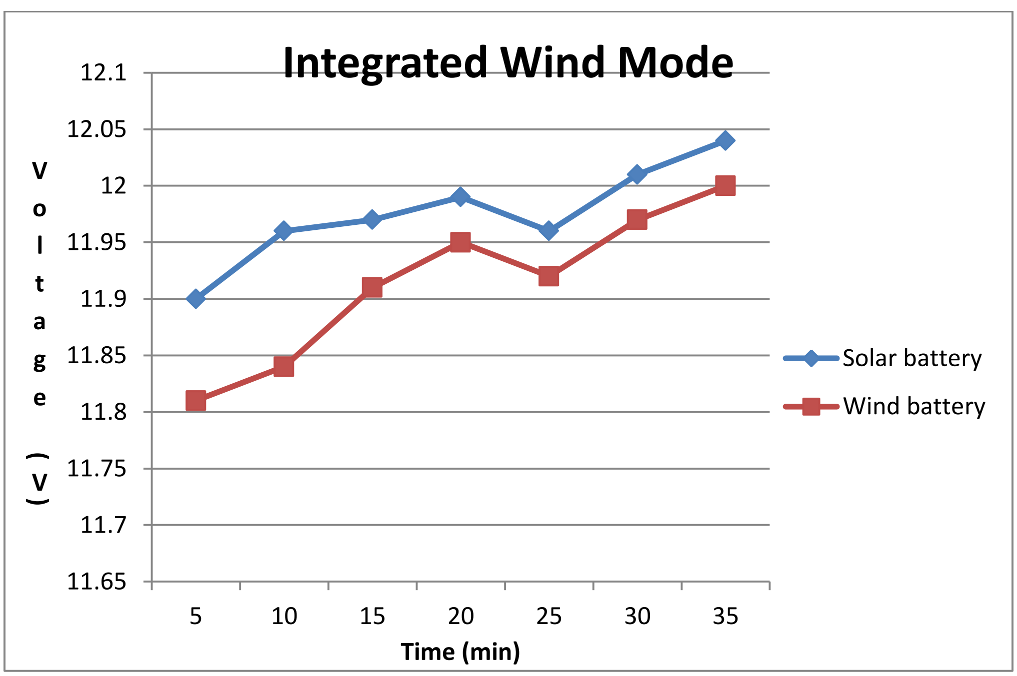


Figure 7.4 Voltage vs. Time for Integrated Wind Mode

It can be seen above that the micro-controller has successfully put both batteries into parallel with the wind turbine and both batteries are being charge. Again notice that the voltage is increasing at the same rate and proving that the wind turbine is charging both batteries simultaneously.

7.6 Storage Testing

There were two important parts of battery testing. One of them is the testing of the time needed to charge up the battery from panel to fully charge. This charging time mostly depended on the output power of the solar panel and the wind turbine. The other part of the battery testing was the time need for the battery to discharge. The discharging time is essential to determine the maximum charge supplied to the inverter.

To test the charging time of the batteries, the following steps was implemented.

1) Test the battery when there is no load in the system. If the battery is connected correctly, the charging process of the battery should start.
2) The voltage of the battery should then be checked by connecting a multi-meter. The multi-meter should have the voltage reading that corresponding to the charging stage.
3) The current going through the battery should also be checked by using a multi-meter. The current reading should coincide with the charging stage current as well.
4) The time taken for the battery to reach the float charging stage should be monitored during the process. The float charging stage voltage level and current level are referenced as the battery manual. According to the battery and charge controller ratings, it should take approximately eight hours.

To test the discharging time of the battery, the following steps was taken.

1) A predetermined load is needed. The battery should be connected to the inverter with the predetermined load. For the expected result, the battery should start to slowly discharge.
2) Connecting a multi-meter to check the voltage of the battery during the discharging process. The voltage reading on the multi-meter should decrease gradually from fully charge.
3) The current going through the battery should also be checked by using a multi-meter. The current that is drawn from the battery should show on the multi-meter reading.
4) The time taken for the battery to reach its final discharge stage should be monitored closely as well. According to the battery and load ratings, the time it takes for the battery to discharge to its final discharging current at 3.0 CA is eight hours. The monitor the time should match the expected time.

7.7 Wind Generator Rectifier Testing

In order to ensure the quality and effectiveness of the rectified ac signal, several steps was taken to analyze the bridge rectifier.

First, the wind generator rotor needs to be stopped and be maintained off of operation. This ensures the bridge rectifier is without power. Check the rectifier to confirm that it is set up correctly. Diodes should be placed in the circuit with the silver band end in the negative direction. The circuit will not operate properly if the diodes in the rectifier are not installed in the correct direction.

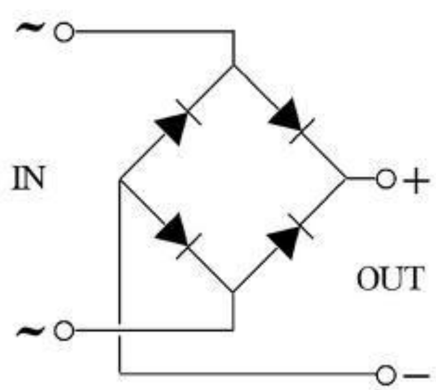


Figure 7.5 Bridge Rectifier

Secondly, set the multi-meter to the diode setting. This setting is generally directly before the lowest resistance measurement setting. The diode setting sets a potential between the test probes and measures the voltage drop through the diode. This is much more efficient than simply measuring the resistance of the diode in multiple directions because the diode is not actually operating when the resistances are measured.

Last, when the test probes are connected as shown. The DMM will read either OL indicating an open circuit; or a voltage of 0.7 volts DC or less. Switch the DMM leads. An operational bridge rectifier diode shows a reading opposite of the previous reading. Perform this test on each adjacent pair of bridge rectifier pins. The bridge rectifier is faulty if the readings are the same for any of the individual diodes.

7.8 Voltage Regulator Testing

LM79xx and LM78xx-series regulators have built-in thermal and over current protection, and will limit output to a safe (but hot) level if the load is too heavy. Although, the voltage regulator is protected for overheat is good to check is the device is defective before we assemble the main circuit. The following steps helped us determine whether the voltage regulator is defective or not.

- Verify variable DC power supply is off

- Connect converter to variable DC power supply and multimeter
- Double check connections of circuitry and equipment.
- Power on variable DC power supply and multimeter
- Vary power supply through expected DC voltage range
- Check circuit for temperature
- Measure and record DC output throughout range of inputs
- Power off equipment before disconnecting
- The efficiency of a voltage regulator defines the percentage of power that is delivered to the load and is given by

$$\text{Efficiency} = \frac{\text{Pout}}{\text{Pin}} 100\%$$

Note: The steps above will help us testing the buck converter as well.

7.9 DC/AC Inverting and Power Output Testing

By efficiency, the actual meaning is the percentage of the power that goes into the inverter comes out as usable AC current (nothing is ever 100% efficient; there will always be some losses in the system). This efficiency figure vared according to how much power is being used at the time, with the efficiency generally being greater when more power is used. The efficiency of the inverter may vary from something just over 50% when a trickle of power is being used, to something over 90% when the output is approaching the inverters rated output. The inverter used some power from the batteries even when AC power was not drawn from it. This resulted in the low efficiencies at low power levels. A 3 KW inverter may typically draw around 20 watts from the batteries when no AC current is being used. It would then follow that if you are using 20 watts of AC power, the inverter was drawing 40 watts from the batteries and the efficiency was 50%. A small 200W inverter may on the other hand only draw 25 watts from the battery to give an AC output of 20 watts, resulting in an efficiency of 80%. Larger inverters generally have a facility that could be named a "Sleep Mode" to increase overall efficiency. This involves a sensor within the inverter sensing if AC power is required. If not, it will effectively switch the inverter off, continuing to sense if power is required. This can usually be adjusted to ensure that simply switching a small light on is sufficient to "turn the inverter on". This means that appliances cannot be left in "stand-by" mode, and it may be found that some appliances with timers (eg washing machine) reach a point in their cycle where they do not draw enough power to keep the inverter "switched on", unless something else, eg a light, is on at the same time. Another important factor involves the wave form and inductive loads (ie an appliance where an electrical coil is involved, which will include anything with a motor). Any waveform that is not a true sine wave (ie is a square, or modified square wave) will be less efficient when powering inductive loads - the appliance may use 20% more power than it would if using a pure sine wave. Together with reducing efficiency, this extra power usage may damage, or shorten the life of the appliance, due to overheating. The following steps helped us determine whether the DC/AC inverter is defective or not.

- Verify the batteries are not connected when measuring system
- Connect converter to variable DC power supply and multimeter
- Double check connections of circuitry and equipment.
- Power on variable DC power supply and multimeter
- Vary power supply through expected AC voltage range
- Check circuit for temperature
- Measure and record AC output throughout range of inputs
- Power off equipment before disconnecting
- The efficiency of a voltage regulator defines the percentage of power that is delivered to the load and is given by

$$\text{Efficiency} = \frac{\text{Pout}}{\text{Pin}} 100\%$$

7.10 Dump and Diversion Load Testing

Two scenarios were considered with respect to testing the dump and diversion load. First scenario was to test if the dump load resistors work properly solely without connecting to the system when expected output power of the solar panel and wind turbine are applied. The voltage across the dump load resistors and current going through them should be measured by using multi-meters. The power that the dump load resistors dissipate should match the calculated result from section 4.11. Each set of the load resistors were tested for both the wind power generation and solar power generation.

The second scenario was to test if the dump load resistors work properly when connecting to the system. When the battery is charging, there should be no current going to the dump load resistors. The dump load is expected to be disconnected from the output of the charge controller. When the battery has reached the fully charge, the dump load should start to work. The output of the charge controller should be connected to the dump load, and the voltage across the dump load resistors and the current going through it should match the expected result calculated from section 4.11.

7.11 Battery Charge and Diversion Controller Testing

The circuit needs to be calibrated for a charging window. 11.9V and 14.9V are set as low and high set points for the controller. These are the points where it switches from sending power to the batteries to dumping power into a dump load, and vice versa (a dump load is only needed if a wind turbine is used, if using only solar panels, the dump load line can be left open).

The best way to tune the circuit is to attach a variable DC power supply to the battery terminals. Set the power supply to 11.9V. Measure the voltage at T_P Low. Adjust potentiometer (low) until the voltage at the test point is as close to 1.667V as possible. Now set the variable power supply to 14.9V and measure the voltage at T_P High. Adjust potentiometer (high) until the voltage at the test point is as close to 3.333V as possible.

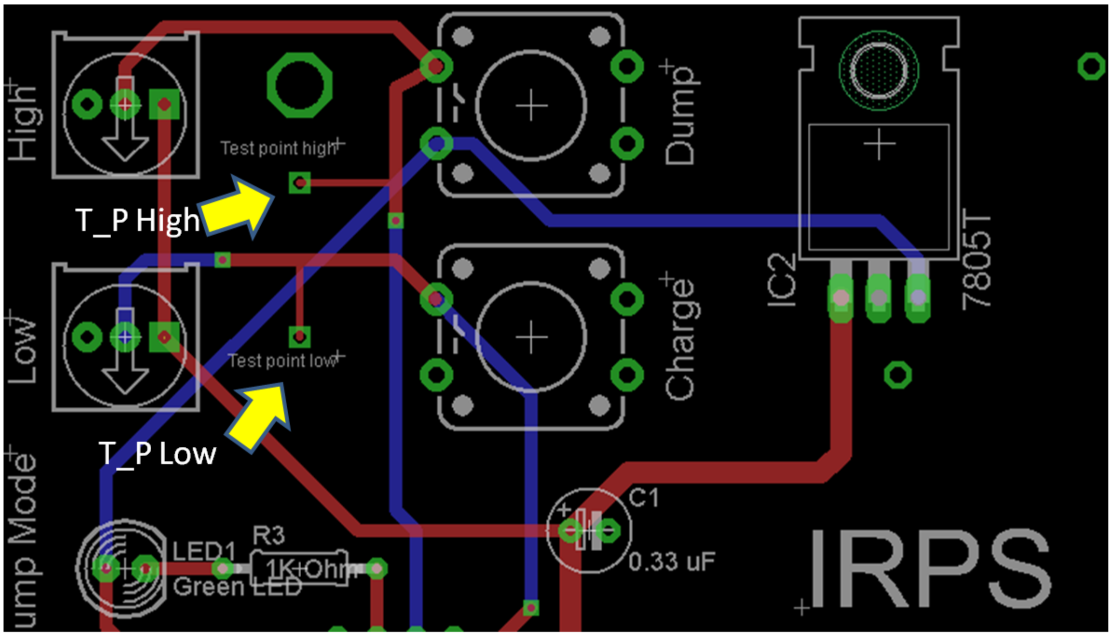


Figure 7.6: Calibrating the Charge Controller

When running the input voltage up and down between about 11.7 and 15.1 Volts, You should hear the relay pull in at about 14.9 Volts and open at about 11.9 Volts. In between the two set points the controller should stay in whichever state it is in. The yellow and green LED indicators will determine the mode at which the system is. When the voltage is between the charging window the yellow LED will glow, indicating that the battery is being charged and safe from overcharging. If the voltage goes above the charging window, in this case 14.9 volts, the green LED will glow indicating that the systems is either acting as open circuit (for solar panel) or is dumping the excess of power to the diversion load (for wind generator).

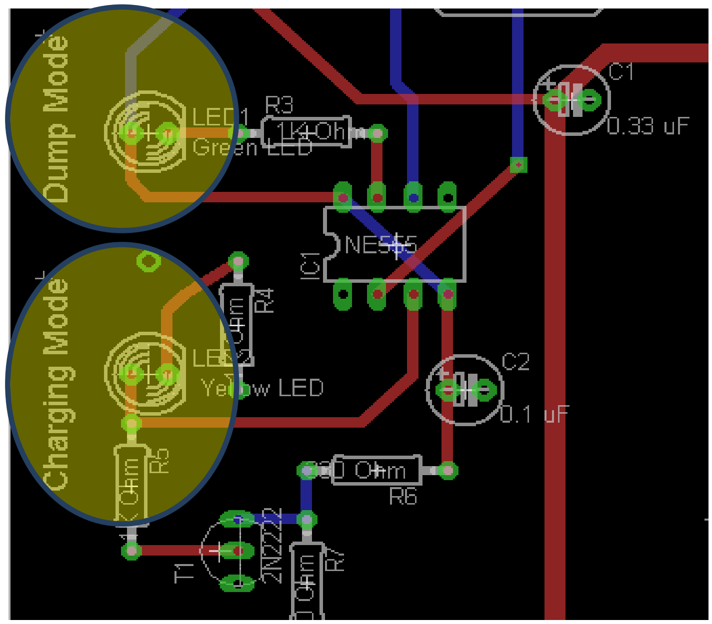


Figure 7.7: LED stage indicators

The polarity of the input voltage is very important for this circuit. Positive and negative terminals should be placed with its respective polarities. This will prevent any damage to the traces and any other component.

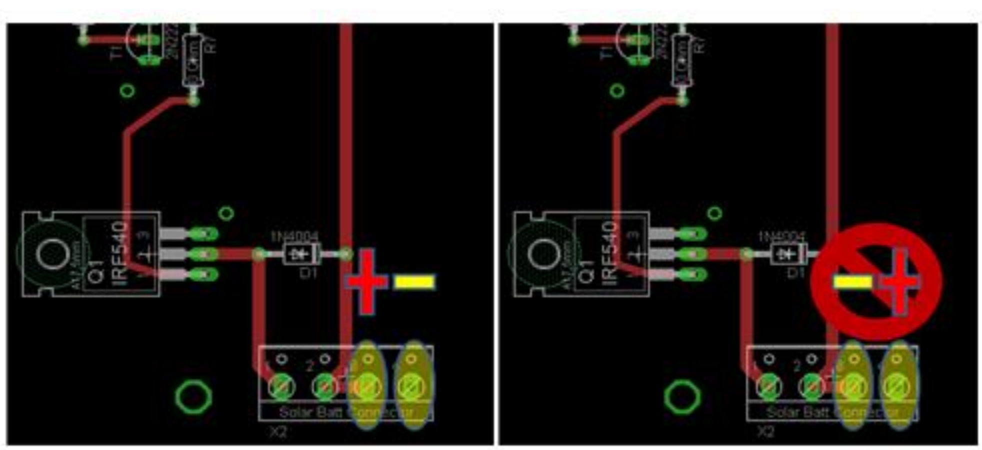


Figure 7.8: Correct polarity

When the voltage goes above the charging window the green LED will glow and the circuit will switch the relay. Before connecting the relays, it is important to check the voltage across the positive and negative terminal of the output. If the yellow LED is on and there is voltage across the output, the circuit is not working properly and the relay should not be connected to the output terminal of the circuit. If the charging window has been set, with a digital power supply set the voltage above the charging windows. The green LED should be on and the voltage across the output terminals should be equal to the input voltage.

Once the functionality has been tested, connect the output terminals of the circuit to the pins 85 and 86 of the relay. Test again the circuit, but now with the relay connected. Increasing the input voltage above the charging window, if the relay clicks when the voltage goes above the charging window, the circuit is working properly and the relays can be connected to its respective sources.

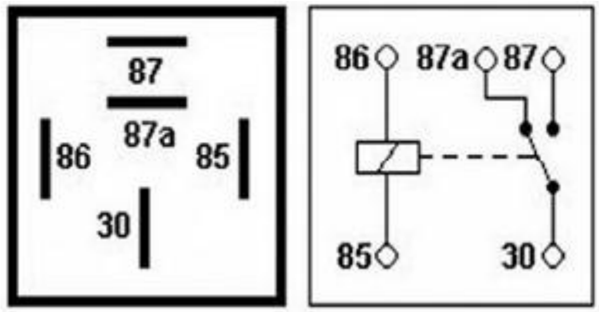


Figure 7.9: Relay configutation.

Chapter 8: Operators Manual

8.1 Procedures

Step 1: Connect the outputs and ground of the voltage sensors to the switching circuit. This can be seen in Figure 8.1, after this has been done hook the inputs of the sensors to the inputs of the load dump PCB which is displayed in Figure 8.2.

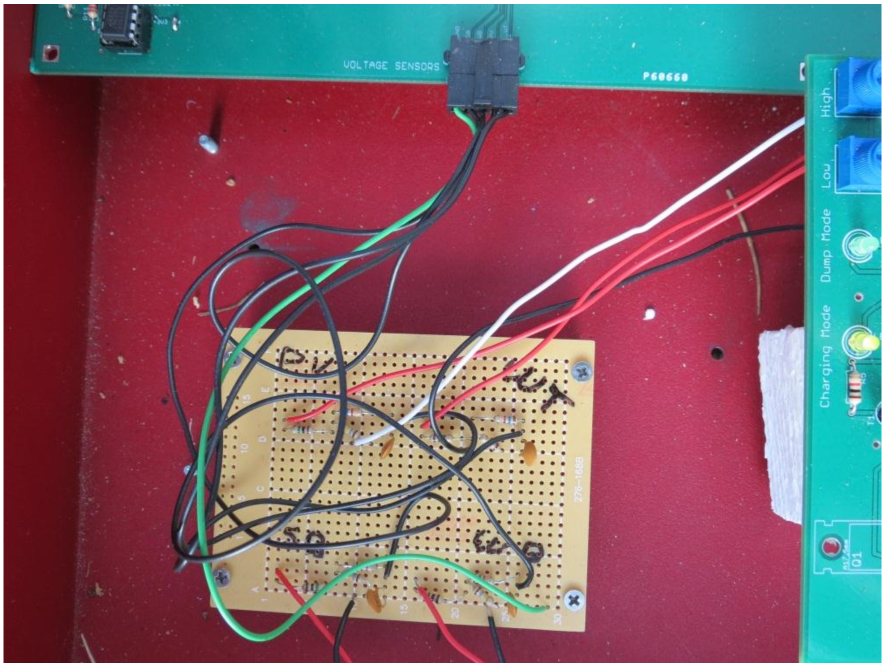


Figure 8.1: Voltage Sensors connected to Switching Circuit

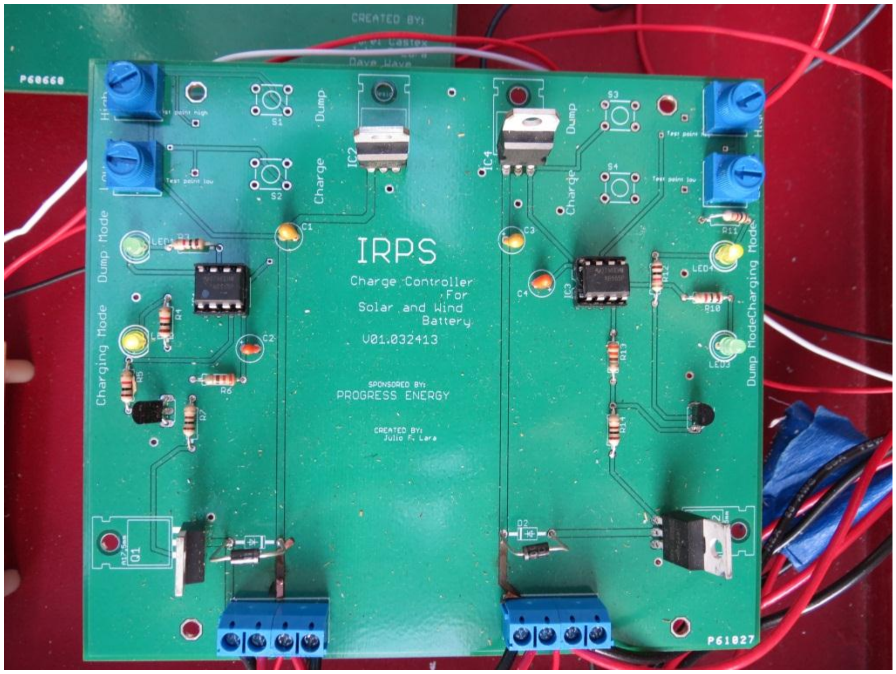


Figure 8.2: Load Dump Circuit, Voltage Sensors Should be Connected to Inputs

Step 2: Make sure that the smaller battery powering IRPS microcontroller board is unhooked. Next connect the voltage sensor to the solar 12V battery which is the smaller alligator clips. Then hook the larger alligator clips on the Romex wire coming from the bus labeled Solar Battery. It should look like Figure 8.3 below. When the Voltage sensors are hooked up LEDS on the load dump PCB will light up saying that IRPS is in charge mode. This happens because the voltage sensors are actually located on the input of the load dump.

Step 3: Repeat step 1 with the wind battery in the same order.

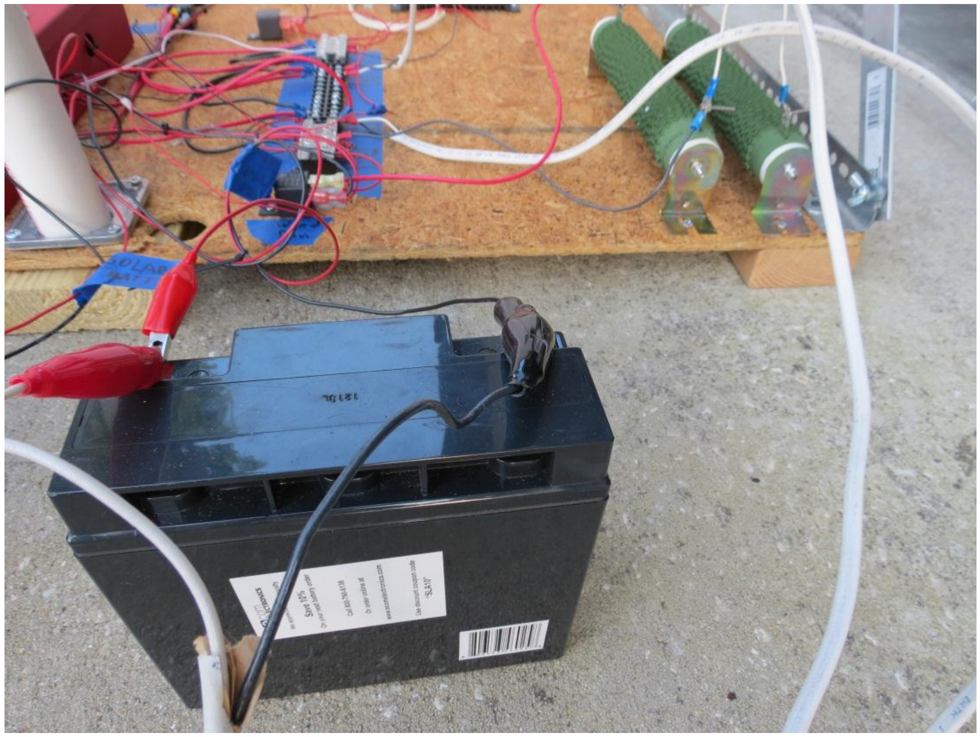


Figure 8.3: Voltage sensor and battery input connected

Step 4: Connect the smaller 12V battery to power the switching circuit and microcontroller of IRPS. The battery is connected to the input labeled solar battery and has a fuse on it. The LED in the upper side of the PCB will light up signaling that the microcontroller based switching circuit has been powered up. This can be seen in Figure 8.4.

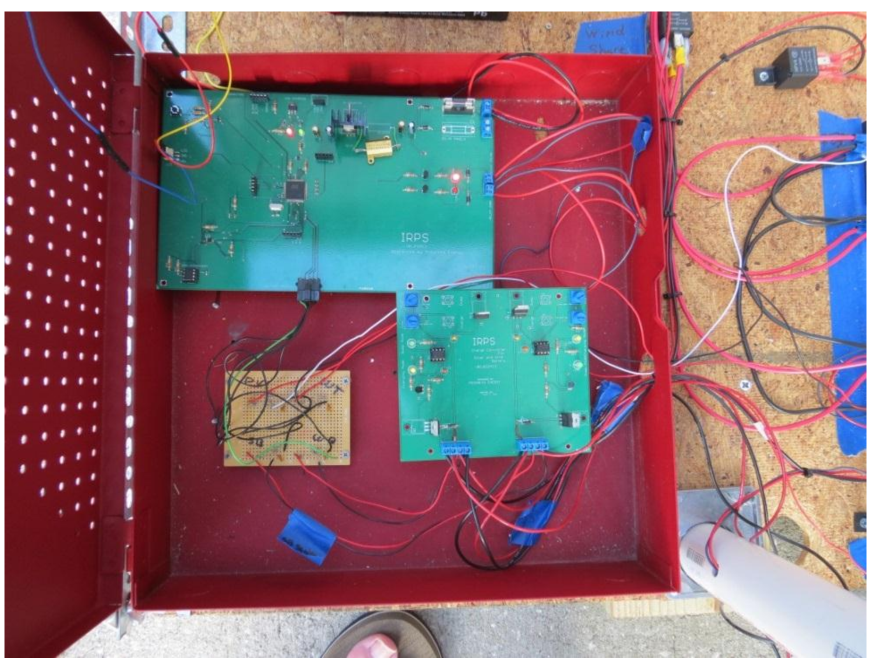


Figure 8.4: IRPS fully powered up

Step 5: Make sure the wind turbine is not spinning and move IRPS out into the sun. If everything is connected correctly the LED labeled “solar relay” will light up. This signals that IRPS is in integrated solar mode and the relay will make a click sound which signals that both batteries are in parallel with the PV panel. This can also be seen in Figure 8.3 and to further confirm check the LCD screen to make sure no errors have occurred. It should read Int. Solar and display the power in watts of the PV panel. The Wind turbine should read 0V and the LCD will display that the batteries are charging.

Step 6: Using a drill with an Allen wrench bit start spinning the wind turbine. As the wind turbine starts to generate voltage the solar relay LED will turn off and the LCD screen will signal that IRPS is now in independent mode. This means that each source is charging its own battery. Keep increasing the speed of the wind turbine. Once the turbine is producing 13V the “wind relay” LED will turn on. This signals that the wind turbine is now charging both batteries and the solar panel is charging the solar battery. The LCD screen will display that IRPS is now in Enhanced wind mode.

Step 7: Increase the speed of the wind turbine even more. Once the turbine produces more than 14.9V IRPS will enter protection mode. The LEDs labeled dump mode will light up on the dump load PCB. This will direct the power to the dump load protecting the batteries. The dump load can be seen in Figure 8.5 and this will dissipate off the energy as heat thus keeping IRPS safe from overloading.

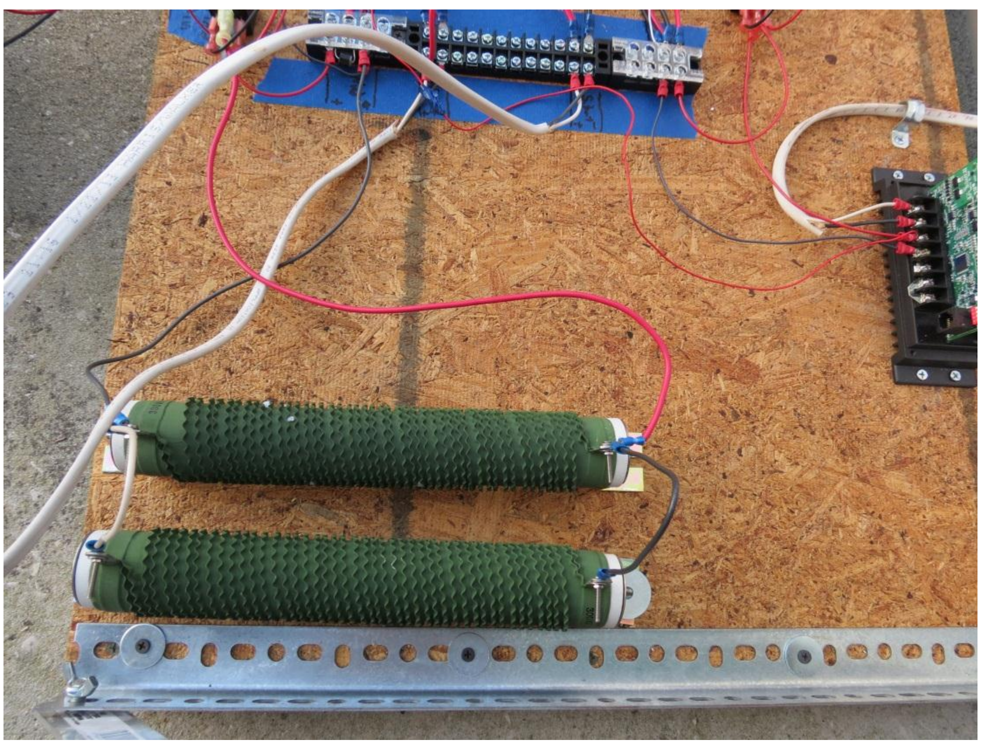
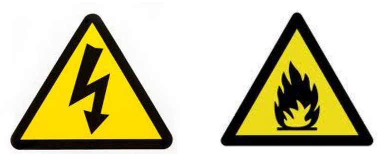


Figure 8.5: Dump load

Step 8: If all of the previous steps are working correctly IRPS is fully operating and can begin charging batteries. If any of the steps fail please see the troubleshooting chapter of this document.

8.2 TROUBLESHOOTING

WARNING



DO NOT INVERT THE POLARITY OF THE INPUT VOLTAGE IN EITHER TERMINAL CONNECTOR OF THE MAIN SWITCHING BOARD.

If polarity is inverted, the reverse current will severely damage traces and burn low voltage components.

8.2.1The Main Switching Board Cannot Be Turned On

The main switching board works with a minimum input voltage of 12 volts. The main components of the board will work at a voltage of 3.3 volts and some other components at 5 volts. However, the switching board needs at least 12 volts to switch the relays.

1) Check terminal connectors of the main board: *The main switching board has two terminal connectors to power the system. There must be at least one source of power connected to the terminal connectors. It is preferable to connect a 12 volts battery to terminal connector "Solar Battery" and the "Solar Panel' connectors to the PV Panel. If there is at least one power source connected, check the terminal voltage. It must be at least 12 volts for the switching circuit to work properly.*

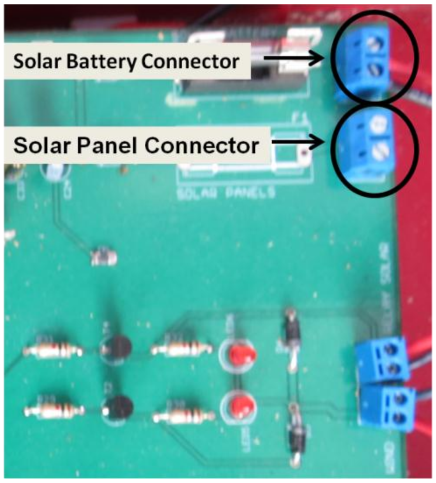


Figure 8.6 terminal connectors of the main board

2) Check terminal voltage of the battery: *If the terminal voltage is below 5 volts the system will not work. However, the system won't work properly. A minimum of a 12 volts input source is necessary for the system to have full functionality.*

3) Check protective fuse: *Each input terminal has a 2A fuse, if one of this fuses is burned the systems won't work. Replace it with a new fuse to power up the system.*

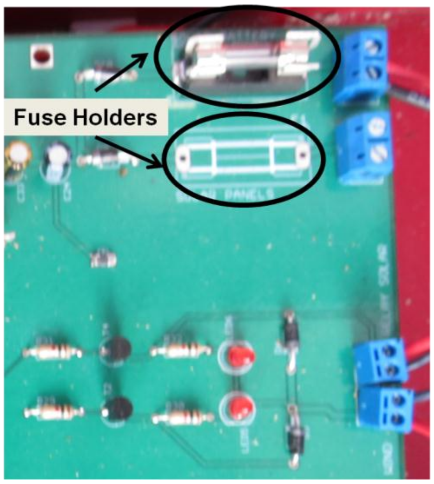


Figure 8.7 protective fuse

8.2.2 LCD Display Not Working or Not Working Properly

The LCD display is connected externally through female-to-female connectors. The connection pins are three: VDD / 5V, GND, RX / LCD. For proper functionality each pin must be connected correctly. For instance; male pin "VDD" on the LCD must be connected with the male pin "5V" on the main PCB board. GND to GND and RX to LCD

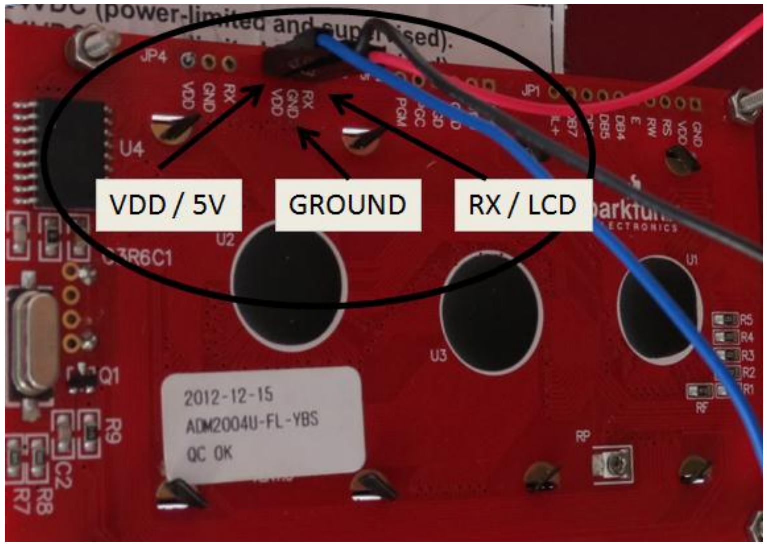


Figure 8.8 LCD connections on screen

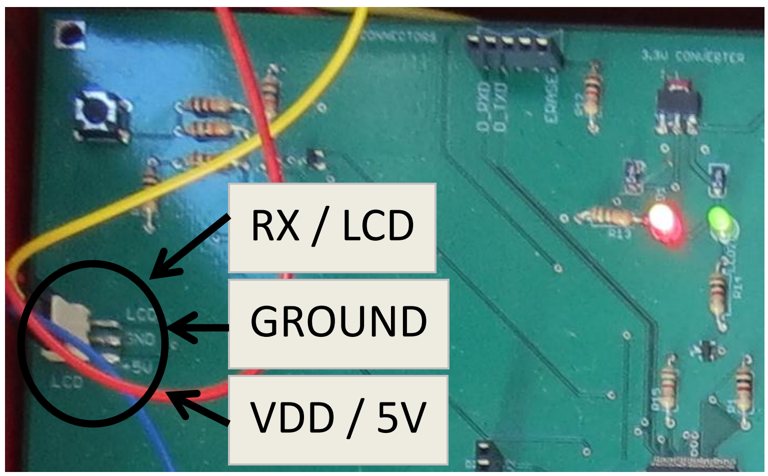


Figure 8.9 LCD connections on PCB

1) Check the connections: *each male pin must be connected as the table below illustrates. Make sure each connection is tied and not loosened.*

LCD DISPLAY PIN	MAIN BOARD PIN
VDD	5V
GND	GND
RX	LCD

Table 8.1 LCD connections

8.2.3 LCD Display Brightness Not Correct

1) Dial the LCD dimmer: If the LCD screen is not well visible, with a small Phillips screw driver dial the dimmer button until display is visible.

Figure 8.10 LCD dimmer

2) Too much sun exposure: if the LCD display has been exposed to the sun too long the screen may become dark. Unplug the LCD display and let it cool down for a few minutes then plug it back to the system.

8.2.4 LCD Display Not Showing Data or Giving Errors

The LCD screen when is working properly should display data as shown in the table below. When voltage sensors are not connected well between the main board – voltage sensor circuit or voltage sensor circuit – source/battery the microcontroller won't computer correctly and therefore the LCD display will give you blank data or errors.

Display header	Type of data displayed	Format of data displayed	Additional data displayed
PV	Solar Panel output	watts	none
WT	Wind Turbine Output	volts	none
MODE	Charging mode	characters	No source, Indepentent, Int. Solar, Int. Wind
SB	Charge	volts	Charging
WB	Charge	volts	Charging
T	Temperature	Farenheit	none

Table 8.2 data display

Figure 8.11 LCD displaying data

8.2.5 PV, WT, SB or WB Status Showing Error or No data

1) Check the voltage sensor connection: Make sure all the sensors are connected properly. A loosened connection may cause an internal error even when the connector looks plugged in.

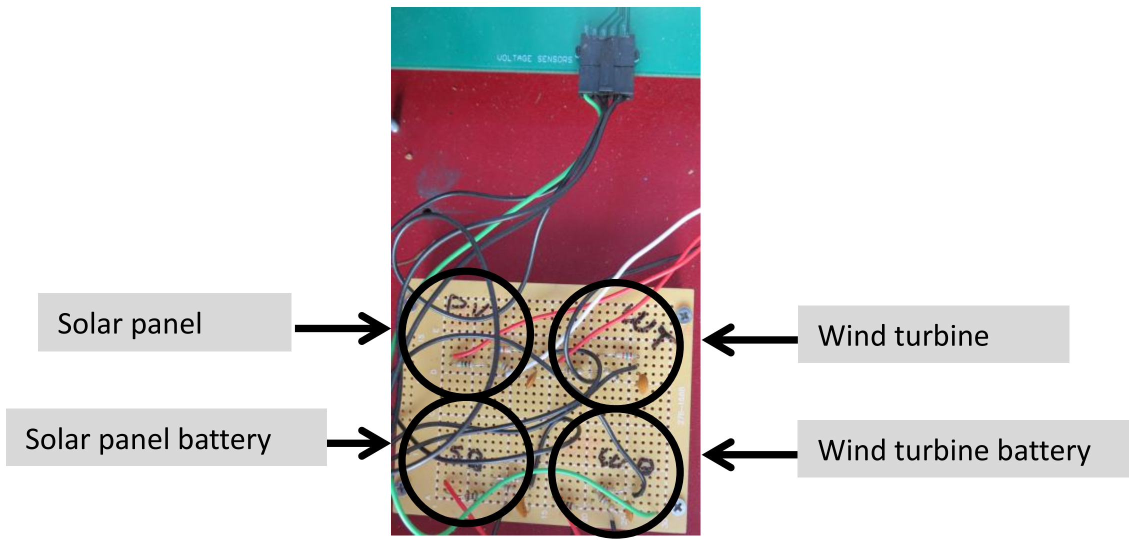


Figure 8.12 voltage sensor connections

8.2.6 The Relays Not Switch Properly

When voltage sensors are not connected well between the main board – voltage sensor circuit or voltage sensor circuit – source/battery the microcontroller won't computer correctly and the sharing modes won't work well.

1) See the following from above first:

- PV, WT, SB or WB header is showing the letter "E"
- The PV and WT headers are not showing any data when solar panel or wind turbine is working
- The SB and WB headers are not showing any data when battery is connected

2) Check the connections: Make sure each terminal connector of solar sharing and wind sharing is connected to relay connector pin 85 and 86.

3) Check input voltage of the main board: Make sure input voltage is 12 V.

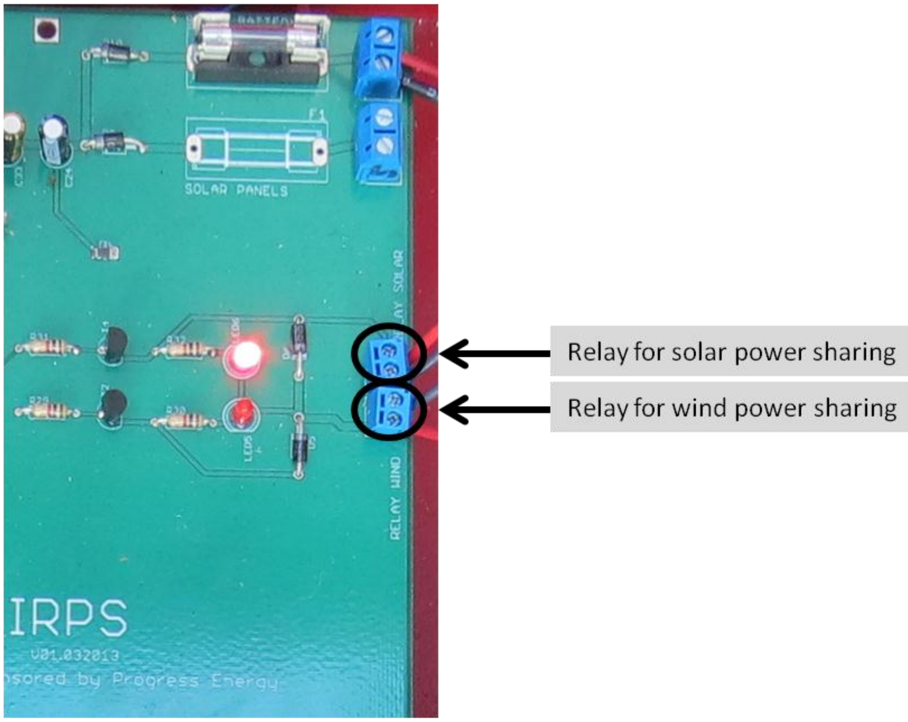


Figure 8.13 Switch Relay connectors

8.2.7 Circuit Does Not Switch Relays

1) Circuit needs to be calibrated: The best way to tune the circuit is to attach a variable DC power supply to the battery terminals. Set the power supply to 11.9V. Measure the voltage at T_P Low. Adjust potentiometer (low) until the voltage at the test point is as close to 1.667V as possible. Now set the variable power supply to 14.9V and measure the voltage at T_P High. Adjust potentiometer (high) until the voltage at the test point is as close to 3.333V as possible.

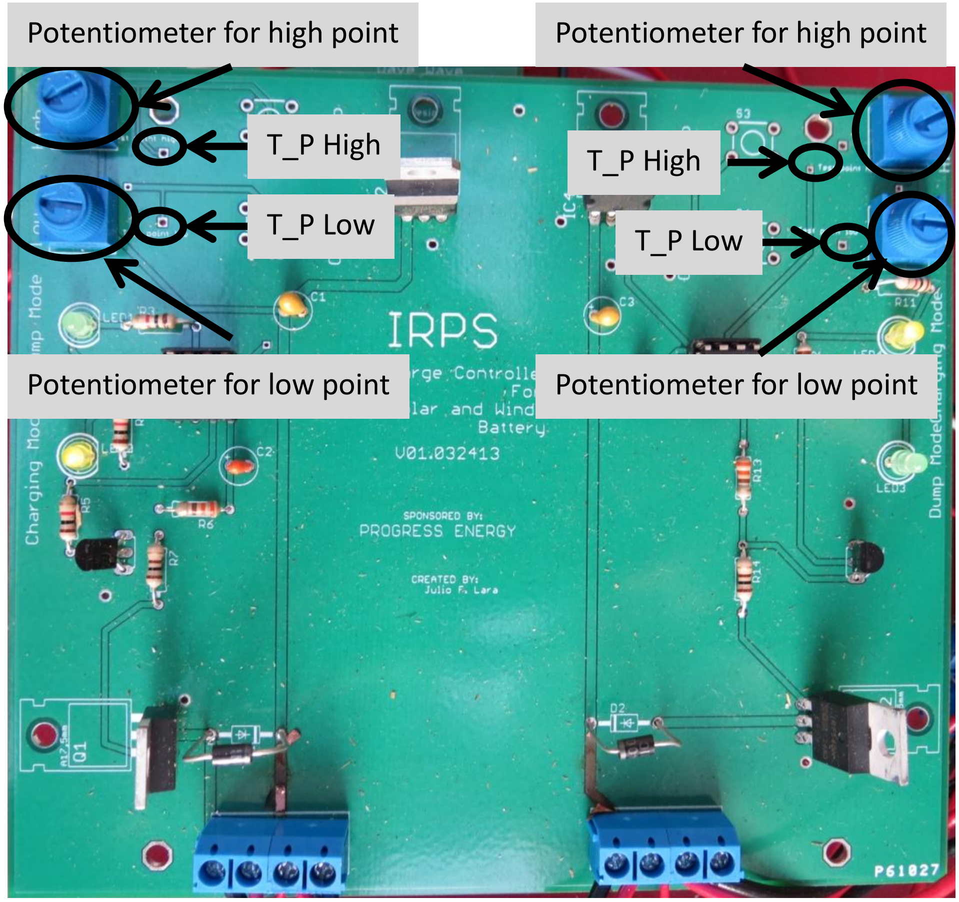


Figure 8.14 Charge controller calibrations

2) Check the connections: Make sure each connection is tied and not loosened.

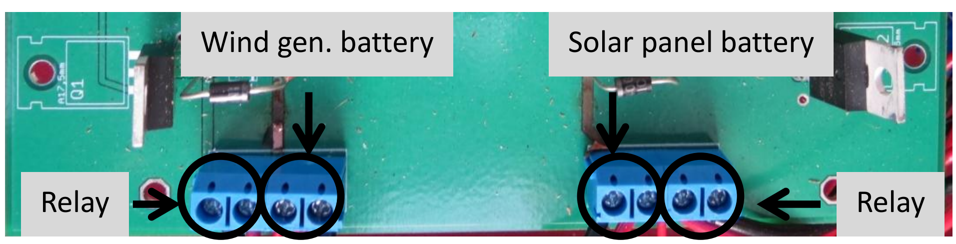


Figure 8.15 Charge controller connections

Chapter 9 Administrative Content

9.1 Milestone Discussion

The senior design project has been break down to two semesters of work. In Senior Design 1, takes place from August to December 2012, the primary subjects should be focused on is defining the project, conduction thorough research on related topics, and proposing a complete design of the project. All of these should be well-documented for Senior Design 1 documentation. Table 9.1 shows the research timeline of the project. The research has been divided into nine sections. Each of the members has assigned two or more sections. A thorough research builds a good foundation for the design stage.

	Research								
	Solar Power	Wind Power	Charge Controllers	Micro-controllers	Sensors	Batteries	Dump Loads	Inverters	Voltage Regulators
Sept-17	■	■	■	■					
Sept-24	■	■	■	■		■			
Oct-01	■	■	■	■		■			
Oct-08	■	■	■	■	■	■		■	■
Oct-15	■	■	■	■	■	■		■	■
Oct-22	■	■	■	■	■	■	■	■	■
Oct-29	■	■	■		■	■	■	■	■
Nov-05	■	■	■				■	■	■
Nov-12	■	■	■				■	■	■

Table 9.1 Gantt Chart Depicting Research Timeline.

The second stage is the design stage. The initial design was conducted in the fall semester and slightly overlapping with the research stage. According to each research section, electrical components of the project were chosen for purchasing. Table 9.2 below shows a tentative schedule of the design stage. The initial design concepts were presented in the documentation at the end of the fall semester. The design process was continued through the first month of the Senior Design II semester.

	Design						
	Solar Power	Wind Power	Charge Controllers	Micro-controllers	Sensors	Inverters	Voltage Regulators
Nov-19	■	■	■	■	■	■	■
Nov-26	■	■	■	■	■	■	■
Dec-03			■	■	■	■	■
Dec-10			■	■		■	■
Dec-17			■	■		■	■
Dec-31			■	■		■	■
Jan-07			■	■	■	■	■
Jan-14			■	■	■	■	■
Jan-21			■	■	■	■	■
Jan-28			■	■	■	■	■
Feb-04			■	■	■		
Feb-11			■	■			
Feb-18			■	■			
Feb-25			■	■			

Table 9.2 Gantt Chart Depicting Design Timeline

During the winter break, parts were purchased for early prototyping in the beginning of spring semester. All of the parts except those were necessary for the packaging of the final circuit board and electronics, solar panel, and wind turbine were purchased before the first half of February. The input of the system can be assembled by using the function generator in the laboratory. Table 9.3 shows the timeline of the parts acquisition stage. The final board was then fabricated once the design has been tested, and the test results had been verified.

	Parts Acquisition										
	Micro-controllers	MPPT	Display	Sensors	Batteries	Dump Load	Inverters	Voltage Regulator	Packaging	Solar Panels	Wind Turbine
Dec-10	■										
Dec-17	■										
Dec-31	■										
Jan-07	■	■		■							
Jan-14	■	■	■	■							
Jan-21		■	■	■	■	■	■	■	■		
Jan-28				■	■	■	■	■	■		
Feb-04							■	■	■		
Feb-11							■	■	■		
Feb-18									■		
Feb-25									■	■	■
Mar-04									■	■	■
Mar-11									■	■	■
Mar-18									■	■	■
Mar-25									■	■	■

Table 9.3 Gantt Chart Depicting Parts Acquisition Timeline

The next section is the prototyping stage. Table 9.4 shows the tentative schedule for prototyping. This stage began once the necessary parts have received. Tests on each individual part were conducted before implementing to the circuit design. All of the components worked properly by themselves, especially the sensors. The results from the component testing should match the data from the manuals. The packaging of the entire circuit design was finalized until the testing results of the module are correct.

	Prototype										
	Micro-controllers	MPPT	Sensors	Display	Batteries	Dump Load	Inverters	Voltage Regulator	Solar Panels	Wind Turbine	Packaging
Jan-14	■	■	■								
Jan-21	■	■	■								
Jan-28	■	■	■								
Feb-04	■	■	■	■							
Feb-11	■	■	■	■	■	■					
Feb-18	■	■	■	■	■	■					
Feb-25				■	■	■					
Mar-04				■	■	■			■	■	
Mar-11					■	■	■	■	■	■	■
Mar-18							■	■	■	■	■
Mar-25							■	■	■	■	■
Apr-01											■
Apr-08											■

Table 9.4 Gantt Chart Depicting Prototyping Timeline

The final stage is the most important stage, which is the testing stage. The testing process followed closely to chapter 7. All of the components, modules, and the complete system were tested. The testing started when some of the acquired parts are received. Testing conducted during the prototyping, and it continued through the beginning of April. Table 9.5 shows the timeline of the testing stage.

	Testing						
	Solar Panel	Wind Turbine	MPPT	Battery Charging	Dump Loads	Outlet	Packaging
Mar-18	■	■					
Mar-25	■	■	■				
Apr-01	■	■	■				
Apr-08	■	■	■	■			■
Apr-15	■	■	■	■	■	■	■
Apr-22	■	■	■	■	■	■	■
Apr-29	■	■	■	■	■	■	■

Table 9.5 Gantt Chart Depicting Testing Timeline

9.2 Budget and Finance Discussion

9.2.1 Budget

The concepts of IRPS controller design was verified by establishing a fully functional sustainable system. The budget is presented in table 9.6 below. All of the required parts for creating the IRPS controller are included. This project is sponsored by Progress Energy through University of Central Florida Foundation. The cost of miscellaneous has not included in the table.

Parts List	**Cost per Part**	**Number of Parts**	**Total Cost**
Solar Panels			
SW-S85P Solar Panels	$249.85	1	$249.85
Mounting Braket	$50.00	1	FREE
Wind Turbine			
Hyacinth P-300W 12V DC	$275	1	$275
Charge Controller			
Morningstar SS- MPPT	$199	1	$199
Printed Circuit Board (Student Special)	$33.00	2	$66.00
DS1624 Temperature Sensor	$9.00	1	FREE
Voltage Sensing Circuit	$3.49	1	$3.49
LCD Screens	$29.95	1	$29.95
Battery			
UPG UB12180 AGM-type Battery	$38.35	2	$76.7
Dump Load Resistors			
300 Watt Dump Load for 12 Volt Systems	$21.98	3	$65.94
Converter/Outputs			
DC/AC	$50.00	1	$50.00
Microcontroller / Development Board			
Atmel AT91SAM7X512	$21.51	2	$43.02
Netduino	$34.95	1	$34.95
Other Components			
Relay	$5.00	4	$20
Bus, wires, cables, metal box	$72		$72
		Total:	$1092.88

Table 9.6 Anticipated Budgets.

9.2.2 Finance Discussion

The main objective of IRPS project is to design a top efficient integrated power system as a proof of standalone system using the benefits of solar and wind energy. The following budget presented in Table 9.6 above includes the required parts that were obtained to create an off-the-grid integrated energy system.

The project can be divided into fourth major sections. First section embraces a 550 W 12V DC wind turbine and SW-S85P 100 W 12 V solar panel. Second partition includes the PCB board with converters, inverters, charge controllers and other electronics. Third section is dedicated to controller box with all components. Fourth partition is mainly composed by wind and solar banks using AGM batteries. Project has performed a period of designing and documenting as part of the first cycle. It is deemed that second phase will count with a period of testing and building the circuit on a solder less plug-in breadboard. The funding for this project is provided through a grant from Progress Energy. The grant is based on renewable energy programs and was intended to support senior design projects working on projects in these industries. Groups were required to provide a proposal and an initial budget for their project in order to apply for the funding. The group was funded based on the proposed budget provided to Progress Energy.

Since IRPS carries good characteristics of being a finalized product to be launched into the market, it was conducted an exhaustive study about energy savings for clients and long-term profitability for large scale production. Economic analysis was managed by IRPS in coordination with UCF graduate student cursing a master program with focus area in Project Management. Implemented economic analysis will refer to how feasible is to create the mentioned integrated renewable energy system for residential and small businesses.

Taken into account average energy consuming in households and small business, it was decided to run a complete analysis with an integrated system capable of delivering 1.5 kW which represent a larger model than IRPS prototype capacity. To develop this analysis, study accounted for the system final price as well as the determination of how feasible is for the final client to make an investment of this nature. Also, study covers on how advantageous would be the large scale production for this type of system. To reach final conclusion of these studies Net Present Values (NPV) were estimated considering today and forecast's market situation. Study relies on computer simulations to calculate the power output of the whole system. These simulations were modeled using Homer software which is a tool for designing and analyzing hybrid power systems. Homer contain predetermined conventional generators, wind turbines, solar photovoltaic, batteries and other inputs, system was modeled with customized elements taking into account the characteristics of the equipment and components to be utilized on the construction of this hybrid system. Below it can be found some of the relevant information used for this purpose:

- 11 solar panels 75-watt 12 V for a total of 825 W of power
- 6 Battery 12V 7AH
- A converter / controller box capable of convert from DC to up to 1.5 KW of AC
- The Derate Factor to convert form DC to AC was 0.770
- The primary load connected to the system was approximately of 1.5 Kw/d with a peak of 63 W.
- The project life time was set to 30 years.
- The operation and maintenance was determined to be approximately a 0.5% of the initial investment per year.

Simulations are created for each state of USA taking into consideration the geographic characteristics for wind [55] and solar [54]. Factors such as longitude, altitude, average altitude above sea level, wind speed annual average and hour of peak wind speed are considered when simulating possible power output per state; Figure 9.1 below shows the result of state of Connecticut as example.

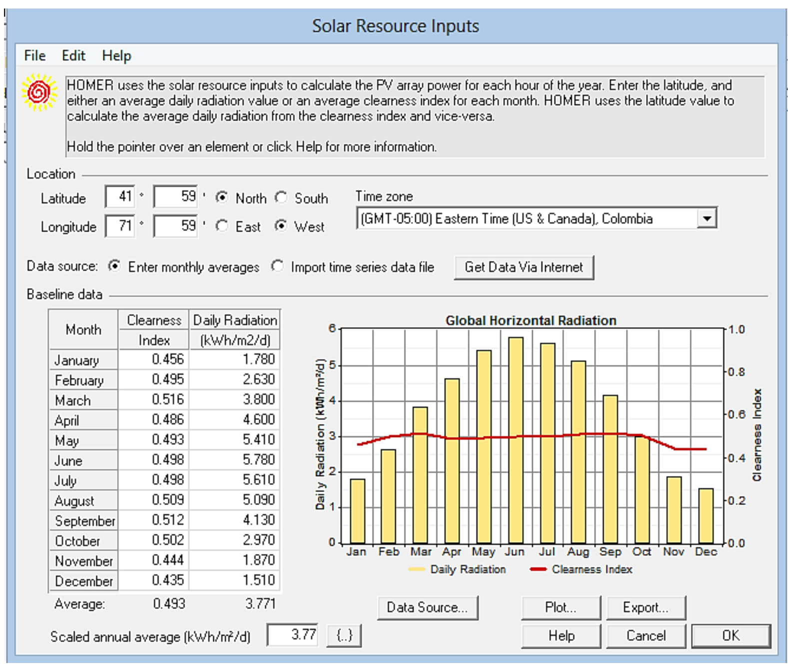


Figure 9.1 Solar resources entered to simulate power output for state of Connecticut.

Each state average power output was calculated, then it was proceeded to do the economic analysis given the average annual consumption (KWH) in each US state for both, residential and small businesses. In addition, it was considered the price per kilowatt hours given that each state has its own rate [56]. The analysis was based on 30 years of project life and both financed and paid off systems; for financed system we only took into consideration a fixed 10% of down payment.

9.2.2.1 Final Client Price

Toward calculating final client price, we used the cost plus pricing strategy which according to Godfrey it “determines the expense associated with producing a product and add an additional amount to that number to generate profit.” and “is relatively simple, as it only requires the unit cost and desired profit margin for calculation. Unit cost consists of all fixed and variable costs associated with making a product and bringing it to market –including raw materials, labor, utilities, packaging, transportation, marketing, and overhead. Profit margin is the markup on each unit sold, which can vary for retail and wholesale sales. [57]”

Given the above concept, for this pricing strategy it was calculated the system cost based on the list of elements required to build the system. The system cost was estimated at $3,810.8, thus we set the margin profit to a 20 % of this cost, and a 10% for installation costs, leading us to an approximated price before sale taxes for the final client.

Final price = System costs + margin profit + installation costs
Final price = $3810.8 + 0.2($3810.8) + 0.1($3810.8)
Final price = $4954.04

Holding up to calculated final price for client and consider that “an investment is measured by its impact over time—positive or negative—on the organization’s cash position [58],” this analysis would be based on the Net Present Value (NPV). Two main distinct states would be considered based on that “positive cash flow indicates an inflow of cash or the equivalent reduction in cash expenditures. Negative cash flow designates an investment of cash or a reduction in cash receipts [58].” In order to calculate de NPV we established a discount rate of a 7% which has been set by the US Department of Energy for this type of investment on residential and small businesses [59]. NVP formula is described below.

$$NPV = \sum_{i=1}^{n} \frac{ACF}{(1+r)^i}$$

ACF stands for annual cash flow for each year that the project is supposed to be implemented. To calculate the annual cash flow we used the initial investment along with the financing and tax credits that government has been giving on this type of investments. The tax credit used was 30% of the total of net project cost on the first year [60]; we also took into consideration the annual costs of operation and maintenance (O&M), so the formula used was:

ACF = -ALP + TxCr – O&M + NES

ALP: Annual Loan Payment
TxCr: Tax Credit
O&M: Costs of operation and maintenance

NES = Net Energy Saving

To calculate annual loan payments we used the PMT formula existent in excel which can be translated as follows:

ALP = $\frac{PV*i}{1-(\frac{1}{(1+i)^n})}$

PV: present value = loan amount
i: Interest rate of the loan – was used 6% for residential and 7.5% for commercial
n: loan term

It was determined that annual costs of operation and maintenance was approximately of 0.5% of the initial investments with an inflation rate of 3 %, so O&M cost were computed with the following formula:

O&M = $PIC * (1 + OMIR)^y$

PIC: present value of operation and maintenance costs (percent of installed costs)
OMIR: Operation and maintenance inflation rate
y: number of years that project has been implemented

Finally, in the case of net energy savings was used an energy inflation rate of 2% based on historical data from US Energy Information Administration. Formula used to compute this value was:

NES =SPO * ER * $(1 + EIR)^y$

SPO: Year based system power output (KWH)
ER: Energy rate (cents per KWH)
EIR: Energy inflation rate

Using excel spread sheet was developed a complete set of tables with numerical result whose numbers represent each state in the residential and small business field. Figure 8.2 allows to quick observing the compiled outcome for NPV calculations stating at what state it is profitable for clients to invest on large scale version of IRPS.

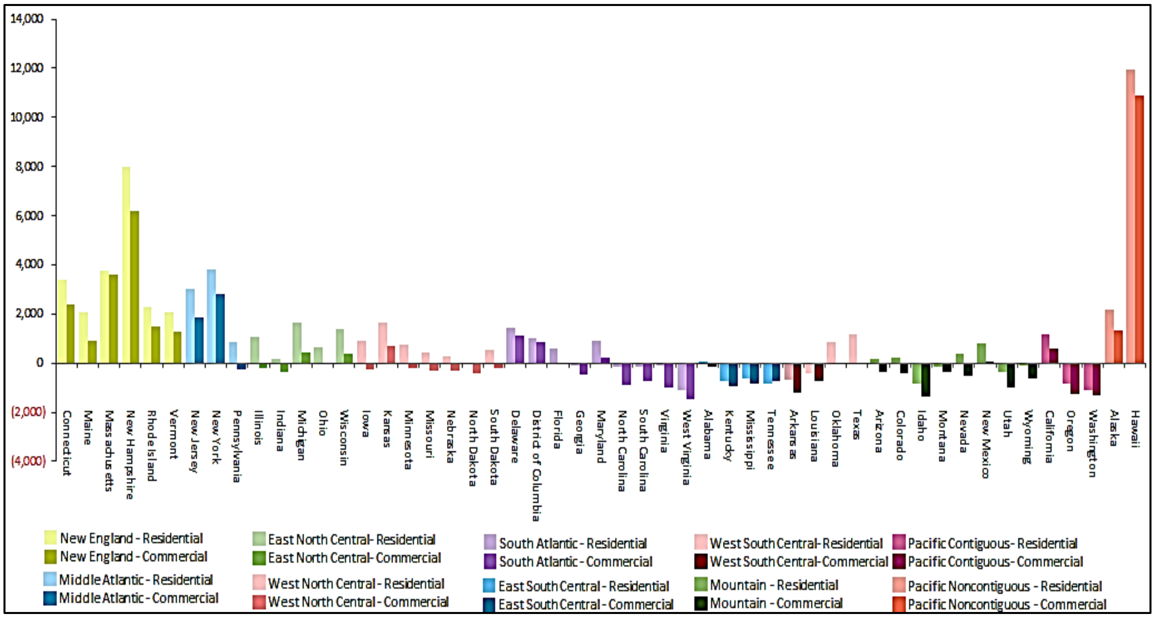


Figure 9.2 NPV for systems on commercial and residential sector in each USA regional division and state

From the economic analysis perspective after NPVs calculation and observing above Figure 9.2, it is conclude that scaled up IRPS version possess a more secure market on the residential sector, given that is a system with not enough power produced to cover commercial sector, although in the New England, some states of Middle Atlantic and Pacific Noncontiguous USA regional divisions could have a great acceptance on the small businesses arena as well given the climatic conditions and high energy rates.

9.2.2.2 Analysis of Profitability

Based on previous market analysis, it is chosen to focus on development for the residential sector, so now the profitability of the project in the residential sector must be analyzed. The main competition is the traditional photovoltaic system. This analysis seeks to improve on the traditional model by adding wind energy generating capabilities to provide energy in different types of weather. Because PV systems were identified as the competition, they were used to project sales for scaled up IRPS. From the Open PV Project, the following Table 8.7 shows the number of PV installations in the United States by year. It also shows an approximated number of installations per manufacturer, given that there are around 30 major manufacturers of PV systems [61].

Year	Number of Installs	Installs/Manufacturer
2002	2537	85
2003	3418	114
2004	5223	175
2005	5242	175
2006	8503	284
2007	15785	527
2008	16528	551
2009	26544	885
2010	38262	1276
2011	34352	1146

Table 9.7 PV installations in the United States

From above Table 9.7, it is apparent that there is increasing growth in the number of installed PV units. Because of incentives such as government tax credits for these systems and increased environmental concern, it is expected that this upward growth continues. A conservative estimate of the amount of units to be manufactured and sold in the first year would be 1000 units; this number is only useful for further estimations. The U.S. Energy Information Administration provides data on the number of PV systems shipped. From this data, an industry growth rate of 46.34% is projected for the residential sector. Overall, the average growth rate in the residential sector between 2000 and 2010 is 46.34%. Using this rate, the number of units sold in subsequent years can be projected as presented in the following table. Assuming that material and manufacturing costs do not change, costs and revenues can also be projected as it is shown in below Table 9.8.

Year	Units Sold (46.34% Growth)	Cost ($3810.80)	Revenue ($4954.40)	Profit
1	1000	$ 3,810,800.00	$ 4,954,040.00	$ 1,143,240.00
2	1464	$ 5,579,011.20	$ 7,252,714.56	$ 1,673,703.36
3	2143	$ 8,166,544.40	$ 10,616,507.72	$ 2,449,963.32
4	3137	$ 11,954,479.60	$ 15,540,823.48	$ 3,586,343.88
5	4591	$ 17,495,382.80	$ 22,743,997.64	$ 5,248,614.84

Table 9.8 Units sold projection

Indeed, the NPV of the profit is calculated to demonstrate the worth of the project today, using the discount rate of 7%. The NPV equals $11,008,420.21. This project’s positive NPV shows that large scale IRPS prototype would be worth pursuing.

Appendices

Appendix A: Work Cited

[1] M. Chen, "The Integrated Operation of Renewable Power System," IEEE Canada Electrical Power Conference, 314-319, 2007.
[2] http://exploringgreentechnology.com/solar-energy/advantages-and-disadvantages-of-solar-energy/
[3] http://www.nrdc.org/energy/dirtyfuels_tar.asp
[4] http://www.solar-facts-and-advice.com/monocrystalline.html
[5] http://en.wikipedia.org/wiki/File:PV_Technology.png#filelinks
[6] ^ Mark Z. Jacobson (2009). Review of Solutions to Global Warming, Air Pollution, and Energy Security p. 4.
[7] "Photovoltaic Cell Conversion Efficiency". U.S. Department of Energy. Retrieved 17 October 2012.
[8] "Thin-Film Cost Reports". pvinsights.com. 2011 [last update]. Retrieved 17 October, 2012.
[9] Georgia Tech, SmartTech Search
[10] http://www.solarchoice.net.au/blog/monocrystalline-vs-polycrystalline-solar-panels-busting-myths/
[11] BI Research (2011). "Thin Film Photovoltaic PV Cells Market Analysis to 2020 CIGS Copper Indium Gallium Diselenide to Emerge as the Major Technology by 2020" gbiresearch.com. Retrieved 25 October 2012.
[12] http://photochemistry.epfl.ch/EDEY/NREL.pdf
[13] http://infogreenglobal.com/the-practical-full-spectrum-solar-cell-comes-closer/#more-2162
[14] http://www.solarpower2day.net/solar-cells/efficiency/
[15] http://www.nrel.gov/gis/solar.html
[16] ^ Thin-Film wins PV market share: Three New Plants in Germany Total Almost 50 MW. Sustainableenergyworld.eu (2009-03-14). Retrieved on 2011-09-13.
[17] ^ a b c d e f "The staus and future of the photovoltaics industry". David E. Carlson Chief Scientist BP Solar 14 March 2010. Retrieved 10 February 2011.
[18] ^ X. Wu et al. (October 2001). High Efficiency CTO/ZTO/CdS/CdTe Polycrystalline Thin Film Solar Cells. NREL/CP-520-31025.
[19] http://www.azom.com/article.aspx?ArticleID=1166
[20] http://www.renewablepowernews.com/archives/884
[21]http://www.gwec.net/global-figures/wind-energy-global-status/
[22] http://www.gwec.net/north-america/

[23]http://cleantechnica.com/2012/08/10/us-reaches-50-gw-of-wind-energy-capacity-in-q2-of-2012/#bstX2X19xVWKhJBK.99
[24]http://energy.gov/articles/energy-report-us-wind-energy-production-and-manufacturing-surges-supporting-jobs-and
[25] http://en.wikipedia.org/wiki/Wind_power
[26] Hattington/ Ktech Corp, Steve, and James Dunlop/ Florida Solar Energy Center. "Battery Charge Controller Characteristics in Photovoltaic Systems." IEEE AES Magazine Aug. 1992: 15-21. IEEE Explore. Web. 8 Nov. 2012. <http://ucf.edu>.
[27] http://www.atperesources.com/PVS_Resources/PDF/ChargeControllerProfiles
[28] Microelectronis Circuit Analysis and Design, 4th ed, Neamen
[29] http://services.eng.uts.edu.au/~venkat/pe_html/ch07s1/ch07s1p1.htm
[30] “Boost Converter Operation.” LT1070 Design Manual, Carl Nelson & Jim Williams
[31] http://www.ti.com/lit/an/snosb84b/snosb84b.pdf
[32] http://ptm2.cc.utu.fi/~ptmusta/kuvat/elektroniikka/mc34063/IEEEXplore.pdf
[33] http://www.linear.com/product/LT1160
[34] http://www.windynation.com/articles/charge-controller/wind-turbine-dump-and-diversion-loads-what-they-do-and-how-choose-right-s
[35] http://bama.ua.edu/~bwbuckley/projects/mppt.html
[36] http://www.allegromicro.com/Products/Current-Sensor-ICs/Zero-To-Fifty-Amp-Integrated-Conductor-Sensor-ICs/ACS712.aspx
[37] "MAXIMUM POWER POINT TRACKING". qwiki.com. Retrieved 2011-06-10.
[38] http://www.dimec.unisa.it/leonardo_new/en/mppt.php
[39] Hohm, D. P.; Ropp, M. E. “Comparative Study of Maximum Power Point Tracking Algorithms.” *Progress in Photovoltaics: Research and Applications*, vol. 11, pp. 47–62, June 2002.
[40] https://www.sparkfun.com/products/11021
[41] http://arduino.cc/en/
[42] http://www.microchip.com/pagehandler/enus/family/16bit/architecture/pic24f.html
[43] http://www.altadox.com/lcd/knowledge/lcd_display_types.htm
[44] http://learn.adafruit.com/tmp36-temperature-sensor
[45] http://www.maximintegrated.com/datasheet/index.mvp/id/2738
[46] http://www.netduino.com/netduino/specs.htm
[47] Spotnitz, R.; Franklin, J. (2003). "Abuse behavior of high-power, lithium-ion cells". Journal of Power Sources (Elsevier) 113: 81–100. doi:10.1016/S0378 7753(02)00488-3
[48]Coppez, G.; Chowdhury, S.; Chowdhury, S.P.; , "The importance of energy storage in Renewable Power Generation: A review," Universities Power

Engineering Conference (UPEC), 2010 45th International , vol., no., pp.1-5, Aug. 31 2010-Sept. 3 2010
[49]http://batteries.batterymart.com
[50]K.C.Divya and J.Østergaard, "Battery energy storage technology for power systems—An overview", Electric Power Systems Research, Vol.79, No.4, pp.511-520, 2009.
[47] http://www.sunwize.com/index.cfm?page=product_successstories&crid=22&scrid=336
[48] http://solarelectricityhandbook.com/solar-angle-calculator.html
[49] http://upgi.com/Themes/leanandgreen/images/UPG/ProductDownloads/D5745.pdf
[50] http://electricalplan.blogspot.com/2008/10/power-inverter-dc-ac-definition.html
[51] http://www.windynation.com/manuals/300-watt-dump-load-12-volt-technical-specification
[52] http://www.youtube.com/watch?v=fkook28HhWI
[53] http://www.wind-works.org/articles/PowerCurves.html
[54] NASA SSE website (n.d).http://eosweb.larc.nasa.gov/sse/
[55] Wind Powering America (n.d.). http://geocommons.com/maps/67683
[56] www.eia.gov/electricity/sales_revenue_price/xls/
[57] Godfrey, E. (February 24th, 2012). What is a Cost-Plus Pricing Strategy? http://smallbusiness.yahoo.com/advisor/cost-plus-pricing-strategy-120017163.html
[58] ENERGY STAR Building Manual (July, 2007). Chapter 3: Investment Analysis [Adobe Digital Edition Version].
[59] U.S. Department of Energy (January, 2012). Rulemaking overview and preliminary market and technology assessment: energy efficiency program for consumer products: Set-top Boxes and Network Equipment [Adobe Digital Edition Version].
[60] Database of States Incentives for Renewable & Efficiency (DSIRE). (2012). Financial Incentives. http://www.dsireusa.org/incentives/
[61] EnergyBible.Com (2012). Solar Panel Manufacturers. http://energybible.com/solar_energy/Solar%20Manufacturers.html
[62] http://www.sunstone.com
[63] http://www.smps.us/pcb-design.html
[64]http://www.radio-electronics.com/info/electronics-design/pcb/pcb-design-layout-guidelines.php

Appendix B: Copyright Permissions

eia.gov

Figure Permission

jingzou

Sent: Tue 10/23/2012 2:15 PM

To: 'infoctr@eia.gov'

Hello EIA,
I am in an electrical engineering senior design class at the University of Central Florida in Orlando, FL. I am currently working on creating an integrated renewable power system controller for my senior design project and I would like to request permission to use three of your graphs in our documentation. I would like to request permission to use the "**Monthly Consumption of renewable and nuclear energy, Jan 2003 - Apr 2011**" , "**Monthly Consumption of renewable energy by fuel type, Jan 2000 - Apr 2011**", and "**Monthly Electricity generation from nuclear and renewables, Jan 2003 - Apr 2011**" from the following pages:
http://www.eia.gov/todayinenergy/images/2011.08.01/nukerenewtop.png, and
http://www.eia.gov/todayinenergy/images/2011.08.01/nukerenewelec.png.

Please let me know if we would have permission to use these figures for a strictly academic and informational purpose in our project research documentation. Thank you.

Sincerely,

Jing Zou
Undergraduate Student
Electrical Engineering Department
University Of Central Florida

RE: Figure Permission

InfoCtr (OC) <INFOCTR@eia.gov>

Sent: Wed 10/24/2012 9:41 AM

To: 'jingzou@knights.ucf.edu'

Dear Jing Zou:

Thank you for your inquiry to the U.S. Energy Information Administration (EIA) concerning use of information on our website.
There is no copyright restriction on the use of those graphics.

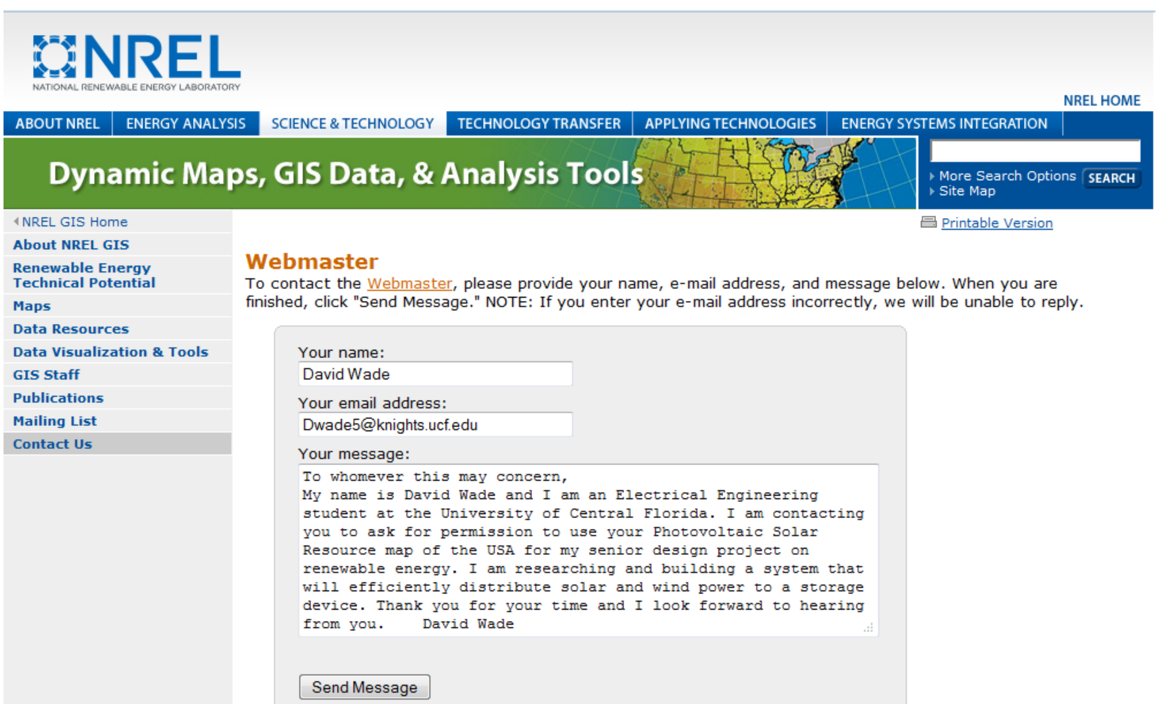
Please see our reuse and copyright info at:
http://www.eia.gov/about/copyrights_reuse.cfm

I hope this information helps. Please contact us again if you need further assistance with energy data and statistics.

Paul Hesse
Z Inc., Contractor to the
Office of Communications
U.S. Energy Information Administration (EIA)
www.eia.gov

To receive notifications of EIA data and report releases via email, subscribe at:
http://www.eia.gov/tools/emailupdates/
and/or follow us on Twitter: @EIAgov

NREL.gov



Solar power information > Inquiry

John den Haan [john@den-haan.nl]

Wednesday, October 31, 2012 9:15 AM

To: Dwade5@knights.ucf.edu

On 29/10/2012 5:47 AM, Dwade5@knights.ucf.edu wrote:

> Name: David Wade
>
> Email: Dwade5@knights.ucf.edu
>
> Message: To Whomever this may concern,
>
> My name is David Wade and I am a senior EE student at UCF. I am building a power generator that utilizes both wind and solar for my senior design project. I would like to ask for your permission to use your figure that displays the response of the solar cell to varying temperature for my report. Thank you very much for your time and I hope to hear back from you.
>

No worries, these are public domain images.

American Technical Publishing americantech.net

Copyright Permissions. - Message (HTML)

To... jdh@AmericanTech.net

Subject: Copyright Permissions.

Hello David Holloway,

My name is David Wade and I am an electrical engineering student at UCF. I am building a renewable energy power generator that integrates both solar and wind for my senior design project. I would like to ask for permission to use the profile graphs of the shunt and series controller. I am not sure which book they came from but here is the website I found them at. http://www.atperesources.com/PVS_Resources/PDF/ChargeControllerProfiles.pdf
There will only be one copy of my research report and it is just for the research on my project. Thank you for your time and I hope to hear back from you.

David Wade
Dwade5@knights.ucf.edu

jdh@AmericanTech.net

J David Holloway [jdh@americantech.net]

Monday, November 19, 2012 1:48 PM

Actions

To: dwade5 [dwade5@knights.ucf.edu]

Thank you for your request. You may use the materials from Photovoltaic Systems in your research project. This is for single use and not to be distributed.

We appreciate your use of ATP publications.

David

J. David Holloway

Senior Vice President

American Technical Publishers, Inc.
10100 Orland Parkway
Suite 200
Orland Park IL 60467-5756

1-800-323-3471
708-957-1100 (Phone)
708-957-1101 (Fax)

www.go2atp.com

2:20 PM

Creative Commons

HyperPhysics

Re: Copyrights: RMS Ripple Voltage graph

Rod Nave [rodnave@gsu.edu]

You replied on 12/3/2012 9:20 AM.

Sent: Mon 12/3/2012 9:19 AM

To: Julio F Lara

Hello, Julio,

You are welcome to use anything from HyperPhysics for purposes of your academic work. Best wishes with the paper.

Regards,

Rod Nave RodNave@gsu.edu
HyperPhysics Project
Department of Physics and Astronomy
Georgia State University
Atlanta, GA 30302-4106

On Dec 3, 2012, at 1:16 AM, Julio F Lara wrote:

Dear Dr. Nave,

I'm working on my senior design project, and part of the project is the research and documentation of the project.
I found a very good image from HyperPhysics that I would like to add to my research paper.

Would you please grant me permission to use your image for my project.

Below is the link to the article where I found the image from HyperPhysics.
http://hyperphysics.phy-astr.gsu.edu/hbase/electronic/rectct.html#c5

Figure 3.26 Permission Granted

Description	A coloured drawing of the front of a TO-220 transistor package
Date	26 March 2007
Source	Own drawing, done in Inkscape
Author	Inductiveload
Permission (Reusing this file)	I, the copyright holder of this work, release this work into the public domain. This applies worldwide. In some countries this may not be legally possible; if so: *I grant anyone the right to use this work* ***for any purpose****, without any conditions, unless such conditions are required by law.*
Other versions	Line drawing

State Energy Conservation Office

RE: Copyrights: Wind turbine mechanism Image

Juline Ferris [juline.ferris@cpa.state.tx.us]

Sent: Mon 12/3/2012 5:13 PM

To: Julio F Lara

First Previous

You have permission to use the wind turbine picture referenced below.

Regards,

Juline Ferris
Program Specialist, State Energy Conservation Office
Texas Comptroller of Public Accounts
LBJ State Office Building
111 E. 17th Street #1118
Austin, TX 78701
512/936-9283
Fax: 512/475-2569
http://www.seco.cpa.state.tx.us/

Dear Juline Ferris,

I'm working on my senior design project, and part of the project is the research and documentation of the project.
I found a very good image from www.energyeducation.tx.gov that I would like to add to my research paper.

Would you please grant me permission to use your image for my project.

Below is the link to the article where I found the image from www.energyeducation.tx.gov.
http://www.energyeducation.tx.gov/renewables/section_4/topics/windmills_or_turbines/e.html

Best Regards,

Julio F Lara

Copyrights: Infographic

Julio F Lara
Sent: Mon 12/3/2012 12:44 AM
To: 'websupport@awea.org'
Cc: Julio F Lara

Hi,

I'm working on my senior design project, and part of the project is the research and documentation of the project.
I found a very good image from the AWEA that I would like to add to my research paper. Would you please grant me permission to use your image for my project.

Below is the link to the article where I found the image form the AWEA.

http://cleantechnica.com/2012/08/10/us-reaches-50-gw-of-wind-energy-capacity-in-q2-of-2012/
http://www.powerofwind.com/uploads/files/INFOGRAPHIC_AWEA.jpg

Best regards,
Julio F Lara

Dear bufalo_jl,

yes

- billydan2011

From: bufalo_jl
To: billydan2011
Subject: Other: bufalo_jl sent a message about WIND GENERATOR TURBINE WINDMILL -NEW ITEM Workhorse 250 pvc #140870866708
Sent Date: Dec-02-12 22:02:46 PST

Dear billydan2011,

Hi,

I'm working on my senior design project, and part of the project is the research and documentation of the project.
Your item can potentially be acquired for our project.
For illustration purposes I would like to add the picture of your item for the research part of our project

Would you please grant me permission to use your image for my project.

- bufalo_jl

WIND GENERATOR TURBINE WINDMILL -NEW ITEM Workhorse 250 pvc	
Item Id:	140870866708
End time:	Dec-19-12 03:05:41 PST
Seller:	billydan2011 (295)
	98.8% Positive Feedback
	Member since May-28-11 in United States
	Location: FL, United States
Listing Status:	This message was sent while the listing was **active.**

Green Energy Star

[GreenergyStar Grid Tie Inverter, Grid Power III 600W, For Solar & Wind Hybrid Systems] Your message has been correctly sent

GreenergyStar Grid Tie Inverter, Grid Power III 600W, For Solar & Wind Hybrid Systems [info@greenergystar.com]

Sent: Mon 12/3/2012 1:08 AM

To: fbufalo@knights.ucf.edu

Your message has been correctly sent to our Customer Service.

Your message: Hi,

I'm working on my senior design project, and part of the project is the research and documentation of the project.

Your item, Apollo 550W , can potentially be acquired for our project.
For illustration purposes I would like to add the picture of your item and the "Voltage and amp vs RPM" graph for the research part of our project

Would you please grant me permission to use your image for my project.

We will answer as soon as possible.

GreenergyStar Grid Tie Inverter, Grid Power III 600W, For Solar & Wind Hybrid Systems powered with PrestaShop™

https://www.sparkfun.com

SparkFun product photo permission

castex

Sunday, December 02, 2012 11:40 AM

To: marketing@sparkfun.com

Good morning SparkFun staff, my name is Karel Castex and I'm a Computer Engineer student at Universal of Central Florida. At the moment, I'm doing my senior design project or my graduation thesis and I would like to as for permission of using the ACS712 breakout board picture located at (https://www.sparkfun.com/products/8882). The sensor is aimed to be the current sensor to be used in our project. Thanks in advance,

Karel Castex

http://scienceshareware.com

CLSA2CD Sensor picture permission

castex
Sunday, December 02, 2012 11:45 AM

To: bdwhaley@scienceshareware.com

Good morning, my name is Karel Castex and I'm a Computer Engineer student at Universal of Central Florida. At the moment, I'm doing my senior design project or my graduation thesis and I would like to ask for permission of using the CLSA2CD Sensor picture located at (http://scienceshareware.com/how-to-measure-AC-DC-current-with-a-hall-effect-clamp-.htm). The picture is the first from top to bottom and it is aimed to be an alternative of current sensor to be used in our project. Thanks in advance,

Karel Castex

Adafruit Industries

Adafruit Industries
150 VARICK ST
NEW YORK, NY 10013
Fax: (917) 210-3397
Tel: (646) 248-7822 ***no phone orders**

Please note:
Adafruit **does not** have a retail store**, orders cannot be picked up**.
Our factory is **not accessible** for visitors at this time.

If you need technical support for your purchase please visit the Adafruit customer support forums. We have a dedicated staff of engineers in our customer support forums who can assist you immediately. Our engineers can answer your questions and assist you 24/7 in the Adafruit customer support forums.

Contact Us

* Required information

Full Name: *
Email Address: castex@knights.ucf.edu *
Confirm E-Mail: castex@knights.ucf.edu *

Category: Press / media inquires

Please supply a detailed description of your Press/Media inquiry.

Good morning adafruit staff, my name is Karel Castex and I'm a Computer Engineer student at Universal of Central Florida. At the moment, I'm doing my senior design project or my graduation thesis and I would like to as for permission of using the TMP36 picture located at (http://learn.adafruit.com/tmp36-temperature-sensor). The picture is the second from top to bottom and it is aimed to be the temperature sensor to be used in our project. Thanks in advance,

Karel Castex

SEND

Copyright permission request

jingzou

Sent: Mon 12/3/2012 3:10 PM

To: 'isidor.buchmann@cadex.com'

Hello Cadex Electronics,
I am in an electrical engineering senior design class at the University of Central Florida in Orlando, FL. I am currently working on creating an integrated renewable power system controller for my senior design project and I would like to request permission to use one of your graphs in our documentation. I would like to request permission to use the " Charge stages of a lead acid battery" from the following page: http://batteryuniversity.com/_img/content/clead1.jpg.

Please let me know if we would have permission to use these figures for a strictly academic and informational purpose in our project research documentation. Thank you.

Sincerely,

Jing Zou
Undergraduate Student
Electrical Engineering Department
University Of Central Florida

http://upgi.com

Copyright Permission Request

jingzou

Sent: Sun 11/25/2012 12:05 AM

To: 'sales@upgi.com'

Hello UPG,

I am in an electrical engineering senior design class at the University of Central Florida in Orlando, FL. I am currently working on creating an integrated renewable power system controller for my senior design project and I would like to request permission to use one of your picture in our documentation. I would like to request permission to use the **"UB12180"** from the following pages: http://upgi.com/Themes/leanandgreen/images/UPG/ProductImages/D5745.jpg.

Please let me know if we would have permission to use this figure for a strictly academic and informational purpose in our project research documentation. Thank you.

Sincerely,

Jing Zou
Undergraduate Student
Electrical Engineering Department
University Of Central Florida

Appendix C: Figures

Appendix D: Tables