Senior Design I
Group VI

STOG
(Solar Tracking pOwer Generator)

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II. Executive Summary

The technical narrative set here describes the process from design to initial prototyping stages of the STOG unit (assembled from letters of Solar Tracking pOwer Generator) undergone by Senior Design Group 6 as part of the noble task of bringing an ecologically unobtrusive version of the 21st century to the sunny outdoors. The team set forth to create an efficient source of energy within a portable module that would enable the user to power up moderately demanding electronic equipment for extended periods of time by harnessing the boundless energy of the sun as the solar panel attached atop the module follows the sun's effulgence across the sky.

I.1 Project Narrative Description

The Group intends to design and build a successfully operating portable solar-powered generator with source tracking capabilities that will charge a battery and possess a useable power output for electronic devices; with the ability to power moderately demanding devices for extended periods of time as part of a charge-discharge cycle involving the battery and an AC 120V output. The main criteria in the development process being dealt with here, is addressing engineering problems regarding renewable and sustainable energy, with an efficient solution utilizing the unbounded energy source that is the sun.

Solar Power, a green energy resource that due to recent technological developments has grown exponentially in economical and industrial feasibility, will be harnessed by the proposed device. With a particular feature that will enable the piece of equipment to track its feeding light source (which for optimal design goals and operating conditions, is intended to be the Sun) through the use of Servo motors on a rotating platform, light absorption, and therefore potential output, will be greatly increased. The motors will rotate a platform attached to a slanted Photovoltaic (PV) Panel rated at 60W/12VDC specifications on a single axis of circular rotational motion. The driving design objective behind the rotational component is to manage to keep the Panel in as close to a right angle with the sun at all times; thereby, minimizing the angle of incidence between the two as much as possible, with the least amount of power expenditure required in moving the tracking component. As the gathered research in the second chapter of this document will show –in the portion dedicated to Solar Tracking-, having the largest possible surface area of the Photovoltaic Panel facing the sun at all times will keep the amount of energy being absorbed from the sunlight at the highest possible level.

The Maximum Power Point Tracking (MPPT) circuit will serve as interface between the power input and the energy storage unit (the battery) to attain the maximum possible power efficiently from the PV Panels. It will do so by sampling

the panels' output and applying the proper resistance by essentially defining the amount of current the inverter should draw from the panels to the 12V battery.
For the ultimate controlling agent for module operations –quite literally the brains behind the operation-, there is the need to design and assemble a Microcontroller Unit (MCU) that will control several different operations within the device's varied range of operation/functionality. Among various inputs being handled by the Microcontroller Unit, a tracking component (essentially a photoresistor circuit) will feed its response as it tracks the light source, which will cause it to adjust for movement of the Motor and Motor Controller components to keep the Solar Panel facing the light source.

The MCU will also be in charge of Load Control monitoring duties, and will be programmed to measure input from a Voltage/Current sensor and battery, outputting visual feedback through an LCD Information Display in response to the measurements. The Information Display component included with the Module's design will serve to relay in a visual manner to the user such information as present battery charge, solar input being fed through the device, and temperature conditions through different components.

At one end, the planned design calls on inserting a rechargeable lead acid battery (this is our present choice for budgetary issues, but we remain amenable to the possibility of trading up to a Lithium Iron Phosphate, or LiFePo, battery of much higher quality and operative capabilities, even though it is still a maturing technology, not compatible with most charge controllers, which often do not have the correct set points for proper charging
[AE1] for prolonged service to the user's chosen devices, that will also be connected to a DC/AC Inverter. This component will feature Oscillator circuits, Low Pass Filters, and will successfully utilize a step up transformer to increase the 12V output from the battery up to a 120V AC output manipulated into a Pure Sine wave.

As preliminary research has yielded that Photovoltaic Panel temperature may directly impact device efficiency, more in depth research is currently underway on the group's behalf covering a vast range of cooling technologies/features and their actual possible impacts to the device's overall efficiency and ultimately project budget. The interest in this area has been peaked by the design possibilities that would entail attaching a liquid-cooling component implementing a system of small hoses and a small pump/radiator, but –again- the research needs much further elaboration not only pertaining the true impact of such a device on the module, but also the individual components' true susceptibility to temperature gradients, and therefore true feasibility of even considering such a component in pure practicality terminology.

The use of heat sinks has also been decided by the group to help defer circuitry overheating, and a viable encasing is undergoing design alterations that will enable the use of a fan for cross ventilation on the components and still keep the portability feature of the piece of equipment intact.

I.2 Motivation

I.2.a Modernizing the Outdoors

The initial motivation when the design for the project was first settled on, was the simple task of bringing the 21st century to any and all outdoors activities/situations/scenarios. This is a device that may be used to make life more convenient for the user wherever life might take him, by allowing him to bring along any of the electrically-powered amenities of in-home living without having them be rendered useless by the lack of said power. As a tour de force, it is not only about bringing the functionality of the 21st century to the outdoors, but also about bring a modern mindset along with it. The design calls for an environmentally-friendly commodity that will ease the city-slicker's path through the woods, enhance the next-generation tailgater's experience, and help the victim during a natural disaster, or simply the next mid-summer outage.

The point is: humans have evolved to feel the need to reside within enclosed dwellings because of the amenities they may once only have been able to enjoy within such. This innovative approach is about performing a service by unleashing that small untamed beast still dwelling deep within, and allowing him to come out to play… comfortably.

I.2.a A Greener Planet

It's in your presidential elections (whether being purposely downplayed by one side, or portrayed as an apocalyptic monster by the other), in the morning radio show, your co-workers' water-cooler banter, your neighbor's bumper sticker, and is now even following you home with your kid's new science fair project:

→The environment is suffering←

Because of modern humans' tendency to exploit all available resources with reckless disregard for non-personal well-being, the so-called carbon footprint is starting to kick back, and it is all the rage to do something about it now a days.
This product is designed to allow the costumer to rejoice in all the materialistic technological evils unleashed upon the world by a capitalist machine, at zero cost to the environment; somewhat similar to "the same coke taste without the calories".

The world's population recently the hit the 7 billion inhabitant population milestone, which only serves to magnify the importance of developing these so-called "green energies" and utilize more of our renewable resources in energy production, manufacturing, and daily life, in order to come closer to achieving a sustainable symbiosis with the Earth where a mutually beneficial relationship may flourish. By 2025, census experts foresee a 2.85 billion [AE2] increase in population on our planet; by which time, mitigating actions must be enacted to continue our prosperous existence on this planet regarding overuse of resources, climate change, deforestation, climate change, H2O supply shortages, and most important of all, energy policies and green technologies' advancements. The energy field alone needs such an empirical boost, because by these calculations, the Earth's population will have grown over an estimated 40% in the next 15 years. With this growth, the per capita energy expenditure will also exponentially increase, as our lives continually grow to revolve more and more around power-consuming activities/environments/lifestyle; thus, fueling a sense of urgency to further develop not only Solar Power, but also Hydrogen Fuel Cell technologies, Ocean Thermal Energy Conversion and Hydro-electrical technologies, Tidal/Wave Power, Wind Power, Geothermal and Biomass power sources.
What this product does for the user is to allow him to give back to Mother Nature in the least painful way imaginable, and enjoy himself in the process.

I.3 Goals & Objectives

This project has been conceived –as aforementioned- out of the need for mainly a portable solar power generator with easy plug and play capabilities, but underneath lay numerous goals and objectives that have been set forth as part of the design criteria and development/prototyping procedures. As stated above, the main tangible outcome by which the product will be measured is actual electrical sustainability and prolonged operation of a moderately-demanding electronic apparatus, but the main focus behind this functionality will be efficiency across all its components in energy transference, storage, output, and most importantly production itself through correct design and implementation of an optimally-operating Maximum Power Point Tracking Unit, and a DC-AC Converter that –with ongoing design efforts- will ideally achieve a Pure Sine Wave. Also contributing to the efficiency of the module, will be the source-tracking functionality, which will enable the panel to absorb the maximum possible solar radiation for its power generation functions. This last functionality does not explicitly impact efficiency per se, but it does maximize power output from the panel, and as long as the motility components do not drain more power from the device that they help contribute, this should be a highly valued functionality in the product –further research and information on which, may be found in the pertaining Research portion on Chapter 2 of this document.

The other two specific main objectives lay with the Battery and AC Output components of the module. As the main goal is aimed towards the "plug and play" prolonged operation of an electronic device, the most important component there is the AC 120V outputs on the component, that will service a load as a regular wall-jack for ease of operation by the consumer, with an easy plug and play approach. However, a Solar Panel with dimensions as –relatively- small as the one that will be used in this project, could never power a moderately demanding device on a prolonged basis, much less multiple ones, which is where the battery component will come into play. The whole principle behind the system is to create a continuous charge/discharge operation state, where the panel will charge the battery at the same time that said battery is being drained by the device. For obvious reasons, the battery must first be charged to a certain point where it can feed a load and at the same time keep an acceptable charging cycle to the point it will not die out on the costumer after a short period of time. Once this level has been set after the testing stages of the prototyped module, this information can safely be provided to the costumer with operation instructions, where a simple reference chart will settle to which level the battery must be charged before safe electronic device operation may be handled; with an LCD visual output device serving to alert the user once said charge level is achieved by the battery.

Lastly, the marketable aspect of the module comes into play, as everything will be designed for encapsulation within a portable enclosure, that will present to the user the convenience of not only portability, but also an easy set up. The manufacturing process and design that was settled on by the group, is explained in depth in part 3 of the third chapter in this document, which deals with the actual design procedures.

I.4 Budget Projections

The group had an original calculation for the total budget to be spent on parts to sum up to $720. However, after careful deliberation and Advisor counsel, the budget was recalculated to cover various parameters. The problem with the original forecasting results was that it accounted almost exclusively for main parts and left no room whatsoever for any potential design problems and scope creep that might affect the design and prototyping procedures later on in the development phases. The budget did not account for miscellaneous parts to cover integration and possible damages of resistors and other small components; thus, not acknowledging that damages to small parts are prone to happen in prototyping R&D endeavors, and that small sums will amount to significant charges rather quickly. The original budget also failed to realistically account for shipping charges, which can become rather expensive when one is dealing with fragile electronic equipment, or potentially hazardous lead acid batteries, which the group found out during research procedures, are not shipped by all common logistics providers because of required licensing and specialized procedures/facilities to handle such dangerous materials. These specially certified handlers are called “contract hazmat shippers”, and have very restrictive guidelines on shipping different materials [AE3]. Amongst other unaccounted-for possible extra expenses, lay contract manufacturing work for the PCB’s and other transistor boards we might need, and the possibility that extra tools, design software, and/or other unforeseen manual labor that might fall outside the field of reference of the group members.

Once proper guidance and careful overview was provided however, the following chart was drafted and deemed to fully encompass most predictable charges that are bound to come up during the design and manufacturing procedures.

Initially Forecasted Budget		
Development Boards, Barebone PCB	…	$100.00
Photocell, resistor, inductors, transistors	…	$40.00
4-PHASE UNIPOLAR STEPPER MOTOR	…	$70.00
PV Panel	…	$300.00
Step-up Transformer	…	$100.00
12-Volt DC Battery	…	$100.00
System Cooling Features*	…	$100.00
Miscellaneous (tools and materials)	…	$100.00
Possible Design Software needed	…	$100.00
Total	…	$1010.00

Table 1- Initial estimates for costs agreed upon by group at the beginning of the semester.

At this point early in the design stages of the program, this revised budget has remained fairly steady and congruent to real values on most materials that have been decided upon. Please refer to the “Final Budget Approximation” section of this document in Chapter 7, for a closer approximation of what all materials will cost, with revised costs on already purchased/ordered items.

I.5 Project Block Diagram

The following “Block Diagram” portrays the division of responsibilities by specific components and functional groups amongst each of the group members. This is a representative repartition of administrative responsibilities by member, and is meant to provide accountability on each area of design and development, but in no way reflects complete partition of research/design/manufacturing duties as a whole per component, as this is a group effort that needs various frames of reference on input for the best possible design to be produced.

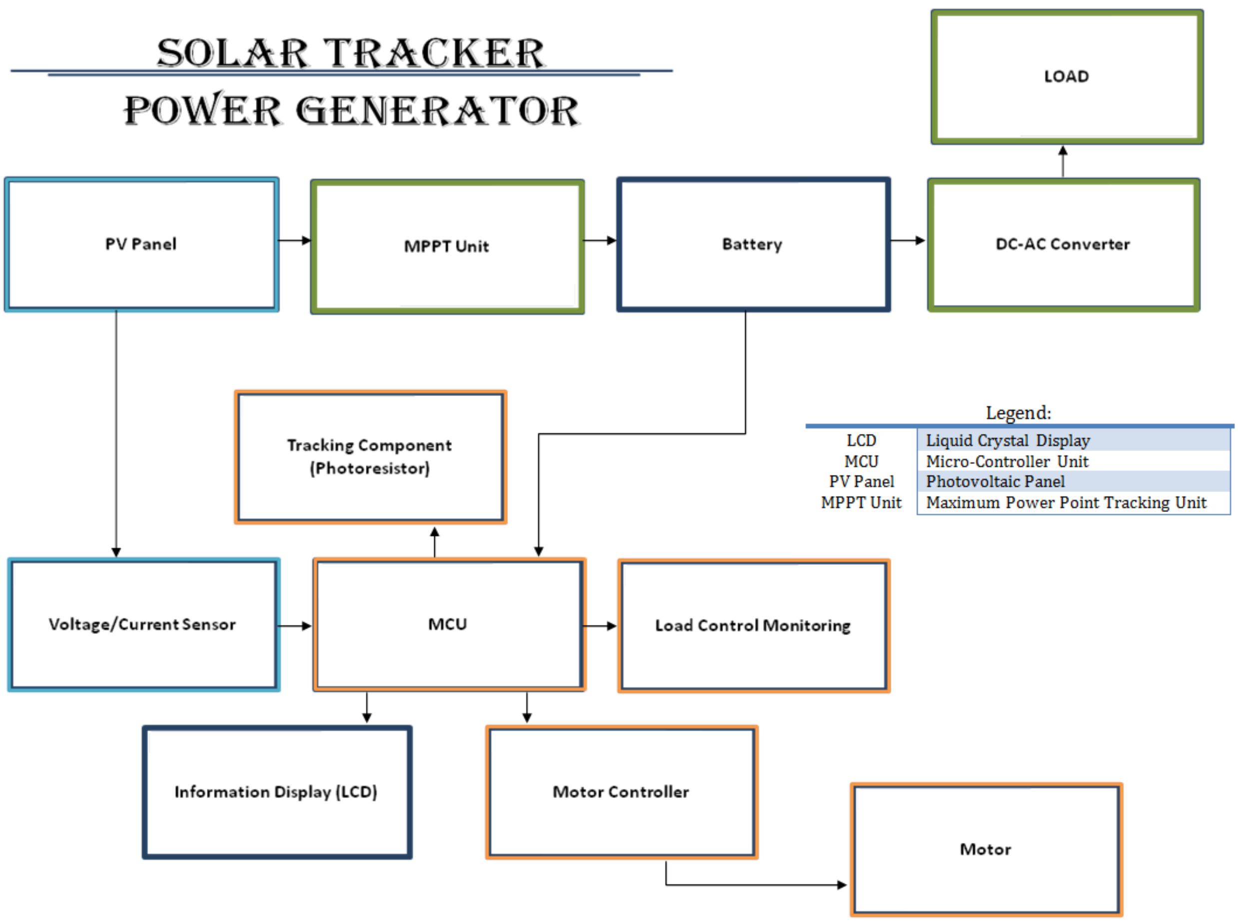

Figure 1 –Program Block Diagram

I.6 Project Timeline/Milestones

In the following section, the milestones pertaining Research efforts, Design Schedule, and Manufacturing responsibilities have been set forth. The group initially settled on a rather aggressive approach to the development process with main goals on sight of beginning prototyping efforts this spring semester. The goal was somewhat achieved, but several milestone problems did arise as delays and design complications affected the schedule.

The overall schedule is divided into Spring 2012 and Summer 2012 semesters, with the 2 weeks of mid-semester pause accounted for, as the group decided the design endeavor would not go passive for the break.

Spring Semester:

(Feb 13) Week 1: -Complete Group.
-Establish meeting frequency.
-Project Proposal Approval by Dr.Richie.
-Financial Backing proposals drafted and sent to any identified potential sponsors.

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(Feb 20) Week 2: -Set Milestones.
-Divide Research & Design efforts.
-Set Communication Procedures.
  -"GroupMe".
-Set File-Sharing resources/system.
  -"Dropbox".
  -GoogleDocs.
-Set a file scheme and logging system in information tracking among team members.
  -Set up Template for meeting minutes' & actions' logging procedure into 1 document for tracking porpuses; include:
    -Minutes
    -Paper Guidelines
    -Milestones
    -Table of Contents (draft)

(Feb 27) Week 3: -1st Prototype of Solar Tracker to be built.

(Mar 5) Week 4: -Ongoing Research endeavor.

-Research analysis:
  -Brainstorm.
  -Idea exchange.
  -Discuss any Design Changes.

(Mar 12) Week 5: -Follow up with potential sponsors on decisions.

(Mar 19) Week 6: -Financial Resources need to be decided going forward.
-Revisit Budget Forecast.
-MPPT circuit designed.

(Mar 26) Week 7: -Start filling product requisitions.

(Apr 2) Week 8: -Process Review.
-DC/AC Converter schematic finished

(Apr 9) Week 9: -Expand on Block Diagram
  -Ensure fluidity/Connectivity between components
  -Check on each component Status.
-Start defining assembly schedule.

(Apr 16) Week 10: -All material for Paper due for review/editing

(Apr 23) Week 11: -120 Page report completed.

MidSemester Pause:

(Apr 30) Week 1:

(May 7) Week 2: -Gather Total Size specifications.
  -Start estimating prototype dimensions/true picture

Summer Semester:

(May 14) Week 1: -Start programming of MCU.
-Start work on general product enclosure & battery casing.

(May 21) Week 2: -Start individual components' miscellaneous circuitry assembly.
-Start LCD Component programming.

(May 28) Week 3: -Individual Component Integration.

(June 4) Week 4: -Assembly should be completed.
-Start setting testing parameters .
note: (**Assembly procedures will be prolonged as needed, depending on assembly complications and shipment delays**).

(June 11) Week 5: -Testing Start.

(June 18) Week 6: -Root cause analysis and resolution of any complications.

(June 25) Week 7: -Product finalized.

(July 2) Week 8: -Website Finalized.

(July 9) Week 9:

(July 16) Week 10:

(July 23) Week 11:

(July 30) Week 12:

1.6.a Milestone Details

The following elaboration on the Milestone chart (refer to previous section) will flow on a weekly basis, with information on what was achieved per weekly meetings.

For week 1 on the timeline the group itself was set up, as well as the main idea for the project along with some initial design ideas and specifications, as the project began to take shape with each members' input. Meeting frequency and structure was set up, as well as information fluency guidelines, as well as the general task to refine design model into a more concrete idea. The action was made for a Project proposal to be drafted for Dr. Richie's review once all functionality was settled on, as well as the task for researching potential sponsors and beginning to trace and open lines of communication through which financial backing proposals could be sent.

During the second week, all research and design efforts were assigned to each group member, as milestones were created and a general workflow was established per component. Actions were followed up on to review potential sponsors, and the action stemmed for a concrete financial baking proposal to be drafted to begin approaching said potential sponsors. Information fluency was reviewed and possibilities examined with the following channels opened: a GroupMe account was opened for Senior Design Group #6, which itself consists of an app to reserve a permanent chat room for the members in the form of text messaging threads directly to each member's cellular phone, with the possibility to send map coordinates, pictures, and audio files for sharing among team members. Also, a "Dropbox" account was opened for the group to upload, organize, and share all files pertaining research, development, and general design process and group interaction to ensure information fluency and round the clock availability; a "GoogleDocs" page was opened as well, where members will be able to share links for research along with notes on different topics, all of which get updated to the word-processing file on a real-time basis, ensuring information fluency at its finest. A meeting minutes logging file "00. Meeting Info" was created and uploaded for all information to reside online, whether it be for meeting recaps or action accountability and record. In that same template, vital information for even workflow was decided upon and added; more respectively, a schedule for meeting frequency, the Milestone Scheme decided upon for the project, and a summary of paper guidelines for implementation, and at the end the section to keep an ongoing log of Meeting Minutes and Actions stemming from each.

On week 3, the first design/development Milestone was met when the 1^{st} prototype of the Solar Tracking Component was built and tested for optimal functionality. The group also met with Dr. Richie to review the general proposal, design ideas/features, and feasibility of each, as well as possible course of action on developing all aspect of the project further. Possible schematics for circuit design were also discussed, along with possible testing procedures/factors. The group was also given the go ahead to apply for the Progress Energy Funds allotted through Dr. Rilley, which were granted and now serve as the sole financial beneficiary to the product.

The fourth week was one of idea exchange to review current design goals, brainstorm on any new features called on, and to check on each member's progress regarding the research portion of the paper; with week five consisting of following up on any responses from possible financial backers.
During the sixth week of the Research and Development task, response was received confirming the availability/granting of the Progress Energy funds, which prompted a re-evaluation of the initial forecast, as well as a go-ahead for the design portion of the process, as financial matters cleared up. The MPPT circuit's functional design was also achieved during this week.

Week 7 brought about the start of product requisitions and general pricing research through different available sources. Between week 7 and 8 it was agreed that all members would be done with the research portion of the paper, as well as the MPPT circuit and sensors' general design schematics.

On week 9, the block diagram of the project was revisited, as the theme of auxiliaries and component integration came about, as members start looking into synergy between schematics and parts. Also, the milestones were revisited to start setting up a feasible assembly schedule that will allow for ample time at the end f summer semester for testing and root cause analysis and resolutions with any problems or scope creep that may emerge in the final prototyping stages.

As week 10 entered the picture, urgency was placed on finishing the Design portion of the paper, to start wrapping up all Design/Research summaries, and all material logging sheets with prices and specifications. All parts of the paper were grouped at the end of the week for start of integration/organization of final draft and paper review, with the final draft of the packaged paper and digital copy due on April 24th the following week.

During the 2 week Mid-Semester break, members of the group will start setting up reference frames taking into account physical specifications on parts bought and in transit, so as to start setting up a cohesive visual schematic encompassing the whole product for a full mental picture and somewhat of a physical representation of the finished module. Having a set picture of what to expect as a finished result, will aide in the speedy start of the actual prototyping process.

For the first week of Summer Semester, work should conclude on the programming of the MCU, and physical work on the general wooden enclosure of the module should begin and conclude. Fiberglass supplies should be arriving around this time fram, allowing for a slight slack in time for perfection of the process and manufacturing of the Circuitry Box and the over flap for the rotating platform enclosure tha will house our photovoltaic panel along with the motors and auxiliary hardware.

By the second week of the summer semester, circuitry assembly should begin across components, as milestones for general circuit design of individual components should have been completed by now. Also, during this week, time should be taken to start programming the LCD Visual Display unit for output of module readings at different components' status.

The third week of the summer should warrant circuitry building completion, leaving all completed individual components ready for integration. A plan for a visual schematic of where each completed component will go on the physical module enclosure should be reached at this point, allowing for encasing modifications were needed. These activities should be done this week, but have been given some slack to carry over slightly into the following one, by which point all required assembly for prototype completion should have come to an end, delivering as close to a completely functional solar tracking power generator as possible. The remainder of this fourth week of the summer semester should be taken for planning of testing parameters and conditions if all assembly has come to an end, even though, as aforementioned, a slight gap has been left in this strenuous development schedule to address any building difficulties that might be carried into this week, or the following.

The fifth week of the summer semester should see the start of implementation in testing plans, in test set up at minimum. Testing set up should at least start at this point, so as to enable the team to use the next 7 weeks (Summer semester weeks 6 through 12) to fulfill all testing necessities. As in all Research and Development procedures, the high probability of technical difficulties showing up at this point in the development process has been accounted for, and these last few weeks of the semester will be dedicated to not only testing, but to examine any problems that might come up, and analyze all Root Causes along with possible solutions to be implemented. In a parallel manner to Prototype finalization and design problem resolution and testing, website development should also be taking place during this last portion of the semester, so as to finalize all portions of the Senior Design Project deliverables on time.

1.7 Past Projects:

In this section, an insight into past projects working within the same subject matter area will be provided by inspecting their motivations and goals, and showcasing the functionality and priorities that set this project apart from the rest. There is an increased focus in efficiency on all aspects from production of energy all the way through minimalistic component energy expenditures. Also, the focus in this project on source tracking, portability functionality, and recreational applicability, do not seem to be present in past projects to this depth.

1.7.a Project Helios

Once we have defined our main goals and objectives of our project, there were certain areas which we had to research in order to come up with a proper design for our project. Some of these problems which we faced are whether to utilized a fixed solar panel mount on 1 axis of motion or use more of an actuation type system which will fully track the sun as it travels across the sky. Another problem which we are researching is whether to utilize a cooling system which can help regulate the panel temperature which will affect the efficiency of the panel.

While researching similiar projects we were able to come across "Project Helios" which was a project done in fall 2010 from Group 10. The main difference between our two projects is the scale of the projects. Their project is for commercial application, a solar array which is to be utilized by UCF specifically. By contrast our project is meant for a personal/recreational use of a solar power generator. However the projects shared some of the same goals and objectives which our project wishes to accomplish but we have plan to implement some other techniques which will provide for higher efficiency. Some of our similar goals are: high efficiency, solar tracking capabilities, DC to AC inverter.

We are still researching the benefits between a panel mounted at a fixed angle while rotating on one axis or whether to have a panel with a full 360 degree range of motion. In this previous project they implemented a fixed mount, rotating on 1 axis. NASA provides a tool which can calculate the optimal angle of tilt for a solar panel by using the exact latitude and longitude of the panel's location. Their calculated angle was 28 degrees, however where there project differs from our is that their project is for a stationary array of 12- 240W Mono-crysystalline panels. Since they have a proposed location for their array they are able to get an exact angle of optimal sun exposure. Our project will utilize one 60 W solar panel which is best utilized for it portability. Since the location of our panel will be meant for portability its given location will vary. Thus design a mount at a fixed angle may not be the most efficient way to mount our panel, thus justifying a design which utilizes more of a full range of motion and utilizes the panels solar tracking ability for the varying optimal sun exposure angle.

Due to the scale of their project they determined that a non-actuation system which was more cost efficient for them since they are creating a solar farm. However, the small scale of our project and the amount of motors needed to fully track the sun maybe be more beneficial for our goals and objectives. Although both actuation and non-actuation systems have their own draw backs which we will finally decide on later.

Another Difference in our designs is their use of an inverter. Since their project is meant for commercial use they determined it was best for them to purchase an already made inverter system. Due to our projects smaller scale and our budget, we determined it is in our best interest to design our own inverter. Since the application of their design is to produce energy for the campus as a whole, they utilized a grid-tied inverter which effectively sends the energy produced from the solar panels and send it back to the grid. This type of inverter is common amongst solar panel arrays used for residential and commercial projects and is cost effective since it is a battery-less system. This application does not make sense for our project because we are aiming for portability. We will have to determine the appropriate battery type and size to effectively store the energy produced from our 60 W solar panel.

The efficiency of Solar panels due to the physical temperature of the solar panel is a problem which this project had acknowledged but decided not to resolve due to its large scale. We are still researching whether a cooling system for our panel will increase its efficiency as the temperature rises or whether this change in efficiency is negligible.

1.7.b Universal Charging Friend

This project provided some insight on possible solutions for helping regulate the temperature of the solar panel. Since the solar panel outputs energy more efficiently while at a lower temperature and increase in sun exposure typically will cause the panels temperature to rise, a solution for this problem will result in higher efficiency. There are many possible solutions to cool our panels ranging from using a fan or running tubing with a cooling liquid along the back of the panel. This Universal Charging Friend project utilized a Heat Sink to help maintain the panel at a more optimal operating temperature. A finned heat sink was utilized in their design due to its durability and heat transfer characteristics. This technique would most likely be appropriate for our design, as it is most cost efficient and will also meet our goal of portability.

II. Research Portion

2.1 Solar Panels

Solar panel technology has come a long way since its functional creation in the early decade of the 1950's. They are made up of semiconductor material, which is the main driving force for solar energy production. When light reaches this semiconductor material –generally made from differently structures silicon, or other semiconductor materials-, the incoming photons from the light source excite electrons within the material, causing them to jump from the valence band to the conduction band. Once this happens, the electrons in the conduction band begin to move, thereby generating electricity. When electrons leave the valence band, there are positively charged holes now present. Since the valence band is no longer full of electrons, it will have an effect in the current flow. Typically most solar panels possess a range of efficiency within about 11-15%. The higher the efficiency, the less surface area you'll need in your solar panels. **[L3]** The project will focus on increasing this efficiency by implementing solar tracking, heat dissipation techniques and proper part selection. Since this technology is consistently improving and different materials are beginning to be implemented in the research and development industry with ever-improving results, careful scrutiny and selection of the best type of solar panel, which will be able to fulfill the goals and objectives of the project, is extremely important. There are numerous different materials which are currently being used in production of photovoltaic panels, including: monocrystalline silicon, polycrystalline silicone, amorphous silicon, cadmium telluride and copper indium selenide/sulfide. Some other methods/types of solar panel production designs include thin-film solar panels, dye-sensitized solar cells, and organic/polymer solar panels.

2.1.a Solar Radiation:

The amount of potential solar energy which can be produced by the panels will be based greatly on the amount of solar radiation which the panel will be exposed to from the sun. The figure below depicts an average approximation by region of the annual amount of solar radiation which the United States is exposed to. Solar panels will obviously be more effective in locations where radiation is higher, which results in providing the panels with a higher potential for solar power. These regional estimates for higher solar radiation however, are very much dependent upon the area's typical weather conditions and geographic locations. Areas with the highest average radiation exposure include the south-western portion of the United States, stretching gradually in a diminishing trend towards the northern and eastern regions, but keeping a higher average on its expansion in a north-eastern direction towards the middle of the United States. The irradiances can be measured in watts per square meter (W/m^2) or Kilowatt-hours per square meter-day (kW*h/(m^2*day)). Photovoltaic radiation exposure can be expressed in kWh/(kW_p*y) (kilowatt hours per year per kilowatt peak rating) [L4]. The figure below from the NREL (National Renewable Energy Laboratory) governmental institution, shows the amount of solar exposure which hits the United States annually.

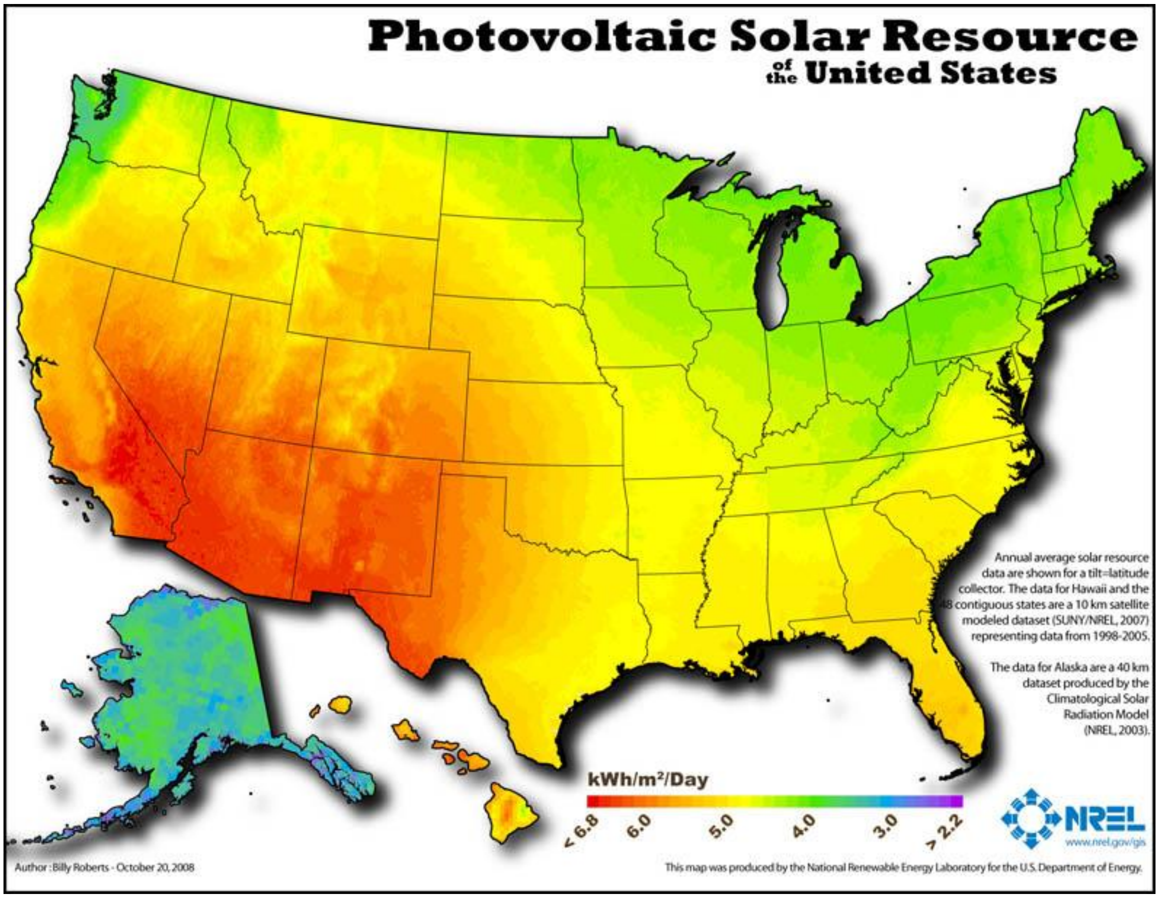

Figure 2 - Diagram of Solar Irradiance on US From http://www.nrel.gov/ (permission pending)

2.1.b Efficiency:

Solar power could potentially be the leading power source in today's world if the efficiency of the current solar power technology were better. Although around Earth's equator there is about 1000 watts/m^2 of solar energy continuously hitting the surface, only about 20 percent of this energy is able to be converted into actual usable energy.[L7] The amount of photons absorbed by solar panel installations directly effects the solar panels' inefficiency. Energy is only produced when a photon excites an electron in the semiconductor material of the solar panels and causes it to move into its conduction band. The photons will either be absorbed, reflected or can even pass right through the semiconductor.

2.1.c Types of Solar Panels

i. Silicon based solar panels:

i.a. Monocrystalline

Monocrystalline solar panels are the industry standard in production –regardless of production costs- and the most commonly used type of solar panel in the world. They are made from a single silicon crystal which is a more efficient production model than the newer generation of polycrystalline type of solar panel. This type of solar panel encompasses the first generation of photovoltaic technology and has tremendous durability and longevity. Typically, most monocrystalline solar panels experience an efficiency of about 22.5%. **[L5]** Although most other types of Solar panels suffer from efficiency loss due to higher physical temperature of the Panels, Monocrystalline panels experience less efficiency loss when compared to Polycrystalline panels. The fact that it is efficient and requires less space than other solar panel options to create the same amount of power, makes Monocrystalline panels an attractive choice to implement in design. Although it is the most efficient of the three types of solar panel technologies, it is also the most expensive; a factor that must be accounted for in feasibility for utilization on the product being designed here, which calls for remaining within the delicate balance dictated by the stringent budget that has been forecasted.

i.b. Polycrystalline

Polycrystalline solar panels on the other hand, are a bit less expensive but also slightly less efficient than the Monocrystalline panels. This is caused by the difference in how these panels undergo production. Polycrystalline cells are created by melting and cooling silicon into large blocks. Since they are not formed by one crystal but composed my many different crystals, this composite structure results in a less efficient product. A Polycrystalline panel only gets the equivalent of about 70% to 80% efficiency of a comparable Monocrystalline solar panel. **[L5]** Although these are less efficient, they are also simpler and less expensive to produce. The fact that the panels would cost less is somewhat negated by the fact that more panels will be needed due to its lack of efficiency. Among the crystalline Silicon solar panel options, Monocrystalline seems to have the edge.

ii. Thin Film Technology:

Thin film solar cells are created by placing the cells between two panes of glass. Both Monocrystalline and polycrystalline panels only use one pane of glass when being made. Thin film solar panels are twice as heavy as the crystalline counterparts, which is a big drawback for this specific project since one of the main goals is portability, making the choosing of this material purely based on physical properties somewhat counterintuitive. Thin film solar panels maintain a better performance record under hot and cloudy weather conditions, however; but these same thin film solar cells are also less efficient than monocrystalline panels, which makes them less desirable for any project shooting for efficiency. Another drawback of the thin film technology is that it would require a larger piece for increased area, to produce the same amount of power as a crystalline solar panel would a much smaller piece of equipment. [L5] The combination of needing greater area for the same power output, heavier weight, and lower efficiency are huge drawbacks when considering the application of a thin film solar panel for this project.

Amorphous Silicon Solar panels were the first thin film solar panels to be commercially produced. These use Amorphous Silicon material, which is the non-crystalline allotropic form of silicon. This type of solar panel is not prone to overheating though, which is a plus. These panels have 1/300th of the active material than in a crystalline silicon solar panel. **[L5]** Typically, this type of material is used for applications which require little power; however, advancements in this technology have led to the material being introduced into manufacturing procedures of solar cells. Although it lacks the efficiency characteristic of crystalline solar panels, its cost is very minute compared to the crystalline silicon panels. Its lower price is due to the fact that it only uses about 1% of the silicon required for a crystalline silicon solar cell. **[L5]** This technology is starting to be used for hybrid solar panels which incorporate applying coats of amorphous silicon onto monocrystalline panels.

Cadmium telluride Solar Panels utilize a different material than the traditional Crystalline Silicon based solar panels currently dominating the marker of photovoltaic panels. This new type of solar panel uses the new thin film technology and is based on the Cadmium Telluride semiconductor material. The need to develop a new, cheaper means of creating solar panels led to the creation of the Cadmium Telluride thin film solar panels. This new thin film technology uses lenses or mirrors to function as concentrators to enhance the solar panels’ exposure to the sun. This new technology aims to use less of the semiconductor material, which will in turn yield a cheaper and more affordable product. The best Cadmium Telluride solar panels achieve an efficiency of 16.5% at best. **[L6]** Another drawback of this type of solar panel versus a silicon based panel is that Cadmium Telluride is a hazard to the environment when it comes time to dispose of the panels, on the contrary from monocrystalline solar panels, which do not pose a hazard to the environment.

iii. Organic Solar Panel:

This type of solar technology utilizes conductive organic polymers to produce electricity from sunlight. The technology has been introduced just recently into the solar panel manufacturing industry, but is actively considered to be the next step in the evolution of the solar panel. These types of solar panels are becoming more and more efficient, due to evolving conditions/results continually being achieved. This is a new type of technology which is not yet found in the commercially manufactured solar panel gambit, which is most prevalent for public access. The optical absorption coefficient is particularly high in these types of solar cells; thus, these actually require much less material to generate the same amount of energy compared to traditional solar panel technologies. The organic solar panel can be very basic such as a single layer organic photovoltaic cell to a more complex bulk-heterojunction photovoltaic cell. **[L5]** Single layer organic cells do not work as well, as they boast very low efficiencies. These problems of efficiency led to the creation of multilayer organic photovoltaic cells, and much pressure for them to be produced and incorporated into the commercial marketplace. Although this new technology is very intriguing and could don this specific project with an innovative light, the likes of which has not been seen by past projects, obtaining an organic solar panel is rather difficult and expensive –if even possible at such early stages of technological development. Its lacking commercial production for this type of solar technology essentially has is rule itself out for use in the present.

2.2 Solar Tracking Approach

2.2.a Panel Exposure Angle

The angle in which a solar panel is installed can affect the amount of solar energy which will be produced by a system. A solar panel will more efficiently produce greater amounts of power when its orientation is exactly perpendicular to the light source feeding it. When considering our design, finding the optimal angle which the angle is to be set at for any given time is going to be important. This optimal angle depends on the geographic location of the solar panel and the current time of year. Solar panels mounted in the northern hemisphere are faced towards the south because of the sun's path in the sky. The panels are able to absorb more sun light when pointed in the south, set upon a variable incline, as opposed to being mounted directly east, west, or north. The angle of incline for a solar panel is dependent on the location of the solar panels. The path the sun takes around the planet will change, as will the magnitude of radiation exposure levels to which the solar panels implemented in this project will be exposed during the day.

When calculating the proper angle that will be needed according to positioning factors needed for specific conditions, one needs to mount the angle according to different important factors, including location upon the Earth, and the seasonal time of the year. The general advice here is that the angle of the panels relative to the horizontal plain should be the same as one's latitude in spring and autumn: 15 degrees less in summer and 15 degrees more in winter **[L1].**

Under this implementation, the angle at which a panel mounted on a unit being utilized in the Orlando area would be as follows in the chart below, all depending on time of year:

Fixed Angle (from horizontal) for Solar Panel in Central FL Area	
Summer	13˚
Spring/Fall	28˚
Winter	43˚

Table 2 –Central Florida Angle Generalizations

2.2.b Need for Solar Tracking

The use of solar tracking may possibly result in a more expensive assembly for the unit at hand, but the amount of extra power generated would be very much worth the expenditure.

A solar panel which is pointed towards the sun produces the most solar energy possible by a system, since a maximum input of radiation will yield a maximum output, as long as all other conditions are kept constant in making this comparison. Therefore a solar panel which tracks the sun is the most effective. There's a few possible approaches to the designing endeavor of the actual tracking portion. The panel can either be tilted at an angle –which equals the angle of incidence-, and consequently can be move on a single rotational axis to follow the sun from east to west. This method would only require one motor and would result in more efficient energy production than a fixed mount without solar tracking. A different method would not have the solar panel set to a fix mounted angle but would have a second motor to control its inclination to better track the sun. There are two methods which are being considered when implementing solar tracking. One is to utilize an Interval based Preprogrammed tracking system and the other utilizes photo resistors.

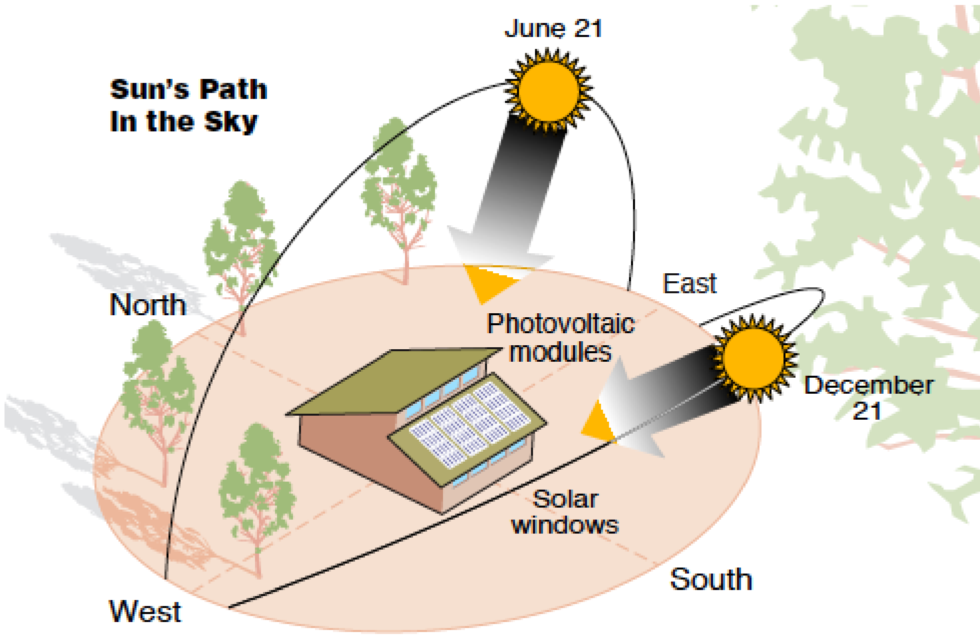

Figure 3 - Image courtesy of department of energy. [permission pending]

2.2.c Fixed Interval Prog Tracking System:

This method of solar tracking will utilize pre-calculated angles of rotation which the solar panel will adjust to at fixed intervals of the day. Since the sun rises and the east and sets in the west, placed at an overhead location at around noon, we can utilize pre calculated angles of the sun's orientation to track the star. These set angles can be programmed to a microcontroller which will enable adjustments of the solar panel depending of the time of the day. This method has the benefit of not utilizing a sensor which would present a higher cost into our expenditures and would additionally consume some of the panel's generated power. In order to calculate the correct angle which the solar panel is to be directed at, a few variables are to be considered: time of day, day in the year and physical location of our tracker. Once this is determined our microcontroller can be programmed to rotate the panel at preset time intervals and will optimize the power generated based on the trackers time and location.

2.2.d PhotoResistor-GuidedTracking Syst:

Photo-resistors possess the capability to convert luminescence from the sun and turn it into a voltage. Cadium Sulfide (CdS) is the most common semiconductor material which is used to make photo-resistors. In this method of solar tracking, we can utilize two photo resistors and compare their voltage output. [L11] Voltage output is dependent on the amount of light which is exposed to each photo resistor. By adjusting the orientation of our solar panel using a motor, our panel can be directly aligned with the sun's rays once the photo resistors output the same amount of voltage. This information can be fed back to the microcontroller unit which will utilize a motor to adjust the photo resistors so they have an equal voltage. This method will be carried out by implementing a voltage divider circuit with the photo-resistor. V_{out} is measured between two resistors which are in series from a V_{in} to ground. By the equation of

$$V_{out} = (R_2/(R_1 + R_2)) * V_{in}$$

Where one of the resistor in the equation is a photo-resistor. The purpose of this circuit is to have the motor move our solar panels in the direction of more light. That means that our V_{out} will increase with higher concentration of light for a given V_{in} and R. The image below depicts the anticipated circuit design of our Photo-Resistor circuit.

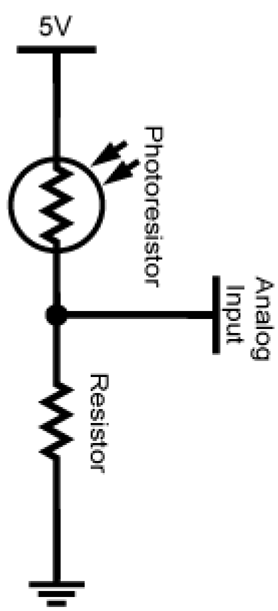

Figure 4 - This figure is of a basic Photresistor circuit. From *[/](#)* (permission pending)

2.2.e Infrared Camera Tracking Systems

A different type of tracking technique which could be applied to our design would be to use an Infrared Camera to track the sun. The IR camera can be mounted on the panels facing the same direction which the panels are pointing. By using a special algorithm in the MCU, it can determine the location of the sun by analyzing the IR image. We will then program it such that the source will be directly fit in the middle of the IR cameras image. If the sun is in any location other than the center of the image, the MCU will control the motor to tilt and rotate the panel such that the sun is in the middle of the image, thus acting as a tracking mechanism. IR cameras will also allow the solar panel to track the sun even when it is a cloudy day which would be very beneficial. When considering an IR camera to use in our design, the two main factors to would be price and size. Although the IR may be a very accurate way to track the sun, its price becomes completely unjustified if it can’t be used. Also, the camera must be of a very small height and of a very lightweight design, such that it does not place too much additional burden on the motors. We must also consider the fact that we are trying to expend the least amount of power to track the energy so that we don't lose efficiency charging our battery. Upon further research it was concluded that the IR camera will not be the most sensible solution as it is more expensive than our other options for solar tracking.

2.3 Temperature Monitoring Sensors

The physical temperature of our solar panel is of interest because as the temperature of the solar panel increases, the outputted energy coming from the panel decreases. Since we will be deciding on a method to help the heat transfer away from the solar panel, it is important for us to measure the solar panel's physical temperature to study the effects of our heat transfer method versus not using any sort of heat transfer alleviation. There are two techniques which could be implemented to monitor the temperature: a Thermistor, and what is know n as a thermocouple or Resistance temperature detectors

2.3.a Thermistor

A Thermistor is a thermal resistor which has a temperature dependant resistance. There are different response varieties with negative temperature coefficient thermistors and positive temperature coefficient thermistors. Some qualities of the thermistor make it a suitable candidate for the temperature sensing system of the project. Since it is just a resistor, it is relatively easy to water proof it which is desirable for the projects goals, as the module is intended for outdoor use. It will interface with a microcontroller, which makes it appealing;

as opposed to a thermocouple, which would require an amplifier to read the change in voltages. Thermistors also work within a range of about -90 degrees Celsius to 130 degrees Celsius –a temperature still suitable for our project's conditions. **[L13]** Their cheap price also makes thermistors a logical choice when concerning parts selection for the project. However, an analog to digital converter would have to be used to read the signals, and can be found on the microcontroller. In order for us to get a temperature reading from our thermistor we will have to create a circuit which will connect our Thermistor with another resistor in series, then measure the voltage in between them. The change in resistance caused by the change in temperature will in turn change the voltage in the circuit and by using a voltage divider equation we will be able to measure the temperature.

The voltage which is coming from the thermistor and connected to the analog pin of our microcontroller will be the determining variable which will give us our temperature reading. **[L16]** Assuming we are to use a 5V microcontroller, the formula which will give us our voltage at this pin is as follows:

Voltage at pin in mV = (reading from Analog input) * (5000/1024)

This formula will convert the number 0-1024 from the Analog input into a voltage ranging from 0-5000mV.
From this voltage reading we can convert it into a temperature by using the formula:

Centigrade Temperature = [(analog voltage in mV) - 500] / 10

To display this temperature in Fahrenheit, our coding will employ the following equation:

$$T_f = (9/5) * T_c + 32$$

Where Tf is the temperature in Fahrenheit and Tc is the temperature in Celsius.

2.3.b Thermocouple:

A different technology which can be used by our project is a Thermocouple which is made up of two different conductors which produce a voltage that is proportional to the temperature difference between each end of the conductors. They are most commonly used for measuring over a large temperature range. There are different types of Thermocouples, each one is calibrated to have a different temperature range and environment. The most common types of thermocouples are type J, K, T and E. There are also R, S, C and GB but these types of thermocouples are most commonly used for higher temperature calibrations. **[L17]** The diameter of the wire also contributes to the temperature range of the thermocouple. Since our application is to measure the temperature of the solar panel, it is important to determine the type of Thermocouple which best suits our expected temperature range. The following table contains common thermocouple temperature ranges which we can use to compare:

Thermocouple Charateristics Table			
Calibration	**Temp Range**	**Std. Limits of Error**	**Special Limits of Error**
J	0 °C to 750 °C	Greater of 2.2°C or 0.75%	Greater of 1.1°C or 0.4%
K	-200°C to 1250 °C	Greater of 2.2°C or 0.75%	Greater of 1.1°C or 0.4 %
E	-200°C to 900°C	Greater of 1.7 °C or 0.5 %	Greater of 1.0 °C or 0.4%
T	-250°C to 350 °C	Greater of 1.0°C or 0.75 %	Greater of 0.5°C or 0.4%

Table 3 –Thermocouple Characteristics Table

Of these types of Thermocouples, it is obvious that the type T thermocouple would be the most appropriate as the J,K and E calibrations measure extremely high temperatures that won't be experienced by our solar panel. The T type thermocouple also boasts the best standard limit of error of all of the thermocouples. **[L17]** A type T thermocouple is made up of copper-constantan. Upon further research of this technology and its availability. It price of $30+ is extremely high for a temperature sensor. Based on the temperature range that a Solar Panel would encounter and the high price of thermocouples, it can be concluded that the Thermocouple technology is not suitable for our project. One of their main limitations is that they have lower accuracy at measuring smaller temperature differences. The thermocouples inefficiency along with the fact that a $30+ temperature sensor cannot be justified leads us to the conclusion that they are not our best option for temperature measurement in our project.

2.3.c Resistance Temperature Detector:

Resistance temperature detectors (RTDs) also known as Resistance thermometers are a type of sensor which can relate the changer resistance of an RTD element and measure it's temperature. Most of which are made up by finely coiled write wrapped around a ceramic or glass core. The element which is used in the RTD is a pure material which has documented resistances at different temperatures. By knowing the elements resistance at different temperatures, it makes it possible to measure the temperature of element. The most commonly used materials of RTDs are platinum and nickel. By applying a voltage to the material, the electrons in the RTD material will move to the positive pole. The crystalline and atomic structure of these elements will impede the movement of the electrons. Since these atomic structures are independent of the Temperature, there is always a constant resistance. When the temperature of the material rises the atoms of the metal will begin oscillating about their rest position and will contribute to the resistance by impeding the movement of the flowing electrons. The oscillations of the atoms of the element which were at rest increase linearly with temperature. This will cause an increase in resistance and will be dependent on the change in temperature. RTD's have several advantages which include their high accuracy, wide temperature range, and precision applications. RTDs don't typically work well in temperatures exceeding 660 °C or in temperatures below -270°C. Since our expected temperature range is not an where near those temperatures, the RTD is still an option which is to be considered.

2.4 DC/AC Inverters

The dc to ac inverter is a device that converts a DC input waveform at 12 volts into a pure sine wave AC at 120 volts. Rating of a inverter is mainly produced by two main components, first: the input of the inverter rating, for example if it's being fed by a PV panel or DC battery, the rating of the PV panel/battery is used as the rating of the inverter because usually inverters are built with components that are rated far from its input incase short circuits occur.

The second main component is the inverter's transformer; a transformer is a device that changes electricity from a low voltage to a high voltage while it decreases the current. This method is very convenient as it decreases the current, it decreases heat and it will have less power loss on the power system, this technique is used a lot by power companies as they transport electricity from the power plant to homes and businesses. They same way a transformer increases a voltage it also decreases voltages depending on the set up, windings it's what directs if a transformer is a step-up or a step-down. Transformers can be handmade and what is needed for them to work is usually a non-magnetic core made out of steel or another metal, this core will transport the magnetic flux from one side of the transform to the end side in a circular form and, several hundred turns of isolated magnet wire the side of the transformer with the input voltage is usually called the primary and the side with the output voltage is usually called the secondary.

Transformers are usually rated to certain wattage depending on the core that it is made out of and the material used on the wires as well. Transformers also have internal impedance that at the end of the power calculation it has an effect on efficiency. Usually home-made transformers are not rated to work with high voltages usually over 30-40 volts because higher amounts of windings are required for this to happen, and most of the times higher amounts of windings are achieved by machines. The transformer's rating puts a limit on how big the load needs to be. A great amount of the dc/ac market claims to offer sine waves but these sine waves are “modified sine waves”, these are nothing but modified square waves, it is very easy to produce a square wave out of a dc input but just doing a couple oscillator circuits and connecting the transformers, the money-making trick in this industry is having a pure sine wave, and the advantage of a pure sine wave is that the inverter will have a longer lifespan also modified sine waves have a long term damaging effect on electronics, but most importantly it will have better efficiency, pure sine wave inverters have a better cost per unit power, based on purchased power charge, a kilowatt of electricity costs about 12-13 cents, this might not sound like a lot of money but electricity do add up and the most important part out a very efficient inverter is that electricity comes out free. Modified sine waves inverters claim to have an average efficiency of 85 to 90 percent but pure sine wave inverters have a 95 to 97% efficiency the difference in efficiency comes to heat and as the equations describes P=IR and current is what generates heat.

Total harmonic distortion plays a very important role in this specific project because what total harmonic distortion THD is a sum of the powers of all the components in the circuit and the less THD the inverter has, the more accurate it is in terms of efficiency, the average pure sine wave inverter has a THD of less than five percent. There are practically countless ways to achieve a full conversion of a dc to a pure sine wave, technology has advanced very much lately and there is quite a few ways to achieve this, up-to-date inverters are turning into using microcontrollers to fully regulate the ac signal and making the output of the inverter a fully functional pure sine wave at 60 hertz. Frequency it’s a major imaginary component of an inverter attaining the desirable 60 hertz can be tricky at times, before turning intro microcontrollers, inverters would use op-amps and low-pass filters to produce a sine wave, it has been seen some early sine wave conversions as far as 600 hertz to 1600 hertz of frequency. Dc/ac inverters were first introduced to the market to be used mainly in cars, now the principle as far as usage, is the same if it’s from a car battery or from a solar panel, it is just a DC input. Pure sine wave inverters at 60 Hz are priced accordingly to peak power capacity, this is usually in watts, more watts means that not only it’s rated for more power output but it has been made with more expensive parts. Prices do range a lot depending on the manufacturer, lesser known brands tend to be cheaper than more expensive brands. There are three main different types of inverters: compact mostly mobile inverters, heavy-duty and, inverter/chargers.

Compact inverters are usually rated with low continuous wattage output, ideally design to power electronic devices as an mp3 player, DVD player, Blu-Ray player, laptop computers, cell phones, and devices where amperage is usually fewer than 2 amps. Heavy duty inverters are usually used in workplaces, they are capable of handling larger currents, these types of inverters usually are connected to heavy-duty material as drills, saws and, pumps. Inverters/chargers are an innovation in technology in this industry, they offer reliable power as they charge the battery they are connected from at the same time, these types of inverters are used mostly connected to a continuous DC source but as the utility is absent the inverter automatically switches from utility power to battery power to continue the inversion, these types of inverters are used mostly in emergency vehicles. It is important to determine what type of inverter and the applications for it before buying or making one, inverter should have 9-16% output capacity greater than its inputs, this is because of the fact that some appliances and or motors do require a significant amount of current to start up. Another of the factors that need to be taken into account before building/choosing the inverter is voltage coming in, and understanding the desired voltage coming out of the inverter. Voltage in the United States and majority of the Americas is 120 V at 60 Hz, for example in Bolivia electric supply is at 220 Volts at 50 hertz so it is very important to understand what is needed from the inverter and the uses that it will have, that's why traveling is a very important factor. For a power inverter running time can be determined by the size of the battery that is feeding it. For example a large battery rated at 300 watts would off course let the user run the inverter for 300 watts meaning powering an object that uses 3 amps at 10 volts for 10 hours nonstop.

When it comes to power inverters, there three main types of inverters per say. Sine wave, Modified Sine wave and Square wave. Sine wave is typically what is used mostly throughout the world because it is the kind of wave that is produced mechanically in other words this wave is produced by generators and motors and is somehow natural, the way is distributed makes pretty much every electrical component around the world work perfectly fine, as explained before the only difference when it comes to sine waves produced by electric companies around the world is the frequency. Usually pure sine wave inverters cost from two to three times as much than modified sine wave inverters. Modified sine wave inverters are very popular in the market nowadays; pretty much the middle class consumer that has a power inverter is a modified sine wave. These kind of inverters are not as efficient as sine wave because of the fact that modified sine waves use about 20% more power than pure sine inverters, about 90% of regular consumer electronics will work fine with this kind of inverters, the only drawback is that synchronous motors, generators and a lot of three phase equipment won't work at the same rate, although one can obtain 50-60 Hertz of frequency on a modified sine-wave inverter depending if using a potentiometer or not it is said that a great percentage of the modified sine wave inverters in the market are well over 60 Hertz making a lot of equipment not work. Modified sine wave inverters don't have a synchronous wave meaning that there are parts of the actual wave operating at a different frequency as the capacitors charge and discharge, some of the effects are for example, making a blender rotate slower or faster timer chips might run faster or slower than usual and appliances like toasters might not be as hot. Square wave inverters are very old technology and the cheapest to manufacture, the advantage of a square wave inverter is that they will run simple things like universal motors with no problem. Meaning one and two pole electronics not three pole.

2.5 Maximum power point tracking aka MPPT

MPP (maximum power point) happens when the highest amount of power is obtained, and MPPT (maximum power point tracking) tracks and targets this quantity of power continuously while receiving different amounts of voltages and currents. Another function of a MPPT is to draw as much current and voltage from a PV panel, regulate it, and charge a battery to a point that keeps the battery fully charged, it measures the level of the battery so it won't overcharge because the battery will not only break but also its lifespan will become shorter if its overcharged over a long period of time. This device is new to the industry as it increases the efficiency of the current and voltage of a PV panel to a maximum, before the MPPT was designed PV panels were used but not as popular because of the fact that PV panels have varying voltages due to weather conditions. The main objective of the MPPT is to regulate both voltage/current so it can charge the battery efficiently; the MPPT would not charge a battery once the input voltage drops under the battery voltage, for example: if the PV panel is producing 11 Volts due to a clouds or weather conditions, even if its producing enough current to charge the battery it will not charge the battery, theoretically it should be able to by stepping up the voltage but majority of MPPTs in the market only have the step-down regulation feature on them, it only makes sense because in basics power systems when the voltage is stepped up, the current would be stepped down, and vice versa. Modern MPPTs with an efficiency of about 95% are costing nearly 100 dollars. Figure 5 shows a privately made MPPT and it costs 95 dollars, ideally made for applications in boats.

Figure 5 - shows a MPPT made by a private company. (Permission pending)[JO1]

If system is providing less current than what is needed for the MPPT to work but is providing just enough or more voltage than what the MPPT is charging, it will step down the voltage to the battery's rated voltage as it is stepping up the current so it will have just enough current to charge the battery. If the length of the wire is very long the wire size feeding and coming out of the MPPT has to be very large so it won't drop significant levels of voltage. MPPT's switches power to match varying impedances. Based on reviews in different websites MPPT's barely work in super hot conditions, reason that this happens is because voltage coming into MPPT might be same or less than what is require to charge the battery, at this point there would be little to no effect from the MPPT. Figure 7 shows two examples of an I-V current, the first one is raw voltage and current from a PV panel and the second one is same PV panel using a MPPT. Modern MPPTs found on the market are enclosed in plastic casings although it has holes for ventilation purposes. Inputs and outputs of MPPTs are with bolt lugs kind of what it's seen in the insides of an electrical panel board. Figure 6 shows distribution and usage of an ideal MPPT. The way this MPPT diagram works is that the MPPT circuit will sense both voltage and current from the PV panel and the heart of the MPPT will be a microcontroller that will perform and algorithm that will track, keep and, utilize the maximum power point, once this calculation is made, the MPPT will send a signal to the Voltage regulation circuit telling it what values of voltage and current to use throughout the entirety of the usage. A reliable microcontroller that has been used lately in the market is the MSP-430, also many MPPT algorithms use PIC microcontrollers; these microcontroller are loaded with an algorithm that will determine a maximum power and keep it as it mentioned above.

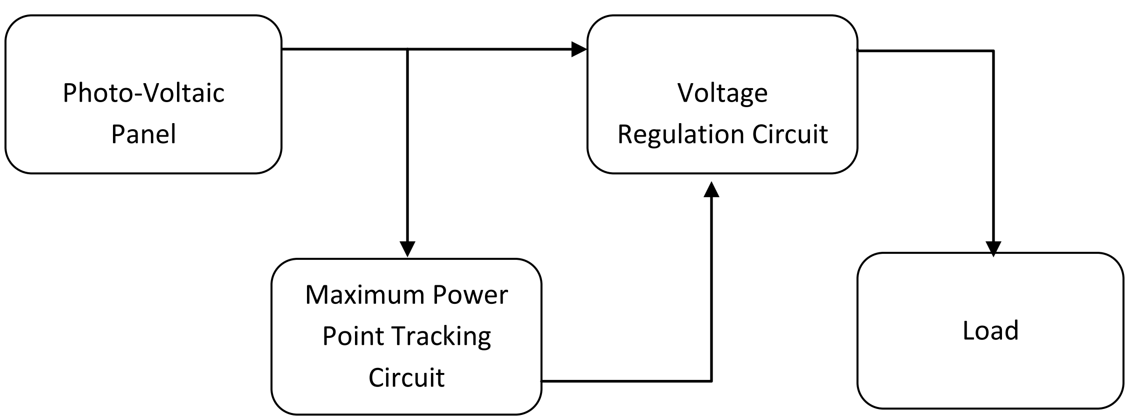

Figure 6- MPPT voltage/current flow

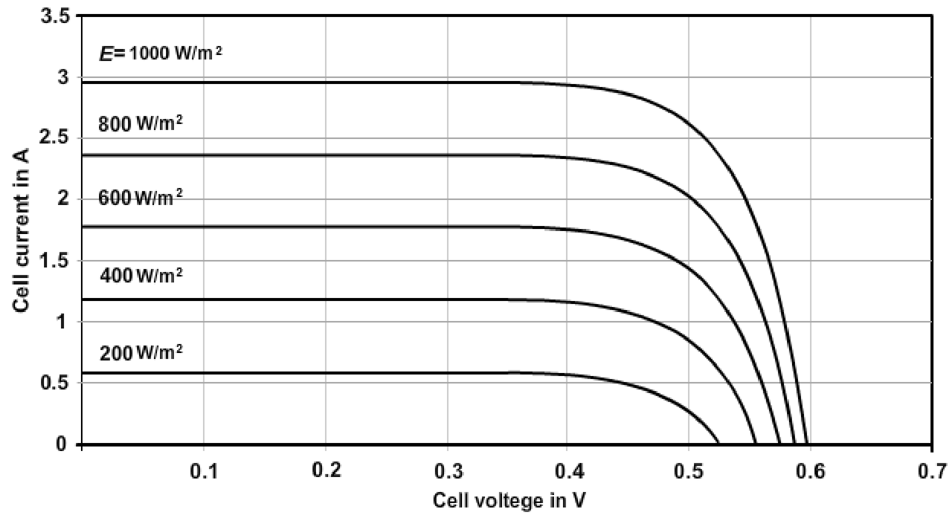

Figure 7 -. I-V graph with no MPPT, Electropedia (JO4).

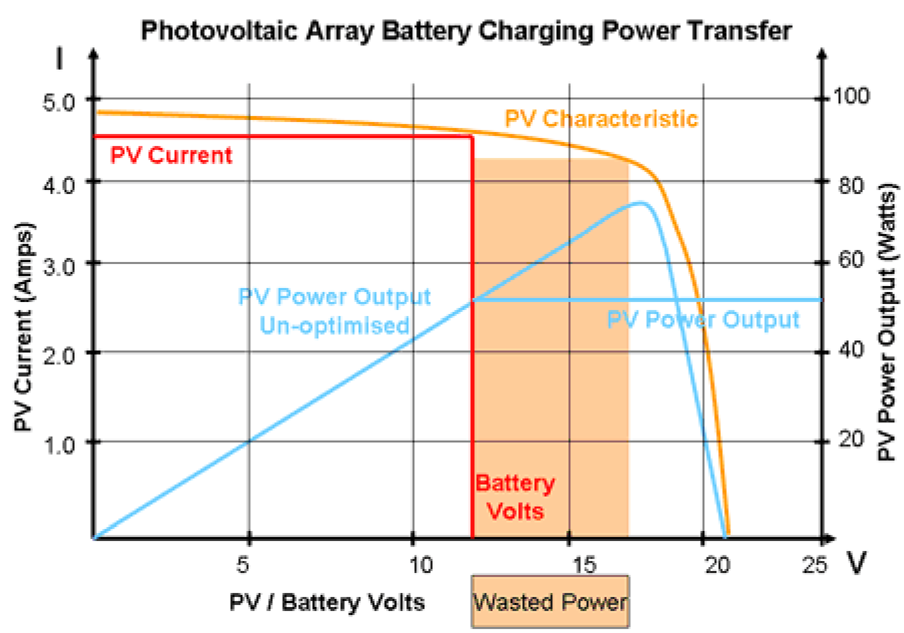

Figure 7b - I-V graph with MPPT, Electropedia (JO4).

An MPPT is a power regulation circuit and, a very efficient MPPT will have the following components: a voltage regulator, diodes, current regulation diodes and, resistors, most if not all of the efficiency comes from the voltage regulator, this is a very tough choice to make because of the fact that technology changes every day, many of the schematics and components in the market, might be obsolete tomorrow since advance in technology is rapid. Voltage regulators are where most of the efficiency lies, early MPPTs and charge controllers where made out of voltage regulators like the L7805 with overall not a very good efficiency, newer regulators like the AD8214 bring efficiency up to a 94%. The MPPT that will be built for this project is going to be more analog than digital, the reason why this is happening is because an all analog MPPT is more efficient by a small percentage and it won't have to be programmed like a digital one, it will be more straight forward and also it has to be done this way for convenience purposes, based on research and mainly reviews posted on different websites analog MPPTs might lose their tracking point and not have good efficiency. MPPT nowadays is achieved mainly by electronic (digital) components and they are harder and more expensive to build. It is a decision that has to be made. from the output of the MPPT there will be 12 volt shunt charge controller, the purpose of this circuit is to prevent the battery from overcharging, overcharging a battery not only reduces battery life but efficiency as well also it might lead to an explosion and eventually death. This solar power generator will use a shunt-mode charge controller, the way it works is that when the battery is full the circuit will sense and bypass the output to a couple resistors that will be placed as an alternate output of this regulator. The main advantage of a shunt regulator is that it won't use switching transistors because they will turn undesired power into heat and it will affect efficiency big time. Having the charge controller in shunt mode will not affect the efficiency of the project because it will just turn on when excess power needs to be wasted. Shunt charge controllers usually have at least one LED to indicate whenever the battery is fully charged. The way the shunt controller feeds the battery is that when the battery charge is low, it will send a continuous current and, as the battery charges up the controller sends short signals of current sensing the charge and when finally the battery is fully charge the control sends a signal and it will bounce back telling the shunt transistor to turn on. Shunt charge controllers are usable in other applications as in wireless applications where noise interference needs to be cancelled.

2.5.a MPPT Algorithms

As described in our research of Maximum Power Point Tracking research, the main purpose is to control the operating voltage of the PV Panel to voltage at the maximum power point where the voltage and current are at their maximum. The MPPT will change the power of the DC/DC converter or some type of dc voltage regulator in our circuit. After doing countless hours of research into MPPT circuits, we found that there are number of ways to write the MPPT algorithm. According to an article written in the International Journal of Photoenergy, there are 5 main criteria to be taken into consideration when choosing an MPPT algorithm.

- Ease of Implementation
- The required number of sensors
- Sensitivity of algorithm
- Cost to implement algorithm
- The application where the Algorithm will be used for.

The first criteria simply state that some MPPT algorithm are easier to implement than others. Some MPPT circuit are purely analog while others are digital. Digital MPPT will like require some type of programming. Second criteria in deciding an MPPT algorithm is to find out how many number of sensors the Algorithm will need in order to be implemented. Most algorithms will require some type of sensor for the PV panel. Voltage sensors for voltage measurement are easier to gather and implement than current. Current sensors are at times expensive and difficult to work with. Criteria 3 deals with the sensitivity of the Algorithm, if an algorithm is too sensitive and there's some shading on the panel, the shading can be tracked by the algorithm and significantly drop the power of the of the panel. The next criteria deal with the cost to implement the algorithm. This step deals directly with criteria 2 because the number of sensors required for the algorithm will affect the cost of the algorithm. Also, depending if the circuit is analog or digital might affect the cost. The last criteria to consider is if the MPPT algorithm chosen is appropriate for the application it will be used for. Some algorithm will not give same result in different applications.

In the article several different MPPT algorithms were described and their efficiency and other characteristics were determined. Overall six different types of algorithms were described. The algorithms are:

- Perturb and Observe (P&O) Algorithm
- Modified P&O
- Artificial Intelligence
- Contrast voltage (current)
- Incremental conductance
- Parasitic capacity

Perturb and Observe (P&O) algorithms are known as the simplest MPPT algorithm to implement and are very popular. With the P&O algorithm, the P-V characteristic of the PV cell is utilized. As the voltage in the panel increase, the changed in power in the panel is measured. If the change in power is positive, the operating voltage is increased to reach MPP. If the change in power were to turn to negative, the operating voltage would be modified to reach MPP. The drawback with a regular P&O is that it cannot determine the exact location of MPP; only an oscillation point can be achieved in the region close to the MPP. This algorithm can track in the wrong direction when the irradiance level of the panel changes rapidly.

To reduce oscillation in the circuit and get a closer approximation of the MPP the modified P&O (MP&O) is introduced. An example of a MP&O is three-point weight comparison algorithm (TPWCs). With the TPWC, a comparison between the voltage (or current) and power of the PV array are used. Instead of using just one reading of power P1 and Voltage V1 like the P&O algorithm, TPWC uses another reading P2 by increasing V1 to V2 and comparing P1 and P1', if there's a change in the difference, the algorithm will determined that there's a change in radiation of the environment and will repeat the process. There are other MP&O

algorithms described and some may increase efficiency of the regular P&O to be over 12%.

Artificial Intelligence-Based MPPT Algorithms are known to be very efficient and very complex to use. These algorithms may use artificial intelligence techniques such as fuzzy logic (FL), artificial neural networks (ANNS), and genetic algorithm (GA) techniques to efficiently track MPP under adverse weather conditions that may affect the power and current characteristics of a PV Panel.

Constant Voltage (or Current) Algorithms is based on a ratio K between the MPP voltage and open-circuit voltage. The optimum value for K is not simple to determine and has been revealed to be between 73% and 80%. Constant Current algorithm may be substituted for the voltage in this algorithm. The current for the MPP is measured against the short circuit current.

An incremental conductance algorithm (IC) is different from Perturb & Observe algorithms and will determine in which direction to change voltage. In this algorithm, the inverse of the instantaneous conductance must equal the incremental conductance at the maximum power point but must have opposite signs. Figure 8 below represents the flowchart of an IC algorithm for maximum power point tracking. In this algorithm, the steps outlined in this algorithm are as followed:

- Voltage and current of PV panel are measured.
- Power is observed from those calculations
- Check if there’s a change between current power and old power.
- If there’s a change between current power and old power calculated, calculate if change is negative or positive. If no change is detected then update M.
- If change in power in positive then check to see if change in voltage is positive or negative.
- If change in voltage is negative or positive then change the value of M by either increasing its value or decreasing it to the change in M calculated.

IC algorithms are not very efficient under rapid changes in atmospheric conditions. IC algorithm does not generate the oscillation problem that P&O exhibits when calculating the MPP of the panel. However, IC algorithms pay a heavy cost for random sampling and speed control.

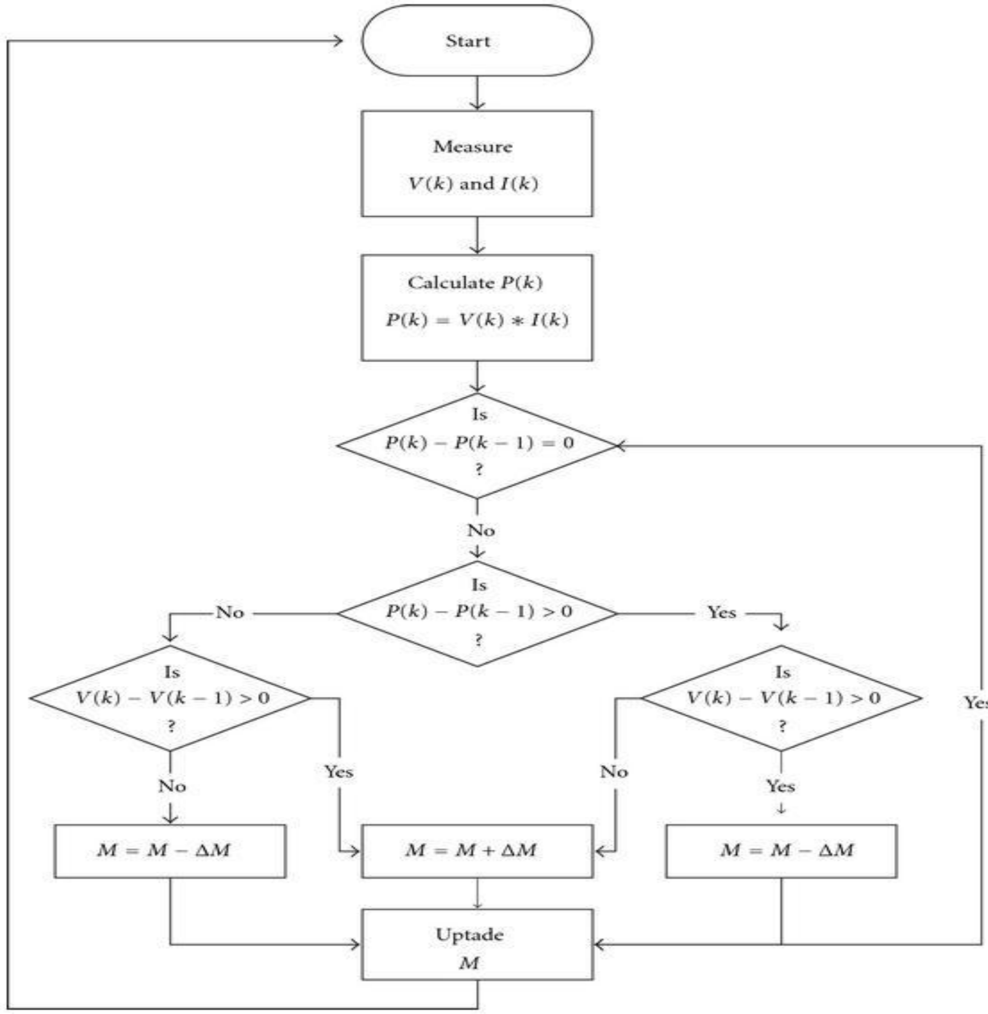

Figure 8: Hill Climbing Flowchart of IC Algorithm [JP8] [10]

Parasitic Capacity algorithms are similar to similar to IC algorithm but differ in the addition parasitic junction capacity (PJC) value. Parasitic capacitance is known to reduce the error signal at operation of the maximum power point and the losses are used in determining the maximum power point. The efficiency of the parasitic capacity may reach its maximum value in high power PV systems that include numerous parallel-connected modules [JP8].

Based on these six different algorithms, the group select on method that is beneficial to our project. Table 4 shows the efficiency and some characteristics of these algorithms. Parasitic capacity algorithm shows the highest efficiency out of all the algorithms with artificial intelligence and modified P&O tying for a close seconds. The other algorithms fall in the range of 73% and 89% efficiency. All algorithms except constant voltage may determine exact maximum power point. According to the table, the algorithms may use analog or digital controls or sometime both. The group will be more inclined to use a maximum power point tracking that uses a digital control. The speed complexity of the algorithm is an important factor in our project and the modified P&O, artificial intelligence and parasitic capacity shows the fastest speed complexity among the algorithms. The algorithms that are attractive according to the table are the modified P&O, artificial intelligence and parasitic capacity based on efficiency and other factors. Our group will try to research for an algorithm that falls under one of the algorithm mention above.

Comparison parameters	MPPT Algorithms					
	Perturb & observe	Modified P&O	Artificial intelligence	Constant voltage (current)	Incremental conductance	Parasitic capacity
Efficiency (%)	81.5–85	93–96	>95	88–89.9	73–85	99.8
PV Panel depending operation	No	No	Yes	Yes	No	No
Exactly MPP determination	Yes	Yes	Yes	No	Yes	Yes
Analog or digital control	Both	Digital	Both	Analog	Digital	Analog
Periodic tuning requirement	No	No	No	Yes	No	No
Convergence speed	Varies	Fast	Fast	Medium	Varies	Fast
Complexity	Low	Medium	High	Low	Medium	Low
Measured parameters	Voltage, current	Voltage, current	Varies	Voltage (current)	Voltage, current	Voltage, current

Table 4: Comparison of MPPT techniques according to several parameters [JP8] [10, 28, 32, 36]

2.5.b Main MPPT Algorithms

There are three main algorithms associated with maximum power point tracking; they are InCond, P&O, and Fuzzy Logic. Here is a very short explanation why these are the most popular algorithms and why they have been so popular all over the photovoltaic market.

InCond stands for incremental conductance InCond algorithm are usually used with PIC microcontrollers; they work by comparing the power versus the increment of the voltage by doing that, the increment in the maximum power point is determined. P&O stands for perturb and observe it is also kwon as hill-climbing, it works by perturbing the operating voltage of the DC link between the solar panel and the power inverter. [JO5]. At one point it perturbates both voltage and current to reach a maximum tracking point. The most popular method nowadays is the Fuzzy logic control, this method is unique because of the fact that it doesn't need to have linear inputs or steady values. Based on a thesis written by David Sanz Morales from the Aalto University in Finland the way Fuzzy logic control works is:

"Fuzzification, inference system and defuzzification. Comprising the process of transforming the numerical crisp into linguistic variables based on degree of membership".[JO5]

Doing further research about fuzzy logic control, it seems it is more of a European approach since most of the universities in Europe have a course just on fuzzy control, although it is rapidly growing and being used all over the world, its advantages are unique because of the fact that it can accept non linear inputs, calculates the error, change in error and with the error calculated control the maximum power point tracking.

2.6 MCU

The microcontroller is one of the most important aspects of the project. With the microcontroller we will be able to monitor the status of the unit, control the rotation of the solar panel and control the Maximum power point tracking circuit. Microcontrollers can be referred to as the brain of a circuit. Microcontrollers are designed for embedded applications while microprocessors are used in general purpose computers. They're not as powerful as microprocessors and don't require as much power. With embedded applications, the microcontroller is used to perform the same task over and over again like power toothbrushes. The Microcontroller in the project will be used to control the rotation of the solar panel when tracking the sun. The microcontroller will be used in the MPPT circuit to regulate voltage coming in and out of the solar panel and into the battery. Furthermore, the microcontroller will be used to monitor some components in the system. Temperature reading from the solar panel will be taken periodically to find out if a higher temperature does affect its efficiency. The battery power level will be measure as well the power coming from the solar panels and their current reading as well. All these information will be relay to the LCD screen and will be shown periodically to the user for monitoring over a specified interval. Depending on our final design, we might end up using more than 1 microcontroller for the project. Even though, there are microcontroller basic boards available for purchase, our group will design our own PCB board and send it to a manufacturing company for building. More will be discussed about the PCB board in its own section.

The group researched several different microcontrollers for this project based on recommendations from the professor and the groups past experience. Some of the microcontrollers we were thinking of using for our project are listed below.

- PIC microcontrollers from Microchip
- Atmel Microcontrollers
- Ti MSP430 line of Microcontrollers

Augmented Microcontrollers and Developmental Boards
The final project board circuit with the microcontroller (integrated circuit) with all the extra components such as resistors and amplifiers will be design by the group on a pcb board. For initial testing and programming, the group will be using augmented microcontrollers. Augmented microcontroller is a predesigned board that has a microcontroller and several other components like LEDs, motor driver, etc. The augmented microcontroller is sometimes referred to as Developmental Boards. Using a developmental board for initial programming over full augmented board has many advantages. The obvious is that these developmental boards are designed and tested by professionals. They have easy to read labels for pins and connectors. These boards are also equipped with components that will eliminate user errors and protect the microcontroller chip from shorts and voltage overloads. The drawback with using these developmental boards is that the cost is usually higher than custom made boards. Some common developmental that the group will consider using for the project are:

- Arduino UNO – R3
- Parallax Board of Education Development Board (USB)
- MSP430 Launchpad from Texas Instruments
- 40 Pin PIC Development Board for PIC18F4550 from Sparkfun.com

2.6.a Arduino UNO – R3

The Arduino is perhaps unarguably the easiest development board to design and programmed with. The board uses the ATmega328 microcontroller chip. It has 14 digital input/output pins, which 6 can be used at PWM outputs, 6 analog inputs, and a 16 MHz crystal oscillator. The USB connection makes it easy to connect the board to a computer and start programming.

To program the board, the user can use the Arduino IDE software created by Arduino or an IDE developed to program AVR controllers such as Makefiles or AVR Studio. The main language used to program the board is C/C++. The board can be powered by the USB connection or and external power supply. With the VIN pin, a recommend power source of 7-12 can be used to power the board. The manufactures don’t recommend operating outside this voltage range because too low of voltage may be unstable for the board and more than 12V may overheat the voltage regulator and damage the board.

The microcontroller chip has 32KB of memory with 0.5kB used for the bootloader. It has 2 kB os SRAM and 1 kB of EEPROM. The EEPROM can be read and written with the EEPROM library. SRAM stands for static random-access memory; it is used to store data for usage by the microcontroller. Data may be lost when memory is not powered. EEPROM stands for Electrically Erasable Programmable Read-Only Memory and is non-volatile memory that stores data and retains the data even if power is lost. The board has USB overcurrent protection that will automatically break USB connection if 500 mA is applied to the USB port and will not commence connection until the short or overload is removed.

Arduino UNO board Property	
Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328)
EEPROM	1 KB (ATmega328)
Clock Speed	16 MHz

Table 5 –Arduino Uno Board Porperty [JP18] (permission pending)

2.6.b Parallax Board of Education Development Board (USB)

There were mix reviews about using these boards. The one incentive about using this board is that it has a built in breadboard. The size of the breadboard makes it ideal to build small circuits on the board directly without using an external breadboard. This board is manufactured by Parallax Inc. The board is rather costly compared to other boards in the same category and it doesn't include the BASIC Stamp 2 module, the chip to program the board. The board alone cost $67.00 and the basic stamp modules start at $49.00 for the basic model. This board runs had approximately 4,000 PBASIC instruction/sec with a BASIC Stamp 2 Microcontroller Module. Another drawback with this board is that the microcontroller has to be programmed in Basic and none of our group members are proficient in programming in that language. After much consideration, we will use this development board just for the breadboard and look at their code example for servos and motors to get a better understanding on how to do the program.

Basic Stamp 2 Microcontroller Module Specs	
Processor Speed:	20 MHz
Program Execution Speed:	~4,000 PBASIC instructions/sec.
RAM Size:	32 Bytes (6 I/0, 26 Variable)
Scratch Pad RAM:	64 bytes
EEPROM (Program) Size:	8 x 2 KBytes; ~4,000 PBASIC instructions
Number of I/O Pins:	16 + 2 dedicated serial
Current Draw @ 5 vdc:	25mA Run, 200 µA Sleep
Source/Sink Current per I/O:	30 mA / 30 mA
Source/Sink Current per unit:	60 mA / 60 mA per 8 I/O pins
PBASIC Commands:	45 commands
Package:	24-pin DIP
Industrial-Rated since Rev. E	

Table 6: Basic Stamp 2 Microcontroller Module Specs [JP16]

2.6.c MSP430 Launchpad from Texas Instruments

The MSP430 Launchpad is a development board designed by Texas Instruments. The major incentive for using this board is the low power consumption. The microcontroller can handle up to 16 MIPS with use of 1.8V to 3.6V. It also has the option of putting the microcontroller to sleep or standby while it's not active and will wake it up and place it into operation in less than 1 MicroSecond. The Series 2 version of this microcontroller has up to 256B and 8 KB of Ram and hold 4 KB -120kB of flash memory. This board also has a feature call brown-out reset that allows the microcontroller to reset if there's any short interruption in power. We will be able to program this board in C using code composer studios which is a great since most of our group members have experience with.

2.6.d 40 Pin PIC Development Board

The last development board our team was considering using for the project was a simple 40 pin Pic Development board at Sparkfun.com. This is a basic development board and it doesn't have the many features of the other boards like usb interface and brown –out reset. The board comes with a serial power plug-in jack and the microcontroller socket. The reason for wanting to use this board was to learn to program using a simple board show that we would easily transfer our program using this board to an empty breadboard where all the circuit protection is not available. This board can also be program in C. The board comes with the PIC18F4550 microcontroller. The prototyping space on the board is available and allows the user to solder on auxiliary circuit on the board. Below are the features of this development board. The MCU provided with this board will most likely used to control the MPPT circuit of our project. Based on research conducted by the group, the PIC microcontroller is widely used because of their simplicity in programming.

40 Pin PIC Development Board Specs
• ICSP/ICD connector for programming with PIC-MCP, PIC-MCP-USB, PIC-PG1,PIC-PG2, PIC-PG3 or PIC-PG4 and programming and debugging with PIC-ICD2, PIC-ICD2-POCKET, PIC-ICD2-TINY • USB 2.0 type B connector allow board to be interfaced to PC host • PIC18F4550-I/P *is* included • Quartz crystal 20MHz • LED connected to RD3 through jumper • User button connected to RB4 • Reset button • Power jack with diode bridge can be powered with AC or DC power supply • 5V regulator • Extension slot on every uC pin • Grid 100 mils • GND bus • Vcc bus • Four mounting holes 3.3 mm (0.13") • FR-4, 1.5 mm (0.062"), green soldermask, white silkscreen component print

Table 7: 40 Pin PIC Development Board Specs [JP15]

Table 8 compares some of the different boards that will be use for the project. The most attractive boards currently based on price is the Arduino Uno R3 board. It is the cheapest out of all the boards and it has several reference materials on how to use the board. The 40 Pin PIC Development board is another board that is pretty useful to the scope of the project. The MSP430 would be a logical board to use base on price but in terms of available resources and aid for the board, it is lacking compared to the more widely used microcontrollers like the Arduino and PIC board. All the boards listed on this table come pre-installed with the chip used for programming. Which makes easy for programming the chip because that would mean that chip installed on the boards already have the development board's bootloader installed on the chip. The Arduino board and MSP430 use C for programming, while the PIC board can use C or Assembly language for programming. The Parallax board uses Basic programming language. In terms of price, the boards have different values and depending on where the group would get each board, the price would fluctuate.

Development Board	Chip used	Comes with Chip?	Power jack w/ Voltage Regulator	USB Or Serial Interface	Programming Language	Price
Arduino UNO - R3	ATMEGA328P	yes	YES	USB	C	$29.95
Parallax Board of Education Development Board	Basic Stamp 2	no	YES	USB	Basic	$60.00
MSP430 Launchpad	MSP430Fxx2	yes	YES	USB	C	$4.30
40 Pin PIC Deveopment Board	PIC18F4550	yes	YES	Serial/USB	C/Assembly	$37.95

Table 8: Comparing Development Boards

2.7 Motors

2.7.a DC vs. AC motors

For the project, the group wanted to compare the effectiveness of using DC motors vs. AC motors and decide which one will be best suited for the solar panel rotation. Both motors have their advantages and disadvantages depending on their application. This research portion of the project will identify those differences between AC and DC motors and will help the group choose an acceptable motor for the solar tracking portion of the project.

2.7.b AC motors

AC motors are electric motors driven by alternating currents (ac). AC motors are used for large applications that require high torque and power. One of the drawbacks with AC motor is their high current usage which might cause sparking and heating at rotating contacts which can waste energy and shorten lifespan of the motor. AC motors are mostly found in electrically powered vehicles.

2.7.c DC Motors

DC motors are electric motors driven by direct currents (DC). DC motors can operate directly from rechargeable batteries. This quality makes DC motors very useful in small appliances and toys such as RC cars. There are many different types of dc motors and each of them has their advantages and disadvantages. For the solar tracking portion of the project, research was conducted on different dc motors to see which one will be more advantageous to the solar tracking system. At the end, the selection for the DC motor would be based on size, efficiency, power usage and availability.

2.7.d Brushed DC Motors

The simplest DC motors and cheapest ones available to date are brushed DC motors, originally thought to be invented by Nicholas Tesla. These motors are low cost and have fairly high reliability depending on the application. They can be controlled for solar tracking purpose using a motor controller and microcontroller. The motor controller will be used to regulate the current going to the motor, thus regulating its speed, the direction of its rotation and will protect it from overloads and faults. The main disadvantage of these motors is the fact that they have brushes that will continually interact with internal components in the motor. These brushes are known to wear out often and require frequent replacements. If the group was to use a brushed dc motor in the project scope and the brushed would happen to wear out, then the group would have to replace the whole motor since the motor would become useless at this by not having the ability to rotate. These motors are more complicated to program for position based applications since they don’t have an internal component that provide feedback about position of the motor. In comparison to Stepper motors, these motors movement are not as accurate. Since the electromagnet is in the center of these motors, they are more difficult to cool down and may cause overheating in some applications if they are used extensively over a period of time. The table below shows a summary of the advantages and disadvantages of using a brushed DC motor. As mentioned already, the biggest disadvantage that jumps out from the table is that the brushes for the motors eventually wear out in regular DC motor and they would have to be replaced over time.

Advantages	Disadvantages
• Low initial cost • high reliability • simple motor control speed	• Brushes wear out • Might get sparking and electrical noise because of the brushes when they make or break connections • Brushes limit the maximum speed of the motor • Are more difficult to cool since the Electromagnet is in the center of the motor • The number of poles the armature can support are limited by the brushes • Cleaning and replacing the commutators

Table 9: Advantages and Disadvantages of Brushed DC Motors

2.7.e Brushless DC Motors

Brushless DC Motors or Electronically Commutated motors are similar to Brushed Motors in the sense that they are both electric motors powered by direct current electricity. However they differ because Brushless motors use electronic communication systems, while brushed motors used mechanical commutators and obviously brushes. The main advantage that brushless motors have over brushed motors is their long lifespan and efficiency. Since these motors don't have brushes, they don't wear out as often and brush motors. There are no brushes interacting with any other components in the motor. These motors can be easily controlled using motor controllers and if they're being used in an application where positioning is important, they will operate on a closed loop feedback system. The table below briefly describes the advantages and lack thereof for the Brushless DC motor.

Advantages	Disadvantages
• Long life span • Little maintenance, no brush to replace • Higher efficiency	• High initial cost • Complicated motor speed controllers

Table 10: Advantages and Disadvantages of Brushless DC Motors

2.7.f Stepper Motors

Stepper motors are brushless DC electric motors that divide can divide a full rotation into a large number of steps. Their motor rotation closely follows the input pulse. DC brush motors rotate continuously when voltage is applied, while stepper motors have multiple “toothed” electromagnets that are arranged around a central gear-shaped piece of iron. When one electromagnet is given power, the gear’s teeth get magnetically attracted to electromagnet’s teeth. When the gear’s teeth are aligned to one electromagnet, they are slightly offset from the next electromagnet. When the next electromagnet is turned on and the previous one turned off, the gear’s rotates slightly to align with the next one and the process gets repeated. Each of those slight rotations is called a “step”. With an integer amount of these steps, the motor can turn by a precise angle. One great advantage of using stepper motors is that they don’t require a lot of power and have high accuracy in motion. Stepper motors also provide high torque to loads even when they’re not moving. The table below describes the advantages and disadvantages of the stepper motor.

Advantages	Disadvantages
• High accuracy of motion are possible even under open-loop control • Motor controller not required • Have internal gears to control speed and torque, not need for external gears for speed reduction. • High torque when not moving	• Cost more than regular DC motors

Table 11: Advantages and Disadvantages of Stepper Motors

2.7.g Servo Motors

A servo motor is essentially a stepper motor and both terms could be used interchangeably except for the fact that stepper motors don’t need to operate on a closed control loop, whereas servo motors depend on a closed control loop to provide it with position/feedback. Similar to stepper motors, servo motors are built to move angular positions based upon each possible step. Servo motors can be of the brush or brushless variety. They use a rotary encoder for position feedback. Servo motors might be useful for our project for the fact that their movement is based on steps, but programming them might make it difficult because we have to essentially design an algorithm to monitor the rotary encoder and get its position/feedback.

2.7.h Piezoelectric motors

Piezo motors or piezoelectric motors are electric motors based upon changes in shape of a piezoelectric material when an electric field is applied. They make use of converse piezoelectric effect whereby the material produces acoustic or ultrasonic vibrations in order to produce linear or rotary motion. These motors are driven by change in frequencies and oscillations. The wave motor patented by Nanomotion uses the Piezoelectric Effect in piezoceramics to convert electrical field to mechanical strain. The advantages to using piezoelectric motors would be high accuracy in positioning with closed loop servo controls.
Insert pic from Nanomotion here.

2.7.i Linear Motors

Linear motors, like rotary motors have magnets and coils to initiate mechanical movements. Unlike rotary motors though, the magnets are laid on a fixed track side by side, parallel to the moving components which contain the electrical winding. When current flows through the windings, the charged portion is engaged with. It would make sense to use a linear motor for our project if we had solar panel array. The linear motor would then be able to move each panel in the array simultaneously. Linear actuators are able to move heavy objects. Some 12v linear actuators are recorded to have a torque of 250 lbs.

2.8 Motion Control

2.8.a Motor controllers:

The discussion for using a motor controller in the project came up because of the idea of using regular brushed dc motors. Motor controllers are used to monitor the speed and operation of a motor. There are different motor controllers available depending on the motor. Motor controllers are used to regulate speed of a motor, limiting the torque and protecting the motors from overloads and faults that might occur from electrical shorts. They are also used to change the direction of rotation of a motor effectively without damaging it. Motor controllers are used in conjunction with a microcontroller to control the motors. Most motor controllers like the ones built by Pololu.com, have their own libraries to aid in programming. These libraries make programming the motors more effectively by using simple methods that takes in some predefined inputs like motor speed and rotation.

Figure 9 below shows an example of a motor controller built for the Arduino Uno. This motor controller is available for sale at the Adafruit shop. The controller comes with 2 connections for 5V ‘hobby’ servos, 4 bi-directional DC motors and 2-stepper motors. The motor controller is also compatible with Arduino Mega 1280 & 2560, Diecimila, Duemilanove, and of course the UNO. The kit comes with tutorials, some examples and its own library for used with the Arduino software. The major problem with this motor controller is that it is used mostly for small motors and those motors wouldn't be powerful enough to move the solar panel. This motor controller is used to powering small motors for hobby projects.

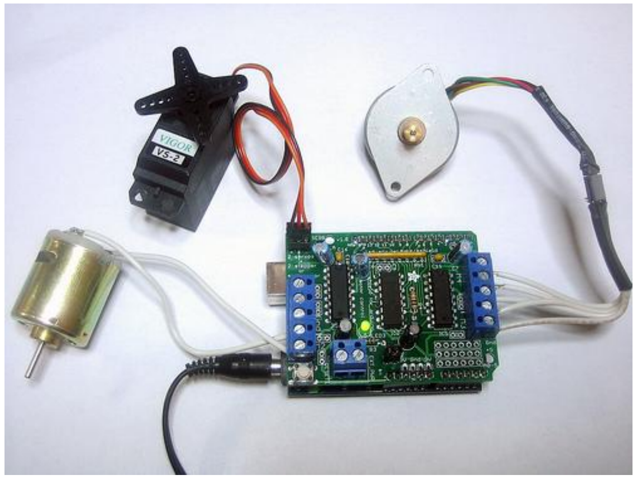

Figure 9: Adafruit Motor Controller for Arduino [JP12] Permission Pending

2.8.b Pulse Width Modulation

Pulse Width Modulation or PWM is an important concept in the project because of the type of motors the group decides to use. Since group is thinking about using DC motor to control the PV panel rotation and direction, the concept of motor speed comes into play. According to the Dallas Personal Robotics group website, "Pulse Width Modulation is the process of switching power to a device on and off at a given frequency, with varying on and off times. [JP13]" The on and off times are referred to as "duty cycle". Duty cycle can be analyzed as waveform over a specific timer interval and can vary from 0% to 100% duty cycle, which will send a continuous on signal that will keep the motor on over specified wavelength. This is important because solar tracking will cause the motors to rotate abruptly. With PWM, we will be able to send the motors a signal that will start from off (0% duty cycle) to full on (100% duty cycle) with good efficiency and stable control. PWM doesn't have to be implemented with Servo motors as they are already driven by Pulse Width Modulation. The length of a pulse will determine how long a servo motor stays on. Motor Controllers have built in PWM control that can be configured by the user during programming to control PWM frequencies of a motor. This will in turn measure the speed and efficiency of the dc motor. PWM can also be of use in charge controllers where voltage coming from PV panel to battery has to be modified.

2.8.c PWM charge controllers

When it comes to charging batteries with a solar panel, there are three widely used methods to prevent the battery from over charging. Solar panels are always sending current to the battery when connected. Certain batteries may prove to be dangerous if certain care's not taking when charging them. According to "DC Battery Specialist" website at www.dcbattery.com, "overcharging is the most destructive element in battery service.[JP17]" The article goes on to talk about how over charging a battery may overheat the battery and will always result in shortening the lifespan of the battery. The reason for this anomaly given by the article is that once the battery is passed its maximum charging capacity, the excessive current from the source leads to a loss of moisture from the battery that can never be recovered. The most proven method used to protect the battery from overcharging is a charge controller. There are different types of charge controllers available with different efficiency and use.

The first charge controller is a basic charge controller. It's designed to simply protect the battery from overcharging or being undercharge. It accomplishes this task by limiting current flow to the battery when the battery has reached its peaked capacity. The charge controller may also divert the excess power to another load where it will not be wasted. In our project, if we determine a basic charge controller to be sufficient protection for the battery, we will divert the excess power coming from the solar panel when the battery is full to power other devices such as the motors and the microcontrollers.

PWM Charge controllers are another type of charge controller used in protecting the battery from overcharging. Pulse Width Modulation, the same concept used in dc motor control is now applied to charging the battery. PWM are more sophisticated then basic charge controllers because rather than just turning on and off and when the battery reaches its maximum capacity, PWM will regulate and adjust the charging rate to match the battery level. According to an article published by Morningstar Corporation, "PWM solar charges uses technology similar to other modern high quality chargers. When a battery voltage reaches the regulation set point, the PWM algorithm slowly reduces charging current to avoid heating and gassing of the battery." The article concludes that by this method, the circuit will be at a higher charging efficiency, and healthy battery at full capacity. Although there's a tremendous increase in efficiency by using PWM charge controllers compared to basic charge controllers, the efficiency is set to a limit because it controls the voltage level of the solar panel by the voltage level of the battery. The article, "Solar Panel Peak Power Tracking System", mentions this disadvantage of PWM charge controllers. "by operating at a fixed voltage level, nothing guarantees that this voltage level is where the maximum amount of power can be drawn. Further, the maximum power point will change due to irradiance and temperature guaranteeing that the PWM and basic charge controllers will rarely draw the maximum amount of power from the solar panel." This statement makes the claim the MPPTs charge controllers will provide better efficiency to charging then battery. The final charge controller and most widely used is the MPPT charge controller. More about this charge controller will be discussed later on as it will be the charge controller used for our project.

2.9 Voltage/Current Sensor

Part of the design of our project is to be able to monitor the amount of voltage and current which is being outputted by the solar panel. This information will be sent to our micro control unit and displayed on the LCD screen.

2.9.a Voltage Sensing

The voltage of our panel can range from around 0 to 22 volts. This voltage range must match the maximum input voltage range of the microprocessor chip which is between zero and five volts. The task of measuring the voltage coming from our panels will not require the implementation of a sensor.
By connecting a voltage divider in parallel with the solar panel we can drop the 22 volt maximum output from the solar panel to match the five volt maximum of the microprocessor.
The following equation:

Vout = (R2/(R1 + R2)) * Vin

will be utilized to find the appropriate values. Where Vout is 5V and Vin is 22V. The values of the corresponding resisters are: 22K and 5K respectively.

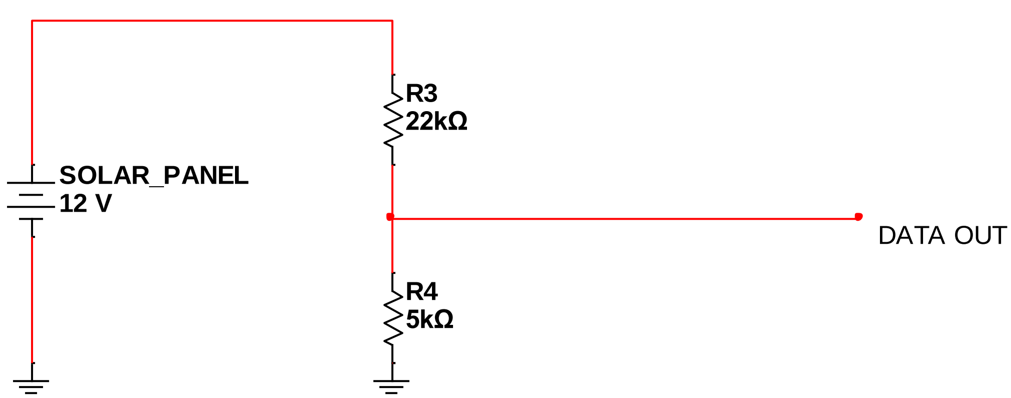

Figure 10 –Voltage divider circuit

2.9.b Zener Diode:

A Zener diode will be connected in parallel with the microcontroller which will help regulate the voltage such that it does not exceed the microcontrollers threshold of 5 volts. A spike in voltage can damage the microcontroller and may be caused by lightning strikes, electrostatic discharge or solar panels operating above the maximum voltage range. Most microcontrollers work in a range of at most 5v. That is why our chosen Zener diode will regulate the incoming voltage into the microcontroller to be no more than 5.1 V.

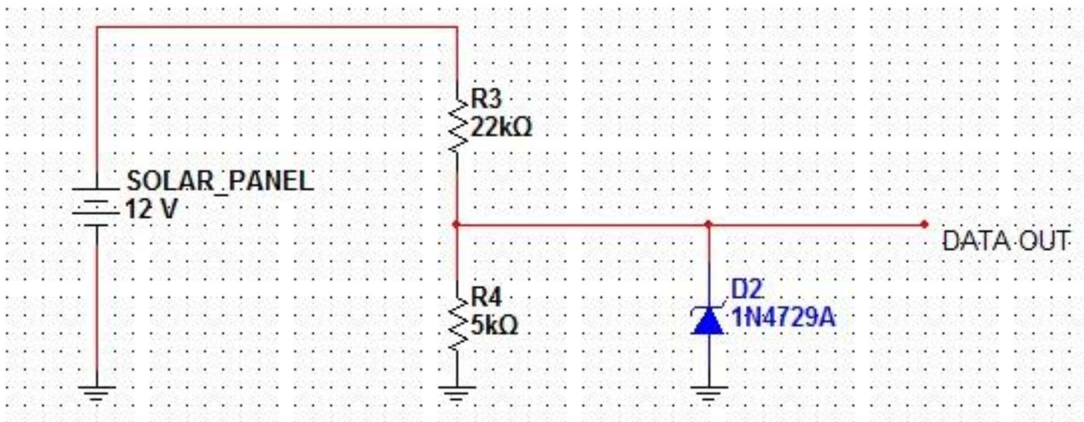

Figure 11 – Voltage Divider Circuit with Zener Diode

2.9.c Operational Amp:

The data which is to be sent from our voltage divider circuit will need to be sent to the microcontroller. However, the use of an Op Amp will be important to our design because it will help ensure that the data being sent to the microcontroller will be accurate and will not be greatly affected by noise. When sending voltages a long distance through a cable, the signal can be affected by noise which may interfere with the outputted data. This can lead to misleading results which is why the use of an Op Amp in this circuit is very important. Amongst the many types of Op Amps which are to be considered, a unity gain Op Amp has characteristic which fit the plan of our design. This type of Op Amp would be useful because the overall gain of the circuit will be in unity. It is important to minimize the exposed to our output because if there is added gain then our results will be wrong and extra circuitry will be needed to step the voltage down before the signal is received by the microcontroller.

2.9.d Current Sensor

A current sensor will be utilized to monitor the DC current which is being outputted from our solar panel. This current sensor will generate an analog signal which will be read into our microcontroller and then displayed to our LCD screen. There are several different technologies which would serve the purpose of a current sensor such as: a surface mount Hall effect sensor, a Hall effect current clamp sensor and a Hall effect open loop current sensor.
Two of the most prominent technologies for current sensing applications include the Hall Effect current sensor and the Inductive current sensor.

2.10 Battery Component

2.10.1 Lead Acid Batteries:

there are two main types of DC batteries, shallow cycle and deep cycle batteries, depending on the use. Shallow cycle batteries offer a high amount of current, for example the current needed to start up a car or a big piece of machinery, these type of batteries might go their entire life without using 20% if its entire capacity, these types of batteries are mostly used in cars. A car without any modifications can use the same battery a large amount of years. This batteries use thin plates and this is to make its surface area larger. Shallow cycle batteries usually have two types of ratings: CAA (Cold Cranking Amps)- that is the number of amps that the battery can produce at c degrees Celsius for a small amount of time. RC (Reserve Capacity) is for example the number of minutes that a 12-volt battery can deliver 25 amps while keeping its voltage above 10 volts. A deep cycle battery is design to have two or three times the amount of RC than a shallow cycle battery, but will only deliver a third or even a fourth of the CCA's of shallow cycle, and this is because deep cycle batteries are design to be discharged over and over again without being damaged, if this happens to a shallow battery it will be damaged very soon. For the deep cycle batteries to achieve the fact that can be discharged numerous amount of times, it uses thicker plates on the insides. Deep cycle batteries are mainly made out of lead-acid; these batteries are designed to discharge from 60-80% depending on the manufacturer. Thicker higher density and active paste material, charging cycles represent actual life of the battery rather than time itself, in other words, overall usage determines how long the battery is going to last.

Discharging a battery fully is called deep discharge and partially discharging might be called shallow discharge, there are numerous uses for DC voltage deep cycle batteries for example: electric skateboards, audio equipment, both portable and stationary also, off-grid energy like solar power and wind energy and, its seen a lot in back up power systems in automatic transfer switches (ATS). In today's economy, modern deep cycle batteries are making a big impact to a greener planet, this because of the fact that the world depends in fossil fuel and electric vehicles are starting to be an alternative to this dependence, popularity increasing by the hundreds daily, deep cycle batteries offer a high power to weight ratio, energy to weight ratio and, energy density. Because of higher prices and lower technology batteries were expensive. Nowadays with the rapid advancements of technology and investments projected market for electric vehicle batteries is around 38 billion dollars by year 2020. Damaged batteries suffer mainly from flooding and what happens when a battery floods is that there is a mixture of water with electrolytes and it generates hydrogen and oxygen resulting in cell loss, flooding occurs mostly due to overcharging a battery. A discharging battery decreases the amount of sulfuric acid; electrolytes are most likely to freeze during winter. To measure the voltage level on a battery, a hydrometer is used to test the specific gravity of each cell determining the charge level. If the level of oxygen increases to a max it will accumulate hydrogen and oxygen and the battery will be ignited creating an explosion. Although some of lead compounds are extremely toxic many ecologic groups and humane societies are making movements to recycle these types of batteries more often. Deep cycle batteries need to be maintained, in other words, they need maintenance done often and effectively due to corrosion problems, these types of problems on the terminals of the batteries decrease the levels of performance ultimately decreasing the efficiency desired. Figure 12 shows an example of a 12 volt DC deep cycle battery with 100 amp hours, after reading the data sheet of the battery showed below, the group became familiar with how a DC battery works, how it charges and discharges, Safety precautions, limits and, temperatures that the battery can withstand.

Figure 12: 12 Volt Battery Selected (permission pending) (JO7)

2.11 Information Display

Another portion of the project was to track some of the components of the system. More importantly, it is desirable for the group to monitor the PV temperature, battery temperature, the battery level capacity. We wanted to have those information available to us so that we would be able to tell if our unit was working effectively. In the initial stage of the project, research was conducted on different lcd components to find out which one would be best suited for our project. A brief overview of the different LCD considered has been provided.

Another factor that the group had to consider was the power consumption of the LCD. Different LCD draws more power than most. We wanted to choose an LCD that was small enough to fit in our design but large enough to show the important information relating to the status of the system. We also figured that choosing an LCD with backlight wouldn't be necessary since our system would be mostly used in the morning when it's bright outside.

In the end, the LCD we decided that an alphanumeric LCD was the way to go. They don't require as much power as a graphic LCD. Also, we won't have that much problem programming one since there are a lot of resources available to help with that. Below are the specs of general 20x4 alphanumeric LCD.

Number of Characters	
-	Module dimension 146.0 x 62.5 x 10.1(MAX)
View area	123.5 x 43.0
Active area	118.84x 38.47
Dot size	0.92 x 1.1
Dot pitch	0.98 x 1.16
Character size	4.84 x 9.22
Character pitch	6.0 x 9.75
LCD type	STN , Positive , Reflective , Yellow Green
Duty	1/16
View direction	6 o'clock
Backlight Type	NA

Table 12: General Specs for CFAH2004L-NYG-EP. Permission pending from [JP2].

The LCD specs were chosen because it met the project specifications and guidelines. From the information listed in the table shown above, the LCD has no backlight. This actually doesn't affect the project because as mentioned above, most of the readings for the project will be taken during daylight when it's bright outside. Therefore, having an LCD with backlight is not necessary. In Addition, LCDs with backlight usually draws more power. Another aspect that is attractive about this LCD is that it has 20 characters by 4 lines. With this much text available, it will give the group plenty of room to display information about the components in our project. Also, if the lines are not enough to display all the information at once, an algorithm can be implemented to change it so that it displays different components status in a scrolling pattern or one after the other. This LCD is small enough to fit in our design and is easily programmable through available libraries for different microcontrollers.

Figure 13 shows the pin diagram of a typical LCD. This particular LCD has 18 pins with the last 4 being no contact pins. No contact pins are generally pins that doesn't serve any purpose and have no use with the LCD. In another LCD, these no contact pins would probably have some purpose, however for this particular model they don't. Pin 15 and 16 of other LCDs would have been used for backlighting if the LCD had that capability.

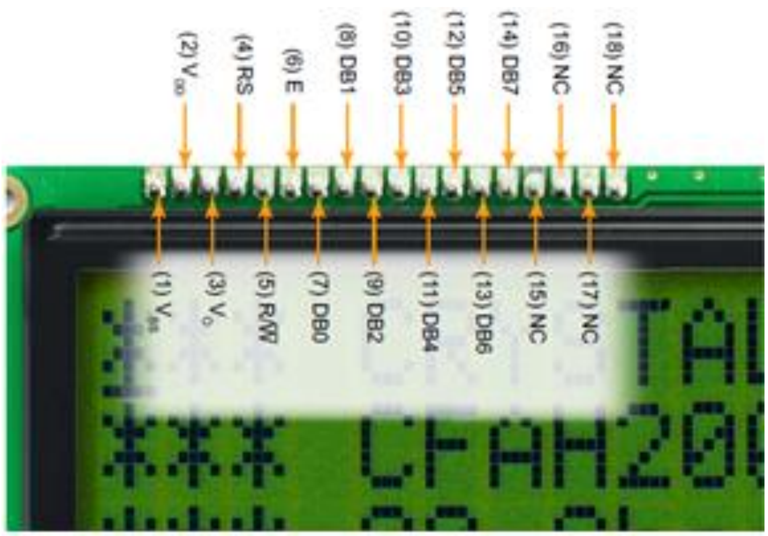

Figure 13: Pin Diagram of LCD. Reprinted with permission pending from [JP1]

The particular LCD chosen for the project will be program by the Arduino Uno Board. A potentiometer will be connected to Vo or Pin 3 from the LCD and it will be used to adjust the brightness level of the screen. At other times when the user wants to keep the contrast the LCD to a constant, he can just replace the potentiometer with a pre-determined resistor and tie that resistor to ground. Pin 1 and Pin 2 of the LCD represent the power supply of the board. The Vss pin is the ground pin to the LCD, this pin along with the R/W pin will be connected to the ground of the Arduino. The register select (RS) pin that controls where in the LCD's memory the user will be writing to is labeled by Pin 4will be connected to an available digital pin on the Arduino. Since we plan on using the LCD for 4 bit operations Pin 7, 8 , 9 and 10 will not be used in programming. Pin 11, 12, 13, 14 which are represented by the symbols DB4, DB5, DB6, and DB7 will be connected to a digital pin on the Arduino board. The Enable pin or Pin 6 is an enable signal that is used when read or writing data. That Pin is also connected to an available digital I/O on the Arduino board. Some LCD with backlight capabilities have Pin 15 and 16 available for the backlight power supply. When connected to a 5V power supply, they will provide illumination for the LCD in night conditions. We don't foresee using these two Pins as draw power and since we will use the unit during the day, there is no purpose in having the backlight.

The table below shows an overview of the each pins purpose. The table shows the confirmation for a typical 16 pin LCD. Each of the pins from the LCD has a general purpose. Depending on the

Pin	Symbol	External Connection	Function
P1	Vss	Power Supply	Signal Ground (GND)
P2	Vdd		Power supply for logic (+5v)
P3	V0	MPU	Contrast Adjust
P4	RS	MPU	Register Select
P5	R/W	MPU	Read/write select
P6	E	MPU	Operation (data read/write) enable signal
P7	DB0	MPU	Four low order bi-directional three-state data bus lines. Used for data transfer between the MPU and the LCD. Not used during 4-bit operation
P8	DB1	MPU	
P9	DB2	MPU	
P10	DB3	MPU	
P11	DB4	MPU	Four high order bi-directional three-state data bus lines. Used for data transfer between the MPU
P12	DB5	MPU	
P13	DB6	MPU	
P14	DB7	MPU	
P15	LED+	LED backlight power supply	Power supply for backlight (Anode)
P16	LED-		Power supply for backlight (GND)

Table 13: Typical Pin Configuration of LCD

2.12 Cooling System

2.12.a Temperature Effects On Panels

When designing our project with a focus on efficiency, the temperatures affect on the output of our solar panel is very important. All solar panels have an output which is directly dependent on the physical temperature of the solar cell. At higher temperatures the output from the cell is reduced which leads to lower efficiency. **[L8]** The efficiency of our panel is an indication of the amount of light from the sun which is being converted into useable electrical energy. The figure below shows an I-V curve representation as a function of temperature. The affect of temperature of current and voltage can both be observed. With the increase in temperature the current goes up slightly. However, the change in voltage in contrast is very drastic. This drastic change in voltage will lead to less power outputted by the formula: ***P = (I * V)***

By controlling the physical temperature of the cells by ensuring that the panel does not get too hot, we can improve the efficiently of our panel.

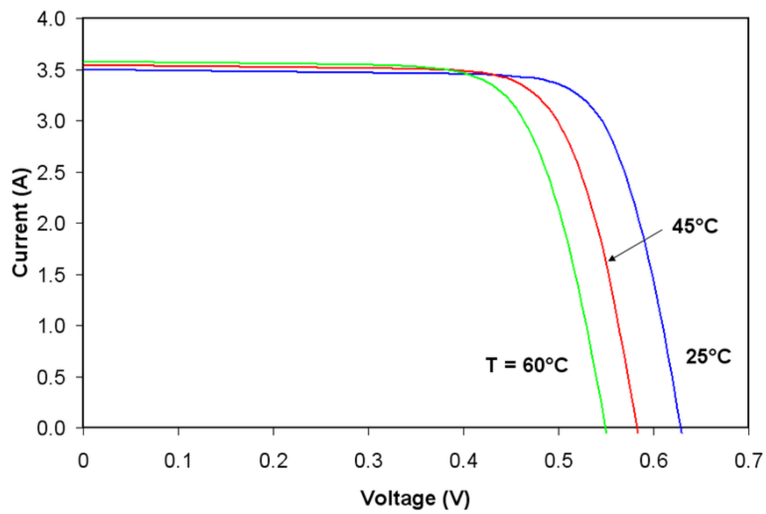

Figure 14 - I-V characteristic of PV panels at different temperatures.(permission pending) [L21]

There are different methods which we can utilize to help maintain a desired temperature of the solar panel.

2.12.b Forced Convection Cooling System

Forced convection is a commonly used method of heat transfer which utilizes fluid in motion to transfer heat from the source, into the liquid and away from the system. It usually uses pump, fan or suction mechanism. This type of heat transfer is used in modern air conditioning. In order to apply this to our project we would need to line the back of our panel with tubes filled with water or cooling liquid. The water will be pumped by a pump powered by the solar panel. However, the drawbacks of utilizing a pump can take away from the project's portability and will require energy from our system which will affect the efficiency.

2.12.c Fan Cooling System

A cooling fan may also be used to help cool the solar panels. The fan would be powered by the battery being charged from our panels. Since hot air rises, the fan would have to be positioned in a way which can effectively circulate the hot air surrounding the solar panel and into the rest of the atmosphere. The drawback with this type of design is that the use of a fan will have to draw its energy from the battery which we are charging which affects the efficiency.

2.12.d Heat Sink

A heat sink can be utilized by helping dissipate the heat into the surrounding air. By adding a heat sink to the back of our solar panel we are increasing the surface area of the heated surface (solar panel) and it will allow for air to flow through it. Assuming the heated surface is hotter than the air surrounding it, the increase in surface area will help dissipate some of the unwanted heat. This method of heat transfer wont require any power from our system so there will be no negative effect on the output of the panels.

By Fourier's law of heat conduction it is understood that when there is a temperature gradient in a surface, heat will transfer from highest temperature to lowest temperature **[L9]**. By the equation:

$$q_k = -kA(dt/dx)$$

where qk is the rate that heat is transferred by conduction, A is the cross sectional area that heat is transferred and dt/dx is the temperature gradient. We can essentially increase the area A by utilizing the heat sink as it increases the surface area of our heated surface.

III. Design by Component

3.1 Microcontroller Dvnt Boards Used

We want to use at least two microcontrollers for our project. One of the microcontrollers would be used for the major functions of the project like motor control, interfacing with the LCD and monitoring the overall performance of the system. The second microcontroller would be used for the MPPT circuit. We decided on this approach so as to protect the overall system from shorts that could occur with the MPPT charge controller circuit. The microcontroller chosen for the overall design and solar tracking was the one that came with the Arduino board, the Atmega328P. We decided to go with this microcontroller because we wanted to program the chip with the Arduino board. The Arduino Uno board will provide us with an easy interface to program our chip and transfer it later on to the pcb design for our project. The board was ordered from Sparkfun.com and comes with the Atmega328p chip already installed. The chip that comes with board is already loaded with the Arduino bootloader and can be easily transferred to a PCB standalone board. The main property of this board that was appealing was the available 14 digital I/O pins and 6 analog pins. The analog pins will allow us to perform such functions as temperature sensing and the 6 PWM out of the 14 digital pins will gives us the opportunity to use pulse width modulation function when needed. Below is a picture of the Arduino UNO board.

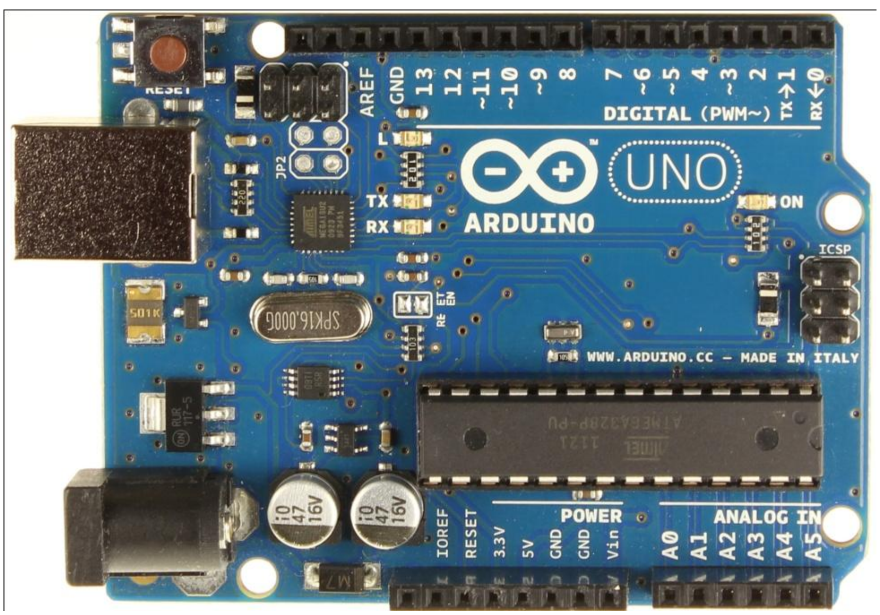

Figure 15: Arduino Uno Board. Permission pending [JP18]

The second microcontroller used for the circuit will be a PIC based microcontroller from Microchip. These microcontrollers are very popular in circuit design and have been known to be used major applications such as Automotive and Home appliances. We will use the 40 Pin PIC Development board from Sparkfun.com to program this microcontroller (seen below). The development board comes with PIC18F4550 microcontroller and has an USB interface like the Aruduino Board. The development board has some major features that make it attractable like the 5v regulator and Quartz crystal already installed. The power jack on the board comes with a Diode Bridge that can be powered with AC or DC power supply which makes it very easy to power the board and microcontroller. The prototyping space around the microcontroller will be used to design other circuits. The main use of this microcontroller will be to control the MPPT circuit. The MPPT circuit is a charge controller that will protect the battery the battery from being overcharged and discharging too rapidly. The microcontroller will allow the charging circuit to operate at its maximum efficiency. To program the PIC microcontroller, the user will have to follow the following steps.

1. Write the program in a text editor like notepad or the Microchip's MPLAB editor. The program can be written in C or assembly language.
2. Compile the code using the MPLAB environment which will invoke the c-18 compiler. The C18 compiler will turn the C code or assembly .asm file into a .hex file.
3. Program the Pic microcontroller using PDFSUSB.EXE program.
4. Run the application by hitting the "execute" button in PDFSUSB.EXE or hitting the reset button on the board.
5. If the application works as should, then great you're finished else Debug the application the Editor.

Figure 16: 40 Pin PIC Development Board Permission pending from [JP19]

Transferring Atmega Chip from Arduino to Breadboard or pcb

For the final design of the project, the microcontroller be transferred to a PCB board and still retain all the functionality of the Arduino breadboard like a 5v regulated power supply and crystal oscillator. The Atmega328 chip from the Arduino can be easily transferred to a breadboard or pcb by easily removing it from the Arduino and placing on a breadboard or pre-designed pin on the PCB. For the PCB board to function like the Arduino, we will use a 7805 Voltage regulator to make sure that the microcontroller is supplied a constant 5 volts. 16 Mhz clock crystal and a normally open button for reset function. These parts will connect to the necessary pin of the Arduino. The final step in making the PCB work with the Arduino is to burn the Arduino bootloader on the chip. This step is not necessary if the chip was already programmed using the Arduino UNO board.

3.2 PCB BUILDING

Talking to local companies about PCB pricing, a PCB is charged by the squared inch. Using a design built in Multisim, the PCB will be about five squared inches. In order to promote local business, a strong belief of working with local businesses is used throughout this project, Micro Engineering Inc located in Apopka Fl and, 4th Dimension PCB Incorporated located in Orlando Fl and, Best Global Source Inc, are examples of local companies where the printed circuit board will be built. Average price for a printed circuit board, given the student discount is about 50-70 dollars, there were numerous companies contacted but the three mentioned above gave the best raw estimate for the prices, The quoted bare bone PCB is using a 4 layer FR4 glass reinforced epoxy laminated sheets; this type of board has less impedance than other boards. Also, it has copper finish to increment its conductivity. Thickness, spacing and width are different when the circuit has higher currents and voltages due to the fact that depending on the value of those there has to be more spacing and width to prevent short circuits.

PCB building has usually a turnaround time of two weeks but, as it was said before local companies are willing to help students a little bit by not only making the prices more affordable but, having a turnaround time of a week. Turnaround time is the amount of time that it takes for the company to receive the initial design and build the PCB, there is little to no experience when it comes to soldering so the group came to the conclusion of using the university's radio club to solder the bare bone PCB. Their work is greatly appreciated and a tip will be provided so they can keep helping students. This method of building PCBs will be used because of the fact that soldering PCB components are small and it requires a steady hand and magnifications, we cannot afford to break our components. It is very important to understand that there will be two PCBs built throughout this project for a total cost of 100.00 dollars for both of them, the biggest PCB will have the DC/AC inverter and, the second PCB will have the MPPT and the motor controller circuits. It has been estimated that about 9 square inches of PCB will be used for the DC/AC inverter and, about 10 squared inches used for the MPPT and motor controller circuits. All the PCBs will be packaged on a box for this box the “brain” of the system, each PCB will be in top of each other forming a story type of container; it will have two sets of inputs and outputs:

- Input from the solar panel to MPPT.
- Output to battery.
- Input from battery to DC/AC.
- Output to AC device.
-

There are a variety of cables that will be used on this project, cables are elemental in power systems because of the fact that using the right cable will reduce impedance and increase efficiency. Cables are rated by the amount of current that they carry for example a cable capable of carrying 30 amps of current is a size #14 cable and, a cable capable of carrying up to 10 amps is a size #20 cable. For this project a size #20 cable will be used from the MPPT to the battery and, the size #14 cable will be used from the battery to the DC/AC inverter. The PCB will be built by Best Global Source electronic contract manufacturing located in Apopka Florida.

3.3 LCD Unit

The LCD chosen for this particular is the HD44780 20x4 characters LCD module. It utilizes the common HD44780 parallel interface chipset by Hitachi. The Hitachi HD44780 is a popular dot-matrix liquid crystal display controller and driver used in most common LCD module. This makes it an industry standard compatible controller. The LCD is a lower power consumption LCD manufactured by Satistronics.com, an online wholesaler based out in China. This company was chosen over other companies for the LCD because they guarantee that the product is new and in working conditions with no defects. The company also sales LCDs at wholesale price compare to the competitors. The LCD was purchased for $7.88 online through this retailer and would have easily cost over $20.00 from any other company based out in the US. For example, CrystalFontz.com, a company that was researched early on because of their popularity with hobbyist, has a similar 20X4 character LCD that they sell for $35.02. Their LCD cost $20.00 more than the one sold at Satistronics and doesn’t come with a backlight. The technical and mechanical data for this LCD exceeds the minimum requirements set in choosing an LCD. The LCD has a unique white on blue character display. With a module size of 98.0 mm X 60 .0 mm X 14.0 mm, It will be able to display twice as many lines as a 16X2 lcd module and take as much space. The character size for the display is 2.94 mm X 4.74 mm and will be able to be viewed clearly at a fairly close distance. The backlight that comes with this LCD will illuminate the LCD intensely at night if needed. This will provide the programmers with the ability to program the LCD at nighttime. With the HD47880 chipset controller and driver, the module will be able to easily interface with the Arduino microcontroller. The module has a standard 16 pin connections, with the last two reserved for the backlight power and ground connection. The module can be easily powered by a 5V voltage supply. Similar to other typical LCD modules, the contrast on the LCD can be modified by a potentiometer. For 8 bit display programming, this module would require 11 I/O pins from the Arduino, but since 4 bit display programming will be implemented, about 8 pins will be utilized from the Arduino. The pins that will be connected to Arduino are pins 4, 5, 11, 12, 13, and 14 from the LCD module. These pins will be distributed to an available digital I/O on the Arduino board. Figure 6 shows a brief schematic of how the pins from the LCD will be connected. The potentiometer connected to pins 1, 2 and 3 controls the contrast the LCD module. It determines how bright the characters on the LCD module will be displayed. As stated earlier, a single resistor can replace the potentiometer to keep the contrast of the module at a constant value.

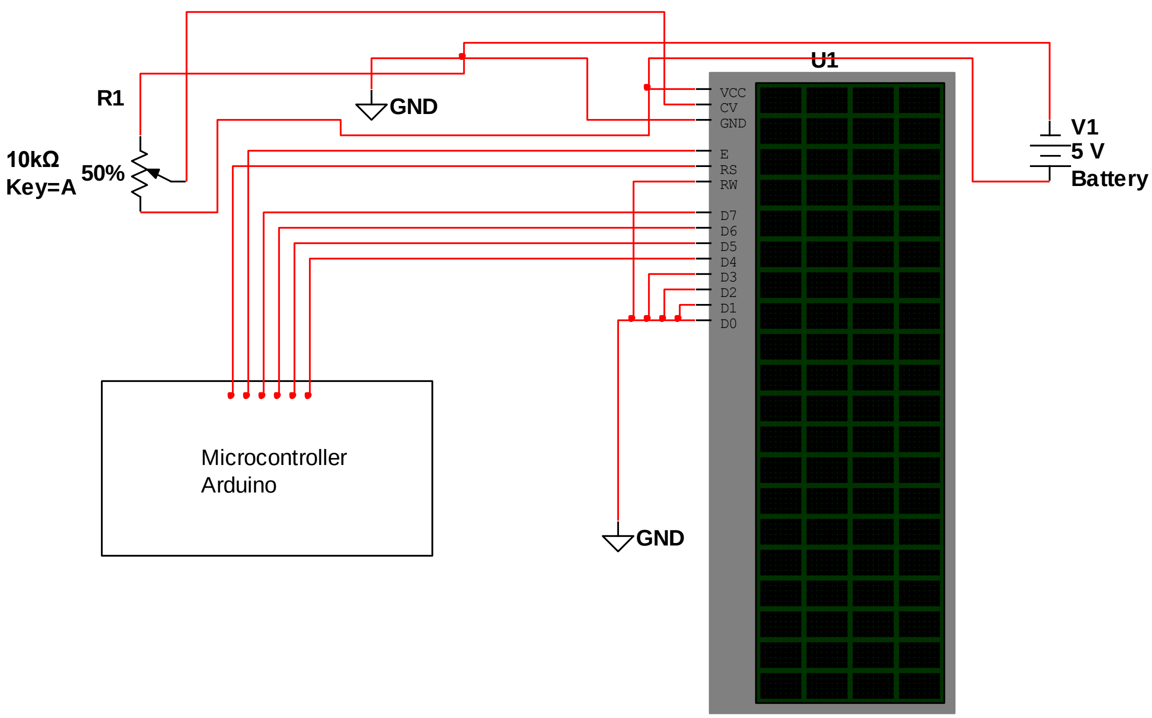

Figure 17: Pin Schematic of 20X4 LCD Module

3.4 Programming LCD

All the members of the group had to become familiarize with programming the LCD since all the blocks in the diagram required some type of information to be displayed on the LCD. The LCD will be used to display important information regarding the status of panel and the battery. It will be programmed by the Atmega328 chip on the Arduino. The Arduino has a built in LCD library called LiquidCrystal that has predefined functions to easily display characters on the LCD. Figure 6 shows the pin that will be used to interface with the Arduino for programming the LCD module. The methods from the LiquidCrystal library will be called to communicate with LCD module.

3.5 Motor Block

3.5.a Stepper motor controller

The stepper motor that will have to be used with this project requires high torque to be able to hold and maintain the solar panel under adverse weather conditions. High torques requires that the motor operate at high currents. To effectively control the stepper motors without damaging any of our other circuits, we decided to use a stepper motor controller. The stepper motor driver should have the following properties to be able to be used in our project:

- The driver should be able to handle 2A/phase current
- It should be able to handle voltage greater than 12 V
- Should easily interface with microcontroller for direction and step control.

Choices were narrowed down to two stepper motors that match those specifications. The first stepper motor driver is called Big Easy Driver and its being sold by Sparkfun.com (per Figure 18). The driver is design by Brian Schmalz and he provides the schematic file and eagle file for anyone to build their own version of the driver. The driver is based on the Allegro A4983 stepper driver chip. It can drive up to about 2A per phase of a bi-polar stepper motor and can handle a maximum voltage of around 35V. A 5v/3.3v regulator is provided to interface with the microcontroller. The main advantage with using this board is the high operating current and the max motor drive voltage. The drawback with this board of course is the price; Sparkfun.com has the board listed for $22.95.

Another stepper motor that the group looked into was the A4988 Stepper Motor Driver Carrier from Pololu.com. the driver uses the A4988 motor driver chip instead of the A4983 chip that the Big Easy driver uses. The two drivers are almost similar in specifications with this motor driver operating at a range of 8 to 35V and can deliver up to 2 A per coil. This board cost around $12.95 from pololu.com, which is well below the asking price from Sparkfun, The drawback with this board though is that it doesn’t include the two voltage regulators for 5 V and 3.3 V. To upgrade the board to include the two voltage regulators, the price will have to increase to $19.95. Figure 19 shows the schematic diagram of the Big Easy Driver v1.2, stepper motor controller. The group will use this schematic diagram and interface with the PIC microcontroller that is used to control the MPPT circuit to drive the stepper motors.

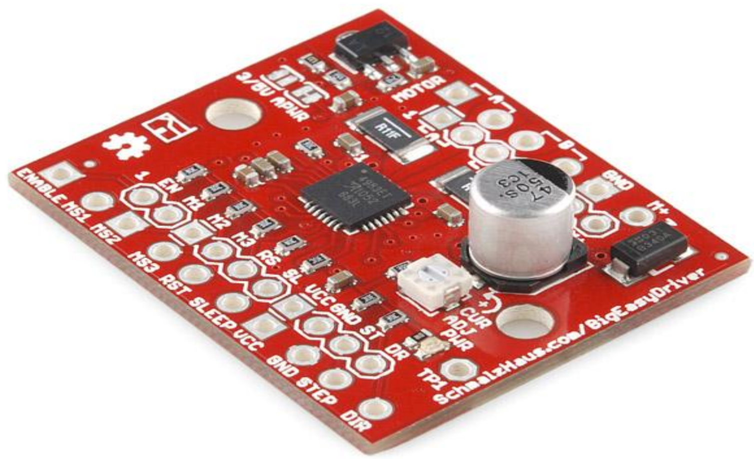

Figure 18: Big Easy Stepper Motor Controller Permission pending [JP20]

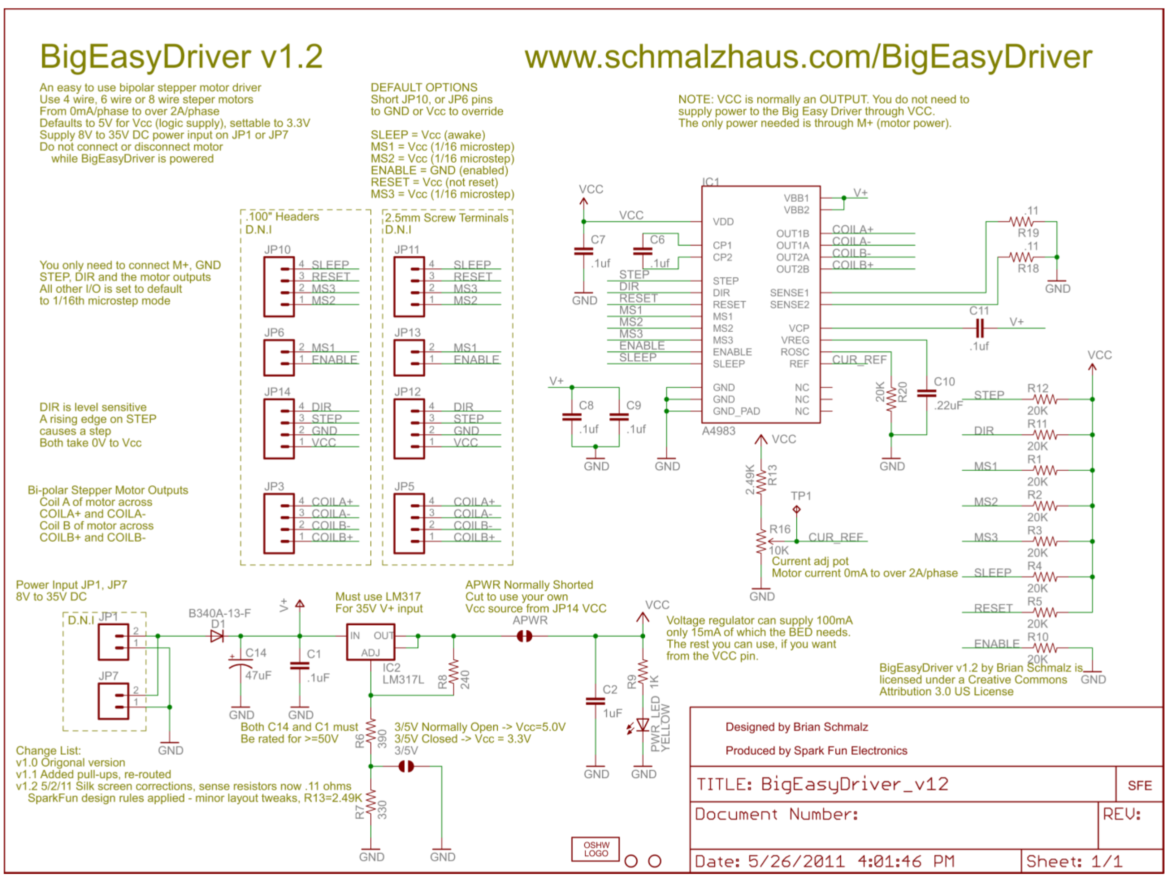

Figure 19: Big Easy Driver Board Schematic. Permission pending [JP20]

3.5.b Stepper Motor Chosen

The motor that will be used to control the rotation of the PV Panel will be a stepper motor. The reason being that stepper motors are more precise in movement and when controlled under open loop and they last longer than brushed motors. They are able to hold a greater torque when not in motion. Stepper motors have an advantage over regular motors in that they have internal gears to control speed and torque, and have no need of external gears for speed reduction. Stepper motors are more precise than regular motors because they move in predefined angle steps. The greater the number of steps in the motor the more accurate the motor will be. Our goal in choosing a motor is to pick one that has at least 200 steps of motion. The motor should have a high holding torque in order to hold the PV panel when it's facing the sun. The motor should also use the lowest current possible in order to keep the motor controller cool and efficient. The stepper motor will be controlled by a stepper motor driver. The stepper motor driver will connect directly to the stepper motor and the DC battery. The battery will be able to power the stepper motor controller, the stepper motor and the microcontroller that is attached to the stepper motor driver. Figure 20 shows how the configuration of the motor controller block and how it will interface with the battery and microcontroller. The battery shown in the figure is the same battery that will be used to in the DC/AC inverter circuit. This battery will be charged the PV panel. The MPPT circuit connecting the battery and panel will allow the battery to charge efficiently. The microcontroller will communicate the stepper motor via the motor controller. Although the figure shows 3 wire connections between the motor controller and microcontroller, the motor controller will only utilize two I/O pins from the microcontroller. One pin will guide the direction of the stepper motor going clockwise or counterclockwise. The other pin will guide the step taken by the motor. Each steps of the motor is 1.8 according to the specs of the motor. The third pin connecting the motor controller and microcontroller is the GND, which is the ground pin and that will connect to the ground of the pcb board. According to the manufacturer of the motor controller board, the board current rating can be modified to drive at the maximum current rating of the motor. Although the same battery powering the load attached to the DC/AC inverter is powering the motor controller circuit, the power generated from the motor controller block will be minimum considering that the solar tracking circuit will only be active for a couple of seconds every half hour. The microcontroller will keep the motor controller block asleep during periods where it's not active to conserve power. Every 30 or so during the time when the sun is above the sky, the motor controller circuit will track the location of the sun and direct the PV panel to directly face the sun. This tracking algorithm will allow the battery to conserve most of its power for supporting the load attached to the DC/AC inverter.

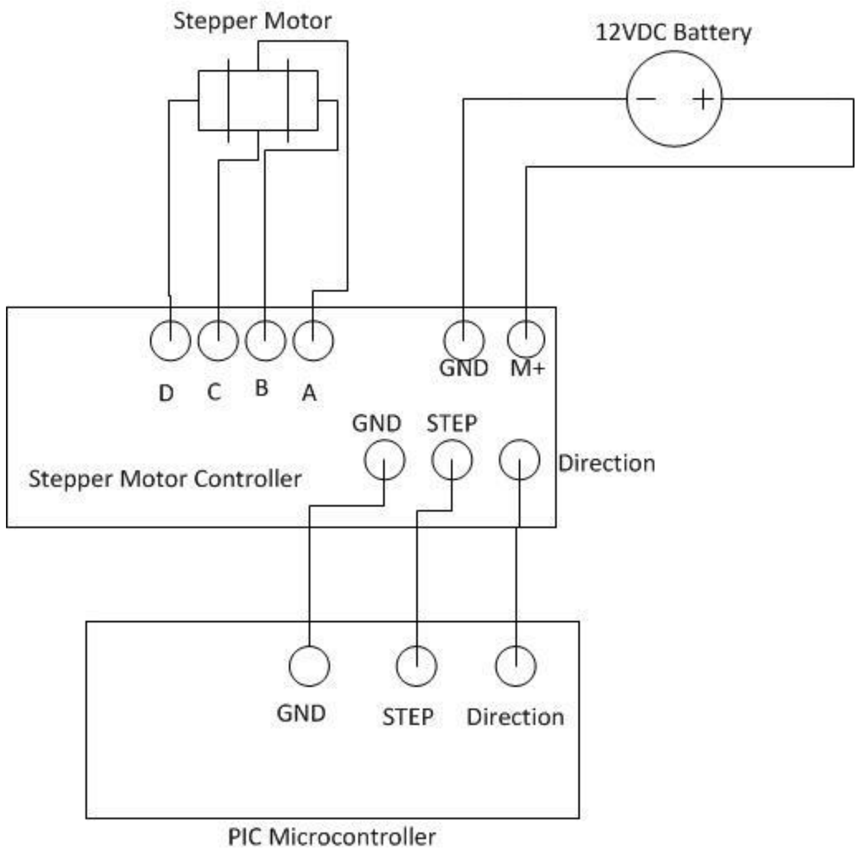

Figure 20: Motor block portion of Project

3.5.c Solar tracking algorithm:

The solar tracking algorithm is an important aspect of this project. It has been shown that a solar panel that directly follows the path of the sun has higher efficiency than those which don't. This efficiency can sometimes come at great cost though to the overall project. For example, the motor that will be used to rotate this solar panels cost more than the solar panel itself. Therefore, it might be easier to buy a separate panel than to implement a solar tracking algorithm circuit. Also, the motor operating current of the motor rotating the panel might be high enough to reduce the efficiency of the overall circuit. The overall goal of this project is to create a solar tracking algorithm that utilizes the smallest power possible from the battery so that it won't reduce the efficiency of the circuit. Figure 21 shows an oversimplified version of the solar tracking algorithm. This figure only shows the important aspect of the code and how it will be used to maximize efficiency of the circuit. When the solar tracking circuit is on, the algorithm will take two measurements from the two photo resistors. The photo resistors will be attached to the microcontroller operating the stepper motor. These measurements will be converted to digital values. Then, it will compare the values of the two photo resistors by subtracting P1 from P2. If P1 is bigger than P2 above a certain threshold, the panel will rotate towards P1 and will continue to do so until the difference between the two values are below the threshold. If P2 was to be greater than P1 and above the pre-determine threshold value, then the panel will moved toward P2 until the difference value was lower than the threshold. After this brief correction, the microcontroller will put the circuit to sleep for at least 30 min to conserve power. When the timer is up, the microcontroller will awake and track the path of the sun again by taking measurements for photoresistor 1 and photoresistor 2. Another setting that this algorithm will implement is a clock so that if the circuit is operating at nighttime or in the afternoon when the sun has already set, the microcontroller will shut the tracking circuit down and turn the panel to face East for when the sun rises in the morning.

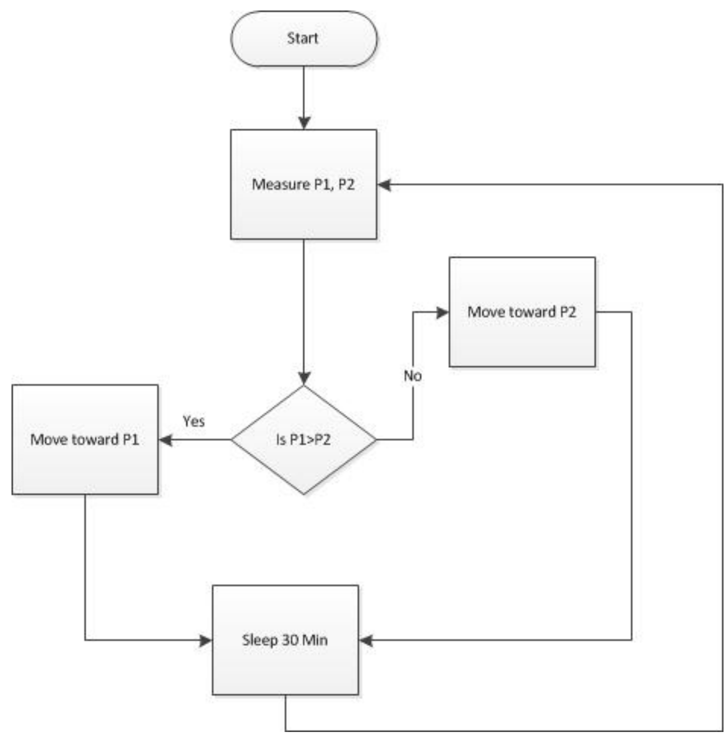

Figure21: Oversimplified Flowchart of Solar Tracking Algorithm

Table 22 shows some sample stepper motors research for the project. After extensive research on motor size and attributes, it was decide that a stepper motor size 23 will be sufficient enough for this project. Size 23 motors are have some of the highest torque rating and depending on the holding torque of the motor itself, it should be strong enough to drive to the solar panel and hold it under steady state conditions. All the motors listed on this table are fairly equal in terms of specs, but might have some irregularities on some category. Ebay.com seems to be a great site to acquire the motors and have some of the cheapest stepper motors available. The top three motors according to price was found on Ebay. These motors however excluding the first one required a current rating above 2.0. Since it was decided based on the motor controller that the maximum current rating would be below 2.0, these two stepper motors could not be chosen. One stepper motor that stands above all the rest is the NI NEMA 23 stepper motor from National Instrument. This stepper motor has a high torque rating of 180 oz-in and would require 0.4A per phase. The drawback with this stepper motor however is the price. At $139.00, this stepper motor is 4 times the price of any of the stepper motor on the list.

Based on Table 14, the group decided that the stepper motor from Lin Engineering will be the motor chosen for the project.

Stepper Motor	Website	Manufacturer ID	Holding Torque Oz-in	Voltage (Vdc)	Current Rating (A)	Weight (Kg)	Cost
Nema 23	Ebay	57BYGH 41-601B	55	12 Vdc	1.0 A	0.47	$30.11
Nema 23	Ebay	57BYGH 41-401B	76	12 Vdc	2.8 A	0.47	$30.11
Nema 23	Ebay	57BYGH 56-401A	175	12 Vdc	2.8 A	0.70	$37.99
Lin Engineering	Alltronics.com	5718M-05E-04	124	12 Vdc	2.0a	n/a	$19.95
NI NEMA 23	National Instrument	780073-01	180	12 Vdc	0.4 A	n/a	$139.00
AMCI	AMCI.com	SM23	240	12 Vdc	2.0 a	0.99	n/a

Table 14: Stepper Motor Comparison Table

The motor is the standard size 23 like all the other motors on the table. It has a 1.8 degree step and has a high torque rating of 124 oz-in. According to the manufacturer, the motor has the highest Step accuracy and high resolution. The operating voltage for this stepper is not specified, but it is stated according to the manufacture's spec that the power supply voltage can be any value as long the as the driver output current is controlled at the motor's rated current, which is 2.0A. The rated current amp of this stepper motor matches the maximum current at which the motor controller board will operate which is 2A. The number one reason for choosing this motor though is the price. For $19.95, this motor is cheaper than all the motors listed on the table and it exceeds the project's motor specification requirement.

3.6 MPPT

3.6.a Reference Design:

The goal of designing an MPPT (Maximum Power Point Tracking) circuit as previously explained is to obtain the largest amount of voltage vs. current from a solar array. There are numerous ways of designing and building such circuit. As shown in figure 22, from the solar panel the voltage will go to the dc/dc converter, this voltage will be going in parallel to a microcontroller and to the battery. The microcontroller will choose the maximum point at where the voltage and current will create the maximum power output as depicted by the equation P=IV. The goal of this MPPT is to obtain efficiency higher than 90%. Doing numerous amount of hours of research it seems the concept as described above is the same for pretty much all MPPT's but what changes is the way to implement them, efficiency do change depending how the MPPT is implemented but not by a lot. As described before analog MPPTs are cheaper and faster to build than digital MPPT's. Figure 22 is an all analog MPPT circuit; there are pros and cons regarding this circuit. One of the pros is that is it is very cheap to build as it is portrayed in table 15, it is basic electrical engineering because of the fact that the LM312H op-amp compares the incoming current and voltage and it maintains the maximum power point of both. The biggest issue with this design is that after varying the incoming voltage but keeping the same current this Maximum power point circuit wouldn't change the values from the old one to the new one, in other words it kept running with the chosen values of the old voltage and current and it wouldn't change to new values. This design reaches its peak to peak power when the FET is turned on with the 18 volts and 3.3 amps coming into the circuit making the wattage 59.4, but power loss is 15 watts on the output. This design is not going to be used because it is old technology and it defeats the purpose of efficiency. It is rated at 75% efficient leaving a lot of room for error, The LM312H op amp has been discontinued and, there are no substitutes for this specific op-am because of the fact that technology has evolved in such manner that the closest thing to make this specific design work is a Tl084 from Texas Instruments. Thanks to this reference design the concept of maximum power point tracking was understood.

Part	Manufacturer	Price
Capacitors	RadioShack	1.79
Resistors	RadioShack	1.19 (5-Pack)
LM312H Op Amp	Texas Instruments	2.30
Zener Diodes	ON Semiconductor	2.30
FET transistor	RadioShack	2.19
Diodes	RadioShack	1.50

Table 15, prices are per unit unless specified.

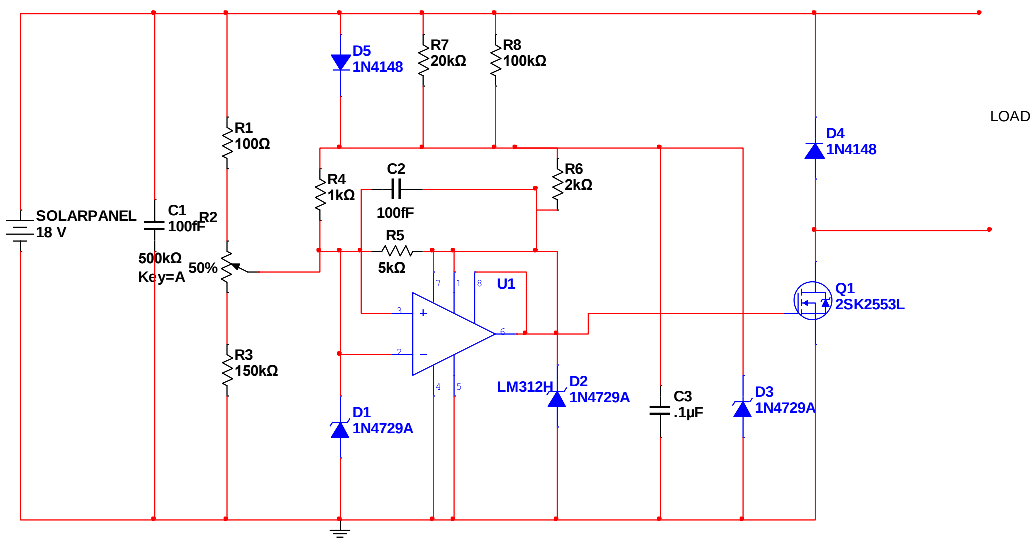

Figure 22, all analog MPPT circuit (JO13)

3.6.b Microcontroller used in MPPT

The PIC16f84A microcontroller from Microchip will be used; it has 1024 words of program memory. It has over 10k erase/write cycles, with enhanced FLASH program memory typical. It is low power, high speed technology, it is static design meaning that even when turned off, and memory will keep what it was saved to it. It has low power consumption. This microcontroller has a special feature that it has data retention for over 40 years. It has in-circuit serial programming via two pins RA1, RA0. Operational voltage is 2 to 5.5 V, which is why there has to be a voltage regulation circuit right before plugging in electricity directly into this microcontroller. Another reason why this microcontroller will be used is because of low power consumption, since the whole goal of the project is to maximize efficiency and reduce power loss, the PIC microcontrollers are known to consume less and less power as technology advances, the new family of the PIC 8-bit MCUs, has 200 nanosecond instruction execution. The PIC family microcontrollers are programmed in Assembly code, it is very easy to program. A compiler like visual basic can be used to compile whatever program is used for the MPPT. The purpose of the code is to loop until it finds a point where the voltage and the current are max, when this happens, it will save those two points to a register and it will send back this signal to the voltage regulator telling it at what points the maximum power point tracking is happening as shown in figure 23. The maximum power point happens when the voltage is at its pick but the current is at a point where it can maintain maximum power as described by the equation P=IV.

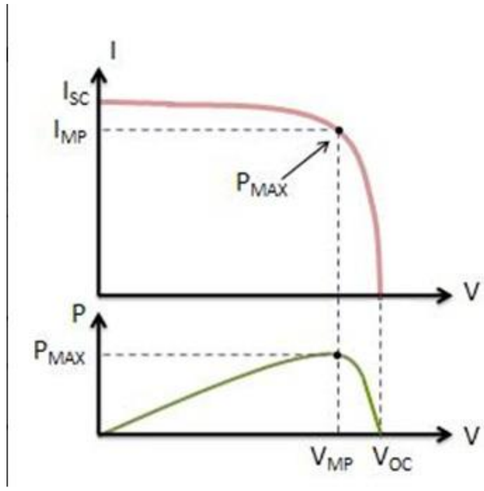

Figure 23, example of a solar panel I-V graph showing where MPPT occurs.(JO5)

This MPPT will use numerous quantities of parts from the basic in parts from Resistor Capacitors and Inductors to more advance parts as the microcontroller and the buck and boost regulators. Two potentiometers will be used, one of them is used to control the frequency and the second one is used to control the current. The following is a list of the parts that are going to be included in this MPPT including manufacturer and price. Majority of the parts will be purchased from RadioShack because of the fact that this store is local and there won't be shipping constraint and time won't be a factor

Part	**Manufacturer**	**Price**
PIC-16F88	Microchip	1.33
LM 358 (op-amp)	RadioShack	2.19
MBR-20100 (Schottky Diode)	ON Semiconductor	.98
Resistors	RadioShack	1.19 (five-pack)
Capacitors	RadioShack	1.23
TL499 (voltage regulator)	Texas Instruments	1.17
NPN Transistors	RadioShack	2.49
Zener Diode	RadioShack	1.59
Diode	RadioShack	1.19
Power Mosfet	RadioShack	3.38
10k Ohm Potentiometer	RadioShack	1.99
Inductor	RadioShack	1.49
Bare bone PCB	Best Global Source Inc	50.00

Table 16 – Prices MPPT

** All prices are per unit, unless specified.

The parts will cost about 37.66 and that is not including shipping in parts like the PIC microcontroller and the Schottky diode, shipping is 5 dollars using domestic shipping, this being the cheapest one. Taking into account that some of the components might be broken or burned out after a few trials, three of each will be bought.

The PIC microcontroller will have to be programmed in a PIC development board, these boards are sold separately, and costs for these types of boards change in a measurable way from 25 dollars up to 150 dollars. It is hard to choose a specific board because of the fact that the concept is basic; each packet brings a PIC USB kit, with a CD and a USB cable, based on reviews and durability a development board made by Microchip solutions has been chosen. It brings the following:

- USB port
- Power LED
- 2 users LED's
- 1 RS232 port communication for connection with PC or other devices
- ICSP port for on-line programming and debugging
- 1 potentiometer

This MPPT will be built in a breadboard first before soldering the components into a bare bone PCB; this is just to make sure that every component is working fine. The TL499A is a step-up voltage regulator that has been used in the design software and simulation, due to reputation, durability and, most importantly good reviews. It is made from Texas instruments, due to technology there are quite a few newer bucks and boost converters from T.I that claim better efficiency. This represents just a bit of an issue due to the fact that there is no simulation software for this components, now the TPS6360 is a buck-boost converter, at 93% efficiency this is one of T.I's newer products, layout wise it is similar to the TL499A and in simulation a TL499A will be used, but for building a TPS6360 will be used.

There are numerous designing constraints, the biggest is that one knows of a part/component that might benefit the project and it has been used before in previous built for other purposes but cannot find a spice model for this part and therefore one won't know how this part behaves. Due to the rapid changes in technology newer parts appear on the market almost every day, and yes many of them are built on previous designs meaning that number of pins, cut-off voltage might be the same but efficiency is different, this is one of the biggest constraints on the current project. The way to overcome such thing is to design using the old part but to build using the newer one, parts are similar enough to simulate an older one but once the project is build, the efficiency of the newer part will be obtained. Designing a circuit board and testing it in real life is totally different due to the fact that theoretical values and real-time values are different.

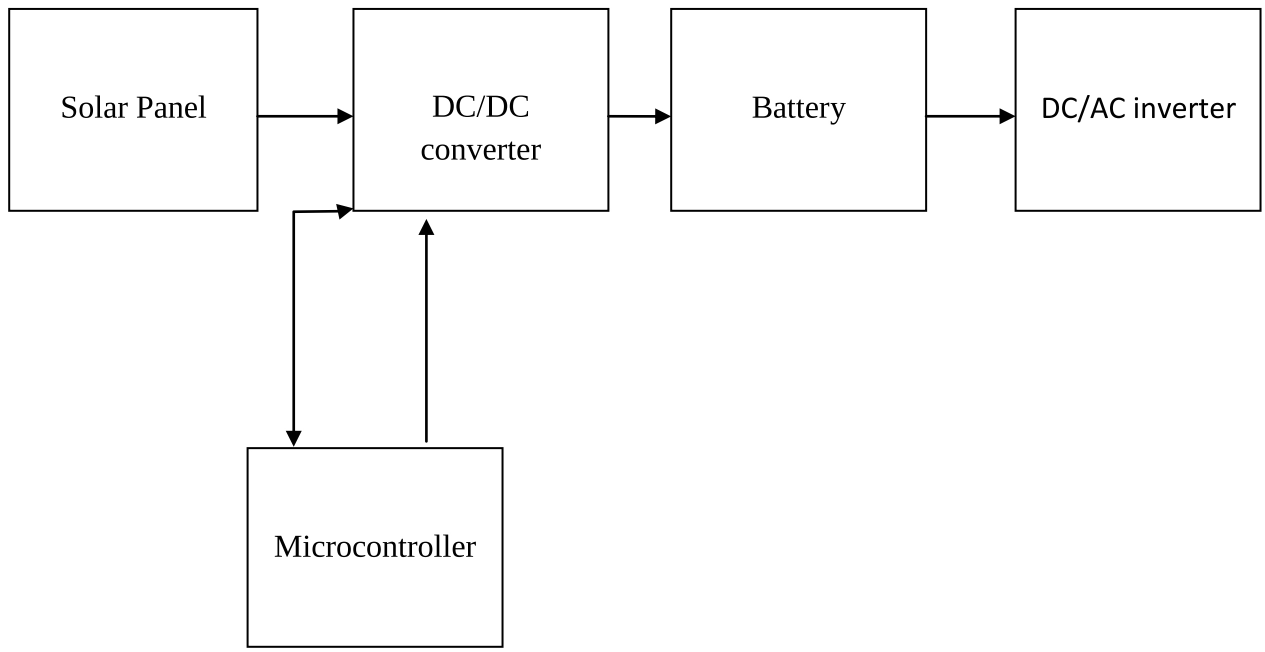

Figure 24, block diagram of main circuitry.

The design that the team will use in this project is by using a microcontroller making it a digital MPPT. The input of this MPPT is from 12 volt solar panel and it will have a configuration of 12 volts throughout the whole circuit feeding a 12 volt battery. This MPPT has a charge controller operating in shunt mode meaning that once the battery hits the mark of being completely charged it will stop charging. The biggest step on designing this MPPT is to code the microcontroller in such a way where timing won't be an issue, even though the microcontroller is really fast executing commands, an efficient code is likely to find the maximum power point faster. The MPPT will be encased in a plastic MPPT efficiency is acquired by power consumed on the circuit by the power generated by the source in this case being a solar panel. The system will suffer from IC losses, diode losses and operating losses. This project will be done using a 60 watt solar panel. Since the MPPT will have a 12 Volt, 24 Volt maximum set-up. For example taking into the account the MBR20100 Schottky barrier rectifier uses about .2 watts of power and irf9540 HEXFET power MOSFET uses about .9 watts of power and 2 watts of power loss due to overall impedance we can easily calculate efficiency on the MPPT thanks to the equation: Efficiency= [(Power in)-(Power loss)]/(Power in). An anticipated total loss of 3.1 watts is expected and by plugging in numbers into the equation, and anticipated efficiency of 94.83% is expected this will be accomplished by using large cables to input the current and voltages from the solar panel to the circuit and from the circuit to the battery, larger cables will have less impedance.

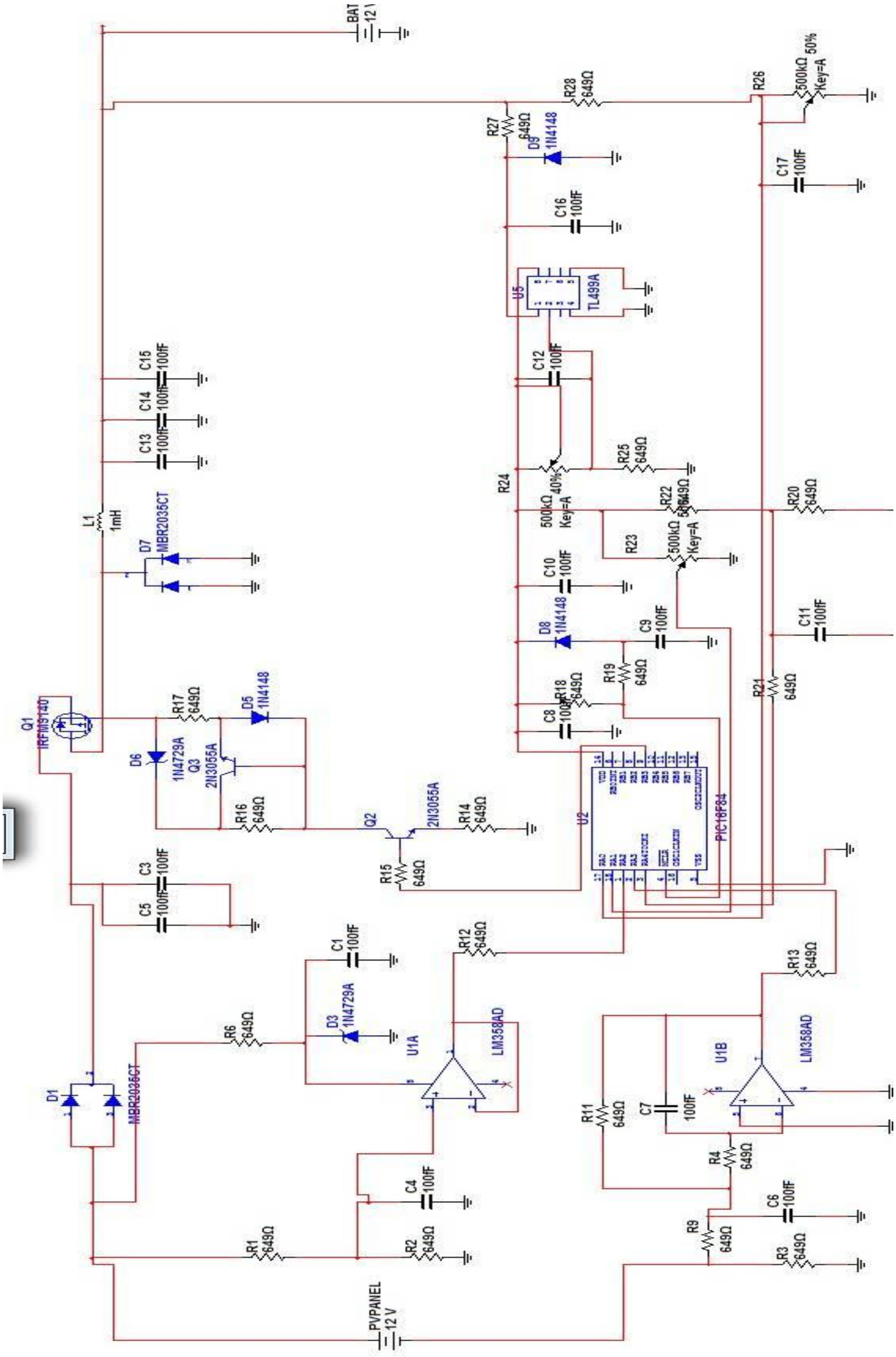

Figure 25 –MPPT Design

3.6.c MPPT Algorithm Used

With all the different types of MPPT algorithms under consideration, the algorithm that will be implemented by this project is the modified Perturb and Observed algorithm. Similar to the regular Perturb and Observed algorithm, the modified P&O is simple to implement with a microcontroller. It will provide the system with over 90 percent efficiency. The modified P&O will reduce oscillation created by the standard perturb and observe algorithm and will get a closer approximation of the Maximum power point of the PV Panel. The PIC microcontroller will be used to run the modified P&O algorithm.

3.6.d DC/AC Inverter Reference Design

By doing an all analog power inverter, parts might be available faster and, it is way more convenient to do it all analog, by using a 1:25 transformer with a rating of 12 amps, we are looking at about 200 watts of uninterrupted power, now for higher power, transformers with a higher rating need to be attained,. Also these transformers are very rare to find because of the fact that the input need to be DC and the output is AC. There is little equipment made this way. A 20 amp transformer usually works at both 50 and 60 hertz usually about half a square foot in size. With a price ranging in 150 US dollars, the transformer is a very big part of this project because it is what will power the electronics connected to the outlet. The DC/AC inverter will get very hot because it will be carrying a very large amount of current. Various schematics have been made like figure 26. That shows a preliminary dc to ac inverter stepping up the voltage from a 12 VDC to a maximum 114 VAC. This approach won't be used because of the fact that it is not efficient outputting milliamps of current when in reality the group needs usable amps.

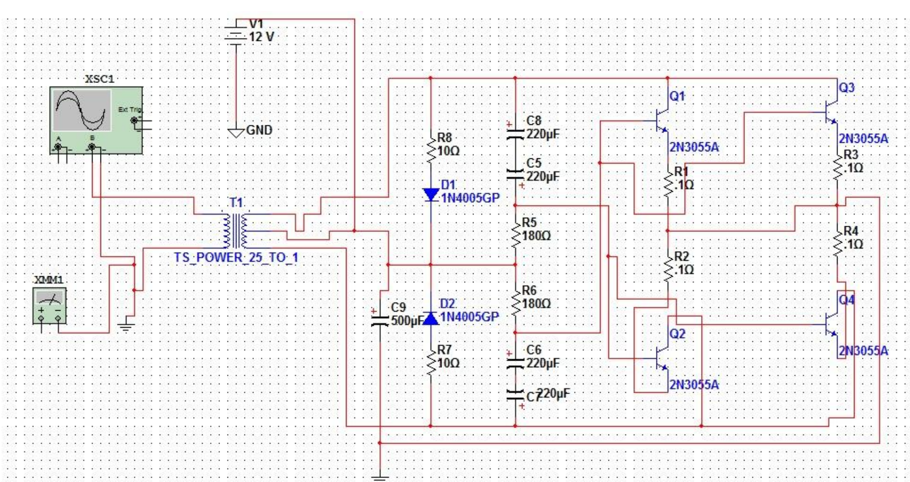

Figure 26. Preliminary DC to AC inverter [JO11]

The design above is a preliminary design that works with a 12 volt input and uses the following parts:
1. One Transformer rated at 12 amps with a turn ration of 1:25.
2. Four 2N3055A high power transistors, rated at 15 amps.
3. Five electrolytic capacitors.
4. Two 1N4005GP Diodes.
5. Eight low impedance.
6. Resistors

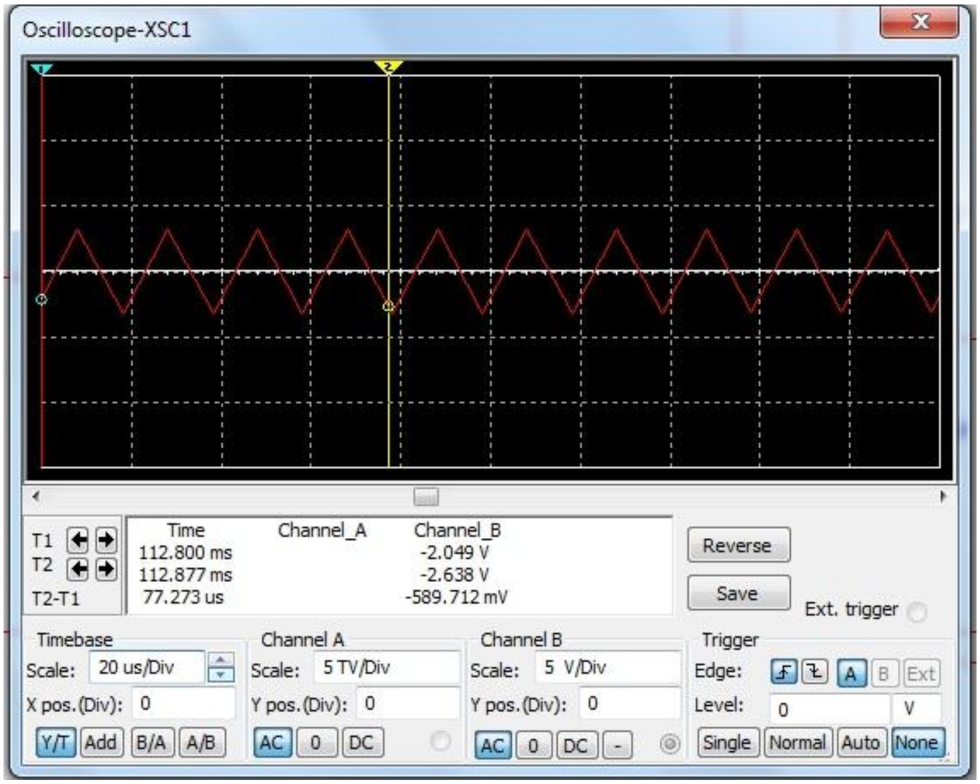

Figure 27, voltage graph.

The voltage graph for this system is shown in figure 28. Although is a triangular wave at very low voltages, this graph is obtained when the capacitors are discharged. This inverter is working at an average of 80 HZ, trying to lower the frequency changes the graph and it makes it more of a square wave. For this inverter to work in an efficient manner, it needs to provide 110 VAC-120 VAC, with 0-10 Amps of current and 50-60 Hertz of frequency, this design is inexpensive but at the same time is inefficient. As mentioned above to have an efficient current being produced out of the transformer, a custom transformer will be ordered. Local or national companies like Renco electronics, where the costumer can send in the schematics or measurements of desired transformer and they will try to accommodate to the best of their capacity.

Figure23. Shows the schematic of a dc to ac inverter using a 555 timer, knowing the structure of a 555 timer, this circuit is expected to save space and time just because of the fact that it uses a LM555 timer that costs 1.99 made by Texas instruments and it can be found at the local radio shack. The schematic below shows the inverter producing and outstanding 61.549 Hz and 114 Volts. The potentiometer on the left side of the inverter is a 1.3M variable resistor and it is set to 90% meaning 1.17MOhms. The way this square wave is produced is that it charges one of the capacitors and as it discharges it will charge the second capacitor oscillating the signal, also the insides of a timer have two OR gates that will alternate the signal helping smooth out the wave form. The potentiometer by being set to a high resistance will slow down the frequency. Theoretically this should make any electronic device work but a design like this one has been tested powering a 13 inch TV and the image was distorted by a little bit. Reliability might be a big factor in this project but after running the simulation for over 20 minutes the graph was steady to 61 Hertz and a peak to peak 114 Volts as its shown in Figure 30. There are three main things when designing a power inverter and they are: surge, typical and Average power. Surge power is the maximum power that an inverter can supply, when designing the schematic below, it was noted that a surge power of 200 Volts was obtained but only for a few seconds. Typical power is the kind of power that an inverter will supply steadily and for long periods of time, as it was explained above the typical power of this design is 114 volts. Average power is not used with the same frequency as Surge or typical power just because of the fact that average power is mostly theoretical and it is used mostly on ratings.

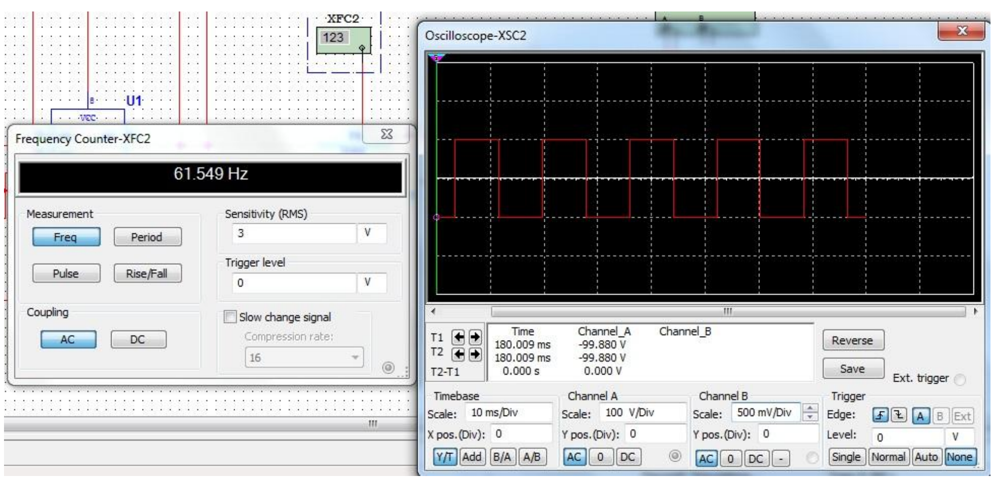

Figure 28 , graph and frequency of a 555 timer inverter.

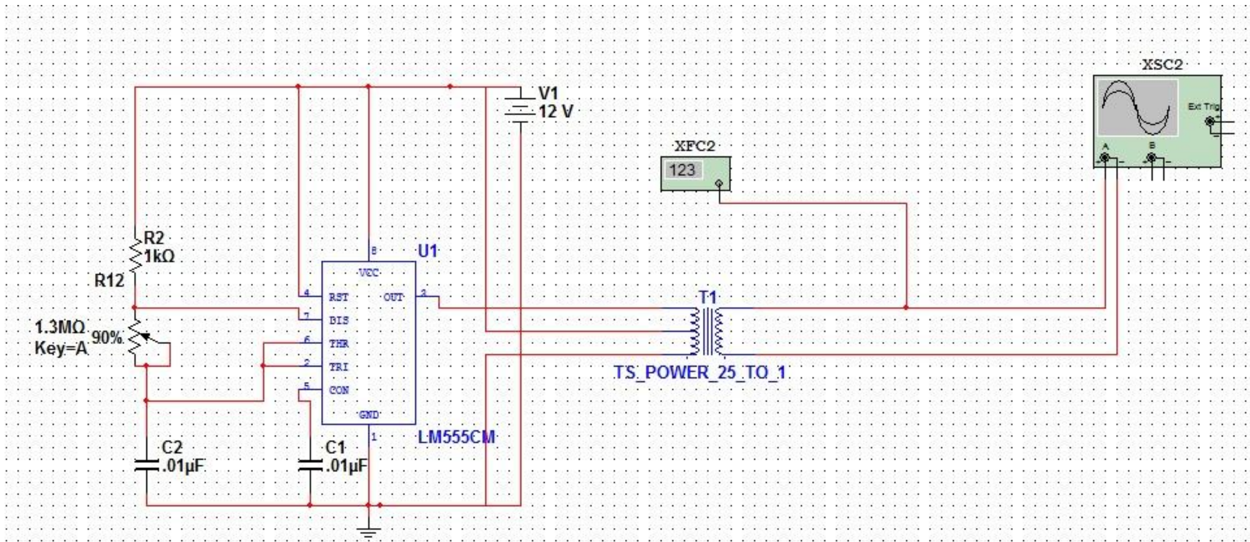

Figure 29. Schematic of a 555 timer.(JO9)

Figure 30 represents a pure sine wave generating circuit using a LM348D op-amp. It has a potentiometer to control the frequency. This is a pure sine wave and the biggest constraint there is, when amplifying the signal using a transformer, the sine wave is distorted and the graph looks completely different. Reading on various journals and articles, it seems that the designing software has infinite harmonics when it comes to simulating the signals, in real life harmonics/graphs do have an end, making the build more reasonable and efficient, although this approach seems to be the way to build the inverter, it is not efficient because of the fact that the output of the wave is in between +/- 2 volts and then the signal is amplified it is not sufficient to achieve the desired 120 volts nor the current is enough.

Component	Manufacturer	Price
LM348D (op-amp)	Texas Instruments	.50
Potentiometer 100Kohms	RadioShack	3.19
Resistors	RadioShack	1.19 (five-pack)
Capacitors	RadioShack	1.23
Step up Transformer	Renco electronics	28.00
Inductor	RadioShack	1.49
Bare bone PCB	Best Global Source inc.	50.00
NPN Transistor	RadioShack	2.49

Table 17 – Preliminary design for DC/AC Inverter

** All prices are per unit, unless specified.

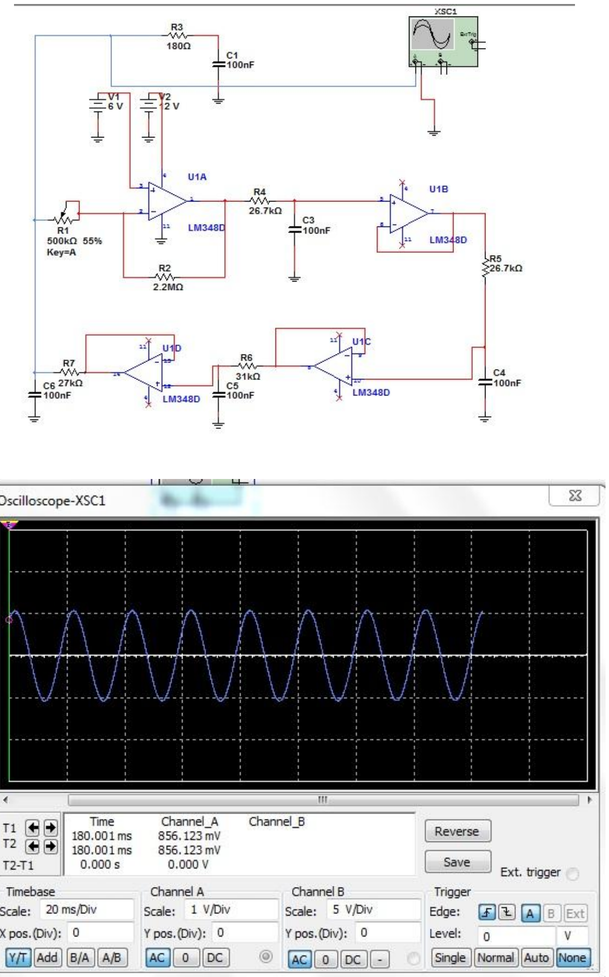

Figure 30, Sine wave generating circuit.(JO8)

3.6.e PIC Controlled DC/AC Modified Sine Wave Inverter

The concept of using microcontroller was discussed and this reference design in figure 31 was used to build the circuit. The design was tested on Multisim to see if it met the project requirements of building an efficient DC/AC inverter. The circuit was found on a website called www.m0ukd.com, and it was designed by John Parfrey, the creator of the site. The original design from the authored featured a PIC16F628A microcontroller to generate the modified square waves, two STP55NF06L mosfet transistors. There's a LM70L05 that regulates the 12 Volt coming from the battery and transfers it to the microcontroller. This voltage from the battery steps down to 5V to safely power the microcontroller. The circuit is supposed to boast about 500 Watts if the supplied battery is 12V at 40A with 220 Volt on the output using 12-0-12 transformer. To test this circuit, it was designed in Multisim using the appropriate parts that the circuit diagram alled for in correct implementation.

The Multisim designed of the modified sine wave inverter is a little different than the parts mentioned in the diagram because Multisim had a limited materials list. Some of the parts from the original circuit were changed to match the circuit parts available in Multisim. The PIC16F628A microcontroller was replaced with PIC16F84, and the two original STP55NF06L were replaced with an equivalent IRL2505S transistor. The LM7505 voltage regulator was also replaced by a LM7818CT regulator. The HEX file was loaded to the PIC Microcontroller using the Multisim function. The Multisim circuit was connected to an oscilloscope and produced the modified wave shown in the figure 31 below. When tested, the circuit produced approximately 120 volt peak to peak. Instead of the 60 Hz projected by the circuit, the frequency counter in Multisim showed 184 Hz. That's a major disparity in the frequency and could really damage whatever load that was connected to it. Another drawback to this circuit is that the voltage is unregulated and depending on the voltage coming in from the battery, the output voltage will be impacted severely. The higher the input voltage from the battery, the higher the AC voltage coming out will be.   This circuit currently represents the intended design that will be implemented in the prototyped module; however, optimal efficiency in power output calls for a Pure Sine Wave, not the Modified Sine Wave that is the output here. Research & Design efforts are ongoing, and if a circuit design can be achieved with this optimal output, the project goals dictate that this, more efficient circuit, will be incoroporated into the design instead of the Modified Sine Wave. After careful consideration weighing all vailable possibilities at hand, it was decide this reference schematic would not be followed for the actual design to be used.

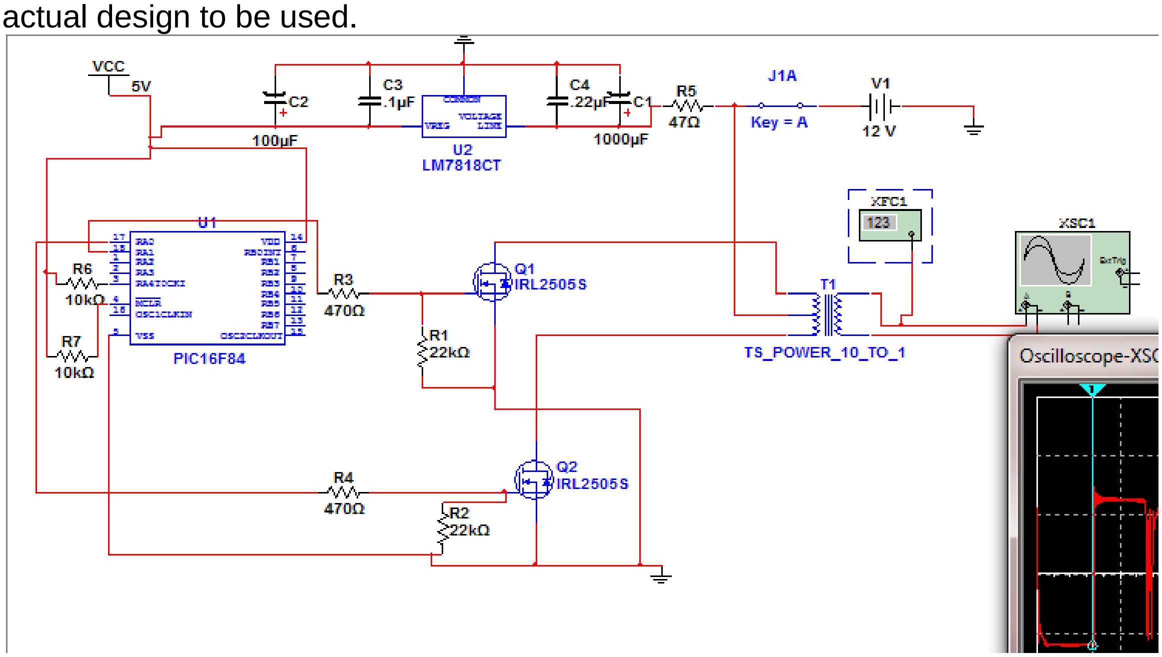

Figure 31: Modified Sine Wave Inverter on Multisim. [JP21]

3.6.f 555 timer modified wave design:

This design features a 555 timer where the output is followed by a fourth order low pass filter, since the output of the timer is a pure square wave. by definition, when a square wave enters a fourth order low pass filter it is supposed to convert it into a modified sine wave, the reason it is showed like a modified sine wave is because of the fact that the simulating software has an infinite amount of harmonics, as it has been explained, in real life the amount of harmonics is limited. Based on conversations with retired electrical engineer Larry Beaty who is retired of a company that made over one hundred of power inverters per day, this approach, will be both, convenient, inexpensive, and very reliable. In figure 31 the two waveforms of this inverted will be examined, figure 32A is the waveform that the 555 timer forms and figure 32B is the output of the waveform after it passes the low pass filter, 6C is a combination of both waveforms. After numerous hours of research and design, this approach will be used as the circuit to take and build. It was a successful implementation of the design that was discussed before; it came as a result of both research and knowledge gained in a couple classes from the electrical engineering curriculum in UCF. Below is a list of parts and prices that will be used in this circuit are:

Part	Manufacturer	Price
TI TLC555 Timer	Texas Instruments	1.99
LM 358 (op amp)	Texas Instruments	2.19
Resistors	RadioShack	1.09 (5 piece package)
Capacitors	RadioShack	.79
Potentiometer	Cermet	2.37

Table 18, all prices are per unit, unless specified.

Power and dimensions of the 555 timer modified wave inverter what makes this inverter so special is the fact that it works providing very little power loss, based on pure theory and information gathered from simulation software, the following values were gathered:

-Voltage (peak-peak): 10.4 Volts without transformer. With transformer it became 162 Volts peak to peak.
-Voltage (rms): 7.45 Volts without transformer. With transformer it became 115 volts.

-Frequency: 61.4 Hertz.
-Input current: 4 amps.
-Output current: 2-3 amps.

It is clear that the signal is modified to a more usable point after it goes through the low pass filter. Another method of trying a higher order low pass filter was tried but it did not give any successful results because of the unlimited amount of harmonics that the simulating program uses makes the result crash. Based on research discussed before, this is the most usable and reliable approach was designed, it is very clear that this design is a combination of both designs discussed above. University of central Florida teaches a course in analog signals and, on lab 4 the group learned how to convert from a square wave to a sine wave, although the lab was done with Texas instruments op-amps TL-084, but better results have been obtained with the use of the LM358, it will be used from Texas instruments as well.
Since the biggest concern in this project is efficiency, following the principle of power in equal power out, the input of the inverter is 12 volts with 4 amps of current and, power out is 10.4 volts with 3 amps of current understanding the equation below:

$$P_{eff} = \frac{P_{out}}{P_{in}} * 100\% \quad , \quad P_{eff} = \frac{31.6}{36} * 100\% \ = 87.7\%$$

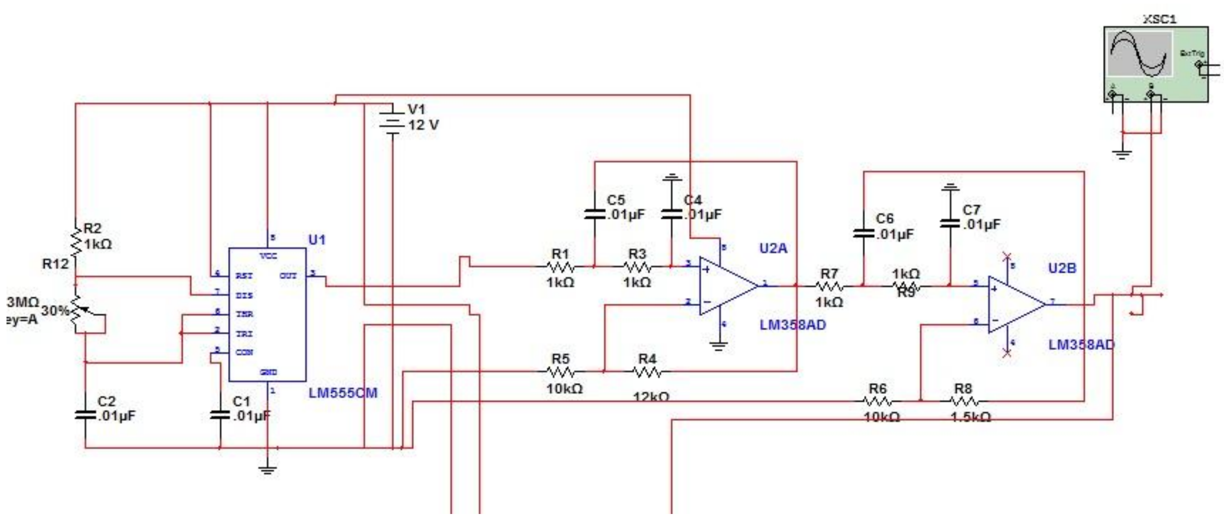

Figure 32 modified square wave DC/AC inverter.

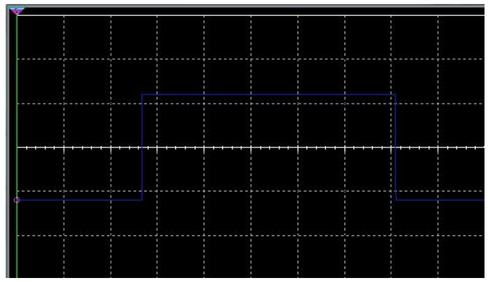

Figure 32 (A)

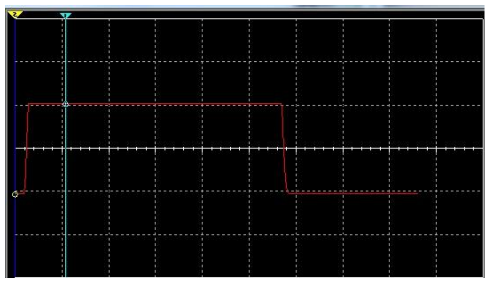

Figure 32 (B)

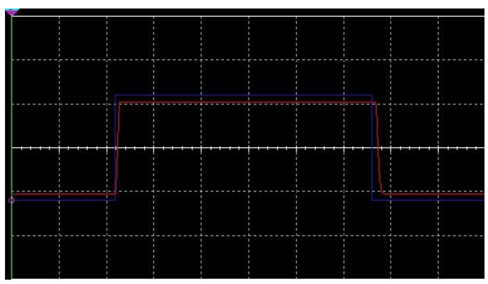

Figure 32 (C)

A. Pure square wave form, B. modified square wave form, C. both waveforms combined.

3.6.3 Transformer

the transformer that will be used to build the DC/AC inverter will be two in one power transformer RL-2270 from Renco USA, it is center tapped ideally used for electronics to step-down 120 volts AC to 12 volts DC, it is chassis mount capable of withstanding up to 130 degrees Celsius. The beauty of this specific transformer is that it can easily be modified to work up to 230 volts AC, although higher current will be needed for this approach, the price for this transformer is 28.00 dollars

3.7 Solar Panel:

A 60 W 12V Solar panel will be used for the project. There are a lot of different sources to purchase this panel, all with very similar specs. This panel was chosen because of its cheap price since that is the only factor that is different than our other options. The panel will be purchased on Ebay and price will include the shipping and handling. Refer to Table 19 for specs on solar panels.

Solar Panel Specifications	
Maximum Power	60W
Nominal Voltage	12V
Operating Voltage (Vmp)	18V
Operating Current (Imp)	3.34 A
Open Circuit Voltage (VOC)	21.24V
Short Circuit Current (Isc)	3.66A
Weight	14 lb
Dimensions WxLxH (mm)	805x535x30
Price	$129.98

Table 19 –Solar Panel Specifications

3.7.1 Zener Diode:

The chosen Zener Diode will be the 1N4733A made by Vishay, seen in the following table.

Characteristics of 1N4733A	
Max Stead State Power Dissipation Tamb ≤ 50˚C	1 W
Operation and Storage Temperature Range	-65˚C to 200˚C
Forward Voltage for If = 200 mA	1.2 V max
Surge Rating	890 mA
Nominal Zener Voltage	5.1 V

Table 20 – Characteristics of 1N4733A

3.8 Current Sensor

3.8.a CSLWT6B100

This is an open loop current sensor which measures AC or DC currents up to 100 amps, has sink or source output, through hole and is bottom mount. This current sensor features a wired open loop design which has multiple turns for increased sensitivity. It's current sinking or sourcing output makes for flexible interfacing. Some of its other features include, fast response time, accurate low cost sensing, minimum energy dissipation and built-in temperature compensation which ensures relatable operation. This sensor has any different types of applications such as current monitoring, over current protection, ground fault detectors, robotics and mobile battery management systems. [L12] With an operation temperature range of -25 °C to 100°C it is a potential candidate for use in our project.

Characteristics of CSLWT6B100	
Sensor Type	Open Loop Linear
Sensed Current Type	AC or DC
Sensed Current Range	±100 AT
Package Style	PCB Bottom Mount
Supply Current	9 mA Max.
Supply Voltage	4.5 Vdc - 10.5 Vdc
Response time	3µs
Operating Temperature Range	-25°C to 100°C
Offset Current	1mA (sinking); 1.5mA (sourcing)
Offset Voltage	Vs/2
Mounting	PCB on 3 pins
Output	2.5 V
Price	$11.62

Table 20a –Characteristics of CSLWT6B100

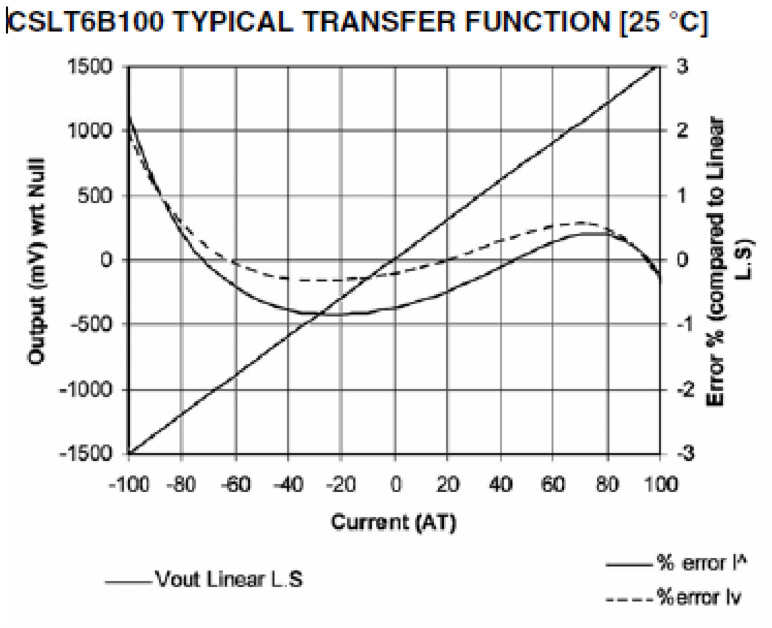

Figure 33a -From CSLWT6B100 Datasheet (permission pending)

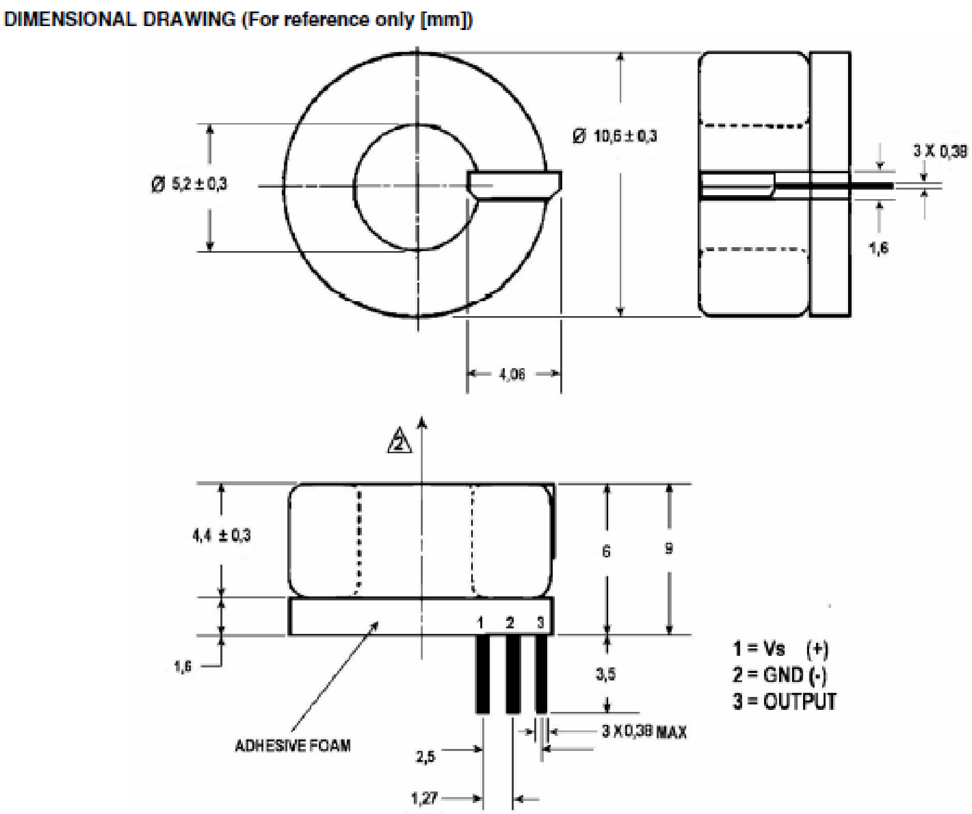

Figure 33b- From CSLWT6B100 Datasheet (permission pending)

3.8.b ACS714

This is a hall effect-based linear current sensor which operates between 4.5 - 5.5 V and has an output sensitivity of 185 mV/A. Since we have to step down our solar panels output voltage to 5 V for our voltage sensor, this makes this sensor a potientially good fit. It has a bidirectional current input which ranges from -5 to 5 A. The sensor will output an analog voltage which is linearly proportional to the input current. When Vcc is 5 V, the output voltage is centered at 2.5 V with 0.185 V/A sensitivity. When there is a positive current, it will increase the output voltage

Characteristics for ACS714	
Size	0.7" x 0.8"
Weight	1.3 g
Current Sensitivity	0.185 V/A
Max logic Voltage	4.5-5.5 V
VCC	5 V
Current input	-5 A to 5A
Operating Temp Range	-40 degrees C - 150 degrees C
Price	$9.95

and vice versa.

Table 22 –Characs of ACS714 sensor

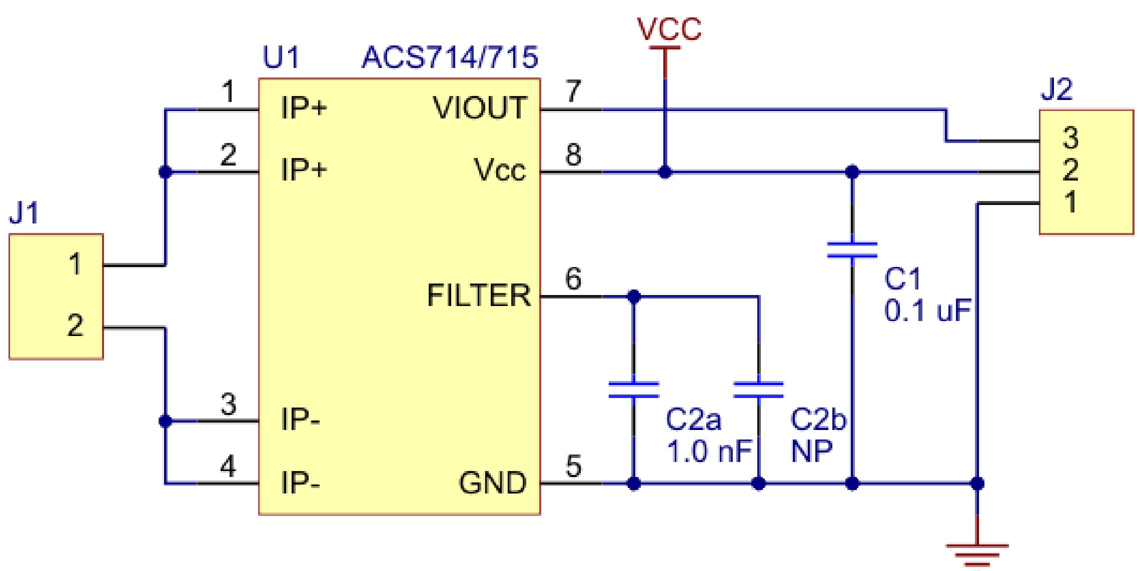

Figure 34 - From ACS714 datasheet permission pending

3.8.c CR5410-20

This is a Hall Effect current clamp sensor which clamp will clamp around the outside of the wire which allows the user to place the clamp where ever it is most suitable. Since this is a current clamp there is not a need to solder pints to a PCB unlike a surface mount sensor. It also doesn't require any extra circuitry to ensure the accuracy of our output.

Dimensions of CR5410-20

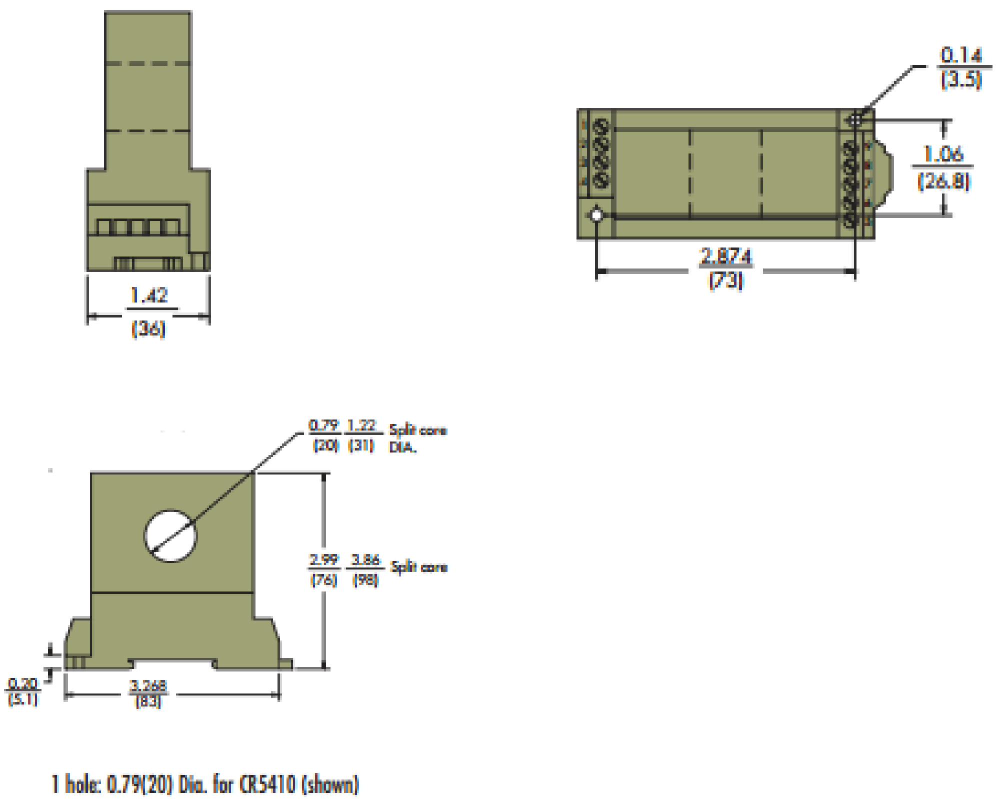

Figure 35 -Diagram shows measurements of the CR5410-20 (permission pending)

Characteristics for CR5410-20	
Supply Voltage	N/A
Supply Current	N/A
Current Measured	0 - 20 A
Operating Temperature	0˚ C- 60˚ C
Output Voltage	± 5 VDC

Table 23 - From CR5410-20

3.9 Temperature Sensor:

3.9.a TMP36

This is a low voltage, precision centi-grade temperature sensor. The voltage output from this sensor is linearly proportional to the Temperature of the sensor in Celsius. We can expect accuracies of ±1°C at +25°C and ±2°C over the −40°C to +125°C temperature range. The supply voltage of this sensor ranges from 2.7 Volts to 5.5 V. This sensor is appealing because of its large temperature range which encompasses any normal outside weather temperature. The most common way to mount this type of sensor would be use thermally conductive epoxy or glue which is electrically nonconductive. The following figure shows a typical circuit configuration of the sensor. It is noted that a 0.1 µF bypass capacitor is at the input. It is important that this capacitor is placed as close to the sensor supple pin as possible and is a ceramic capacitor.

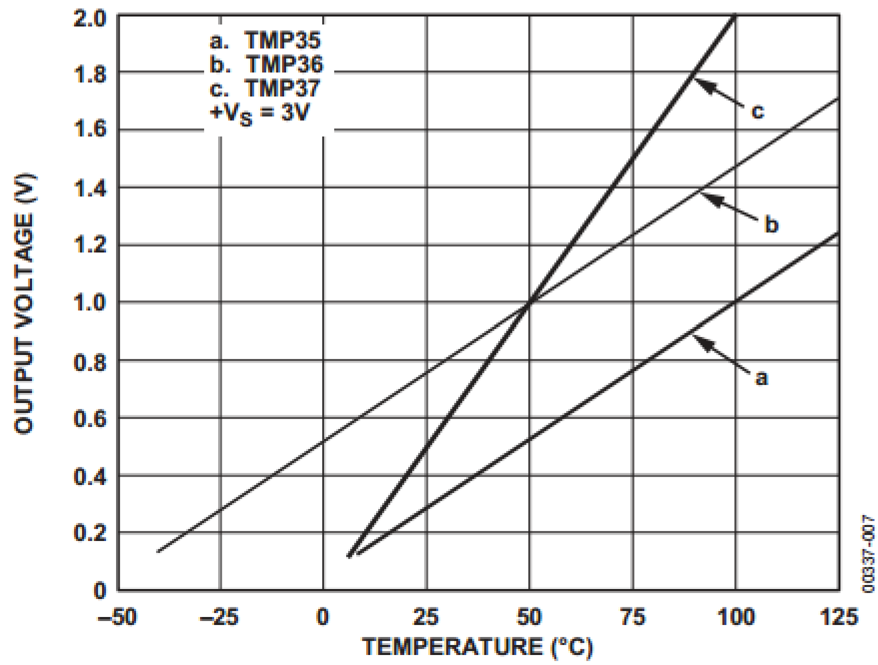

Figure 36- Output Voltage vs. Temp From TMP36 datasheet, permission pending

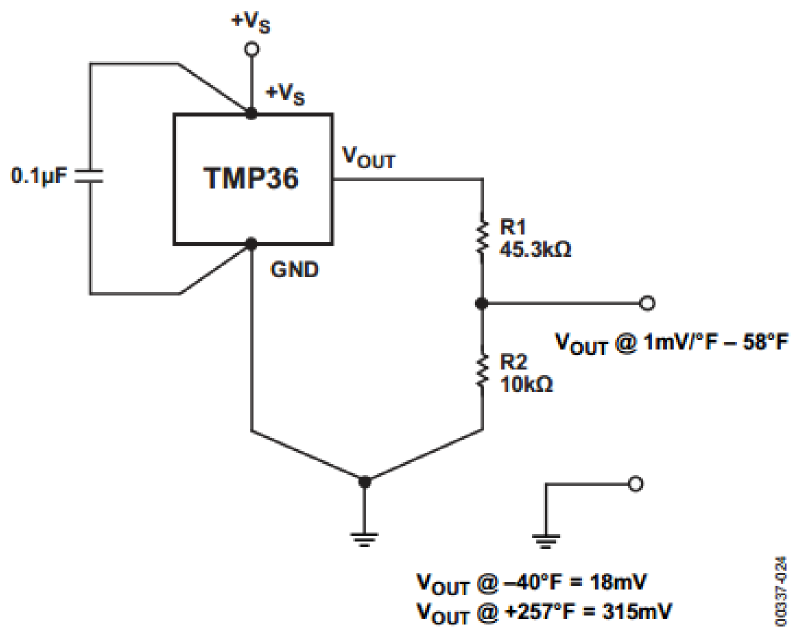

Figure 37 -From the TMP 36 datasheet (permission pending)

Characteristics of TMP 36	
Temperature Range:	-40 to +125°C
Supply Voltage Range:	+2.7 V - +5.5V
Scale Factor:	+10 mV/°C
Sensor Output Range:	0.1 V to 2.0 V
Supply Current	50 µA
Output Type	Analog
Max Accuracy over temperature:	±2°C
Price (including shipping)	$4.30

Table 24 –TMP 36

3.9.b TMP 104

The TMP104 is a temperature sensor that has a digital output and works in a voltage range between 1.4 V- 3.6V. This sensor also operates in a temperature range of -40 to +125°C. It comes in a four-ball wafer chip-scale package and reads temperatures at a resolution of 1°C. This part features a SMAART wire interface which supports daisy-chain configurations, which means it can interface more than one sensor at a time (maximum of 16). A thermally-conductive adhesive would be utilized for mounting purposes and can help to achieve accurate surface temperature measurement. This sensor boasts different types of conversion modes which can help save power. The "shutdown mode" can be utilized if no temperature reading are being needed. When in this mode the current consumption can be reduced to about less than 0.5 µA. The "One-Shot Mode" is utilized when the device is in shutdown mode and one single temperature conversion is needed. This is useful when continuous temperature measurements are not required and one instantaneous temperature is needed and prompted by the user. This mode can be very useful when considering minimizing power utilization. Upon further research it was determined that this part would not be suitable because since it is so new, they don't currently have this part available to the general public.

Table 25 –TMP 104 Sensor

Characteristics of TMP 104	
Temperature range	-40°C - +125 °C
Supply Voltage Range	1.4 V - 3.6 V
Output	Digital
Conversion time (typical)	26 ms
Resolution	8 bits
Max Accuracy (temp error) at -10°C to +100°C, V+ = 1.8V	±2°C
Max Accuracy (temp error) at -40°C to +125°C, V+ = 1.8V	±3°C
Price	Unavailable

3.10 Op Amp

We have two Op Amps which we are considering for the use of our project. The first being the TLV2302 which is made by Texas Instruments. This is a sub-micropower Op Amp and comparator in one part. This type of Op Amp is appealing due to its extremely low supply current at 1.4 µA. The following table shows the specifications of this part.

Characteristics of TLV2302	
Input off set voltage	± 5V
Operational Temperature	-40˚C to 125˚C
Max input current range	±10mA
Supply Voltage	2.5V to 16V
Power	1.4 µA

Table 26 –TLV2302

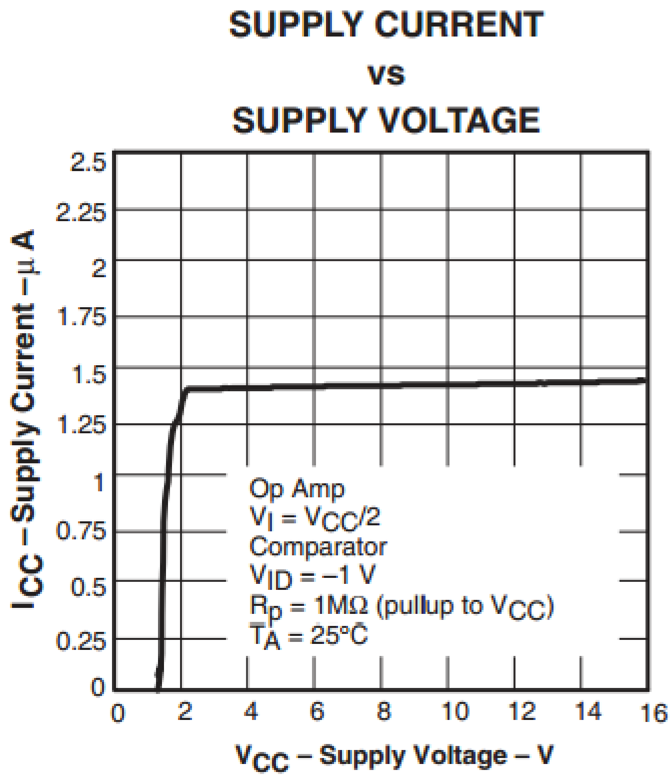

Figure 36- Icc vs Vcc diagram from TLV2302 (permission pending)

3.10.a AD620

The other Op Amp which is being considered in the AD620 which is produced by Analog Devices. It is a low cost,low power, high accuracy instrumentation amplifier which only requires one external resistor to set gains of 1 to 10000. This type of instrumentation amplifier has applications which include: Data acquisition systems, transducer interface, battery powered and portable equipment and industrial process controls. [L14] This type of instrumentation amplifier would be suitable for our project because our data acquisition coming from our voltage divider circuit will be vital to accurate voltage readings from the solar panel. The following is the specifications of the specified part:

Specifcations of AD620	
Input Voltage offset	50µV max
Operational Temperature	-40˚C to + 85˚C
Input current (max)	2 nA
Supply Voltage	2.3V - 18V
Power	1.3 mA

Table 27 –AD620

3.10.b ADA4941-1YRZ

This differential amplifier is being considered as well. It will be useful because it will amplify the difference between two voltages but does not amplify the particular voltages.

Specifications of ADA4941-1YRZ	
Voltage Range	2.7V to 12V
Operating Temperature	-40˚C to + 85˚C
Input Offset Current	0.1µA
Output Current	25mA

Table 28 –ADA4941

3.10.c RTD:

SA1-RTD

This RTD is appealing because it already has a stick-on or cement-on feature which will allow us to surface mount this sensor on the panel without having to by any adhesive. It is not affected by mounting to any curved surfaces which suggests it is very reliable in its abilities. The down side of this sensor is the high price of $50 which may be out of our budget. Refer to the table below for specifications. The diagram under the table shows the dimensions of this part.

Characteristics of SA1-RTD	
Temperature Range	-73 °C to 260°C
Accuracy	±0.6Ω at 0°C
Stability	0.2°C Drift/Year
Response Time	<0.9 s
Cost	$50

Table 29 –SA1 Characs

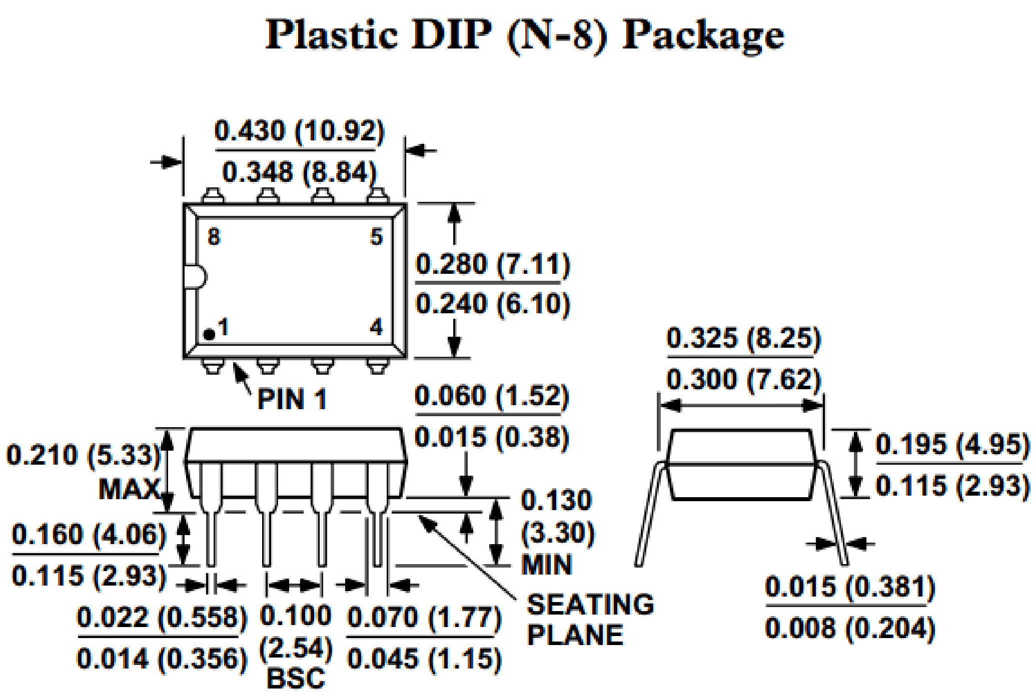

Figure 37 Dimensions of SA1-RTD from datasheet (permission pending)

3.10.d 701-102BAB-B00

Another type of RTD which is available to us is the 700 series RTDs which are made by Honeywell. The type of sensors are relatively cheap compared to other RTDs. It features linear resistance versus temperature which will be vital for our temperature measuring application. Its fast response time and wide temperature range also make this type of sensor appealing. This kind of sensor has applications which include: temperature regulation, electronic thermal management, electronic temperature compensation and room/duct/refrigerant temperature.[datasheet] The specifications of this part are in the table below and the dimensions are displayed in the diagram under it.

Characteristics of 701-102BAB-B00	
Temperature Range	**-** 70°C to 500°C
Accuracy	±2°C
Stability at 500°C	0.04% after 1000h
Response Time	<0.5 s
Cost	$12.62

Table 30 – 701-102BAB

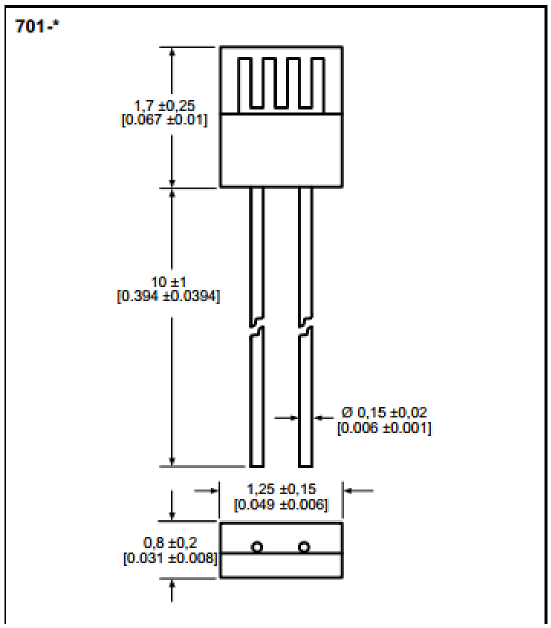

Figure 38 –Dimensions of 701-102BAB-B00 from datasheet (permission pending)

3.11 Heat Sink

CHEH8260

This type of heat sink features flatback shapes for power modules, high fin density for increased performance, and specific designs for stud type and power semiconductors. [10]. The following table shows the specifications of CHEH8260.

Characteristics of CHEH8260	
Device Type	Discrete
Width	2.682 in
Height	0.406 in
Base Thickness	0.100 in
Weight	0.56 lb/ft
Thermal Performance	5.80˚C/W/3in

Table 31 –CHEH8260

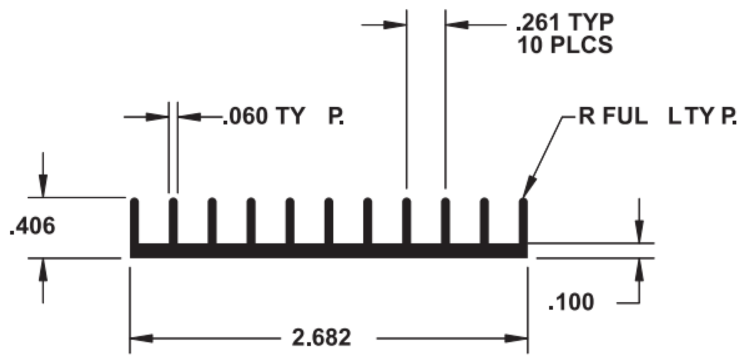

Figure 39 -The diagram below the table shows the dimensions of this heat sink.

3.11.a TO220

This is an aluminum heat sink which is excellent at heat dissapation. The dimensions are 17mm x 17mm x 26 mm. This type of heat sink is available through Radioshack and at even cheapr prices at Futurlec.com.

3.12 Photoresistor:

MJ5517

This is a photoresisor which is made by the Brand, HW. They are a .5mm series photoresistor with a light resistance of 10-20. The photoresistor and will be put in a voltage divider circuit to output a voltage which will have a linear relationship with the amount of light that is exposed to the photoresistor.

3.13 Casings Component

3.13.a Development Process

The approach to the product’s Casing component was a progressive debate amongst the group members, continually evolving and building upon itself throughout the whole of the design process. The group all had justifiably envisioned the product In their individual ways when they came into this, and had to gradually compromise and merge all different visions to reach a consensus, yielding a product of increased functionality by summing the best of all parts.

The group had originally envisioned the product as solely a portable solar tracker and electrical generator that would charge a 12V battery, and have a 120V DC output to sustain medium-sized electrical devices for extended periods of time as long as working conditions were conducive to proper functioning. For the actual enclosure, was originally agreed to maintain three different possibilities under consideration as the group proceeded with the research stage of our project:

1. PVC Cage-typed composite exoskeleton
2. Self-standing carry-on cylinder
3. Using a sturdy pre-fabricated enclosure

As the project evolved and we became more informed pertaining the available resources and the design feasibility of each, however, the three design possibilities narrowed down progressively to make the final design choice the best informed decision that could be made.

The PVC Cage caved in under design problems and practicality measures that made it inherently flawed from early on during the research stage. We envisioned the PVC encasing as an easily assembled enclosure that would provide optimal air circulation to prevent any of the electrical components from overheating, low production costs, and an easily customizable design as a whole –in case the group were ever to decide to make this a more feature-rich product.

The PVC Cage’s principal strength turned out to be its biggest weakness however, when the group members realized that all the crevices that would exponentially increase air circulation, would also increase our product’s susceptibility to climatologically hostile conditions during a brainstorming session directed towards possible testing procedures and potential repercussions concerning each different design. Also, as the group researched possible temperature impacts on circuitry components, it settled that air circulation would present more of a concern regarding the photovoltaic panels than the circuitry components themselves. This was the biggest argument to dismissing the PVC

Cage design approach, along with inherent material weakness that might cause the PVC piping to rupture under the increased weight of the battery, and under duress and possible impacts that would come along with the portability aspect of the design.

Progressively, the group also disqualified the “golf-bag” approach (seen below in Fig. AE 10) that involved an elongated cylindrical container with self standing capabilities (with legs that would extend from the side when the cylinder was slanted on a pedal at the bottom), because of inherent danger to the photovoltaic panels that would be attached on the side. The beauty of this design was set around its practicality regarding the building phase, and easy portability feature through the use of a shoulder strap (as you would carry a golf bag).

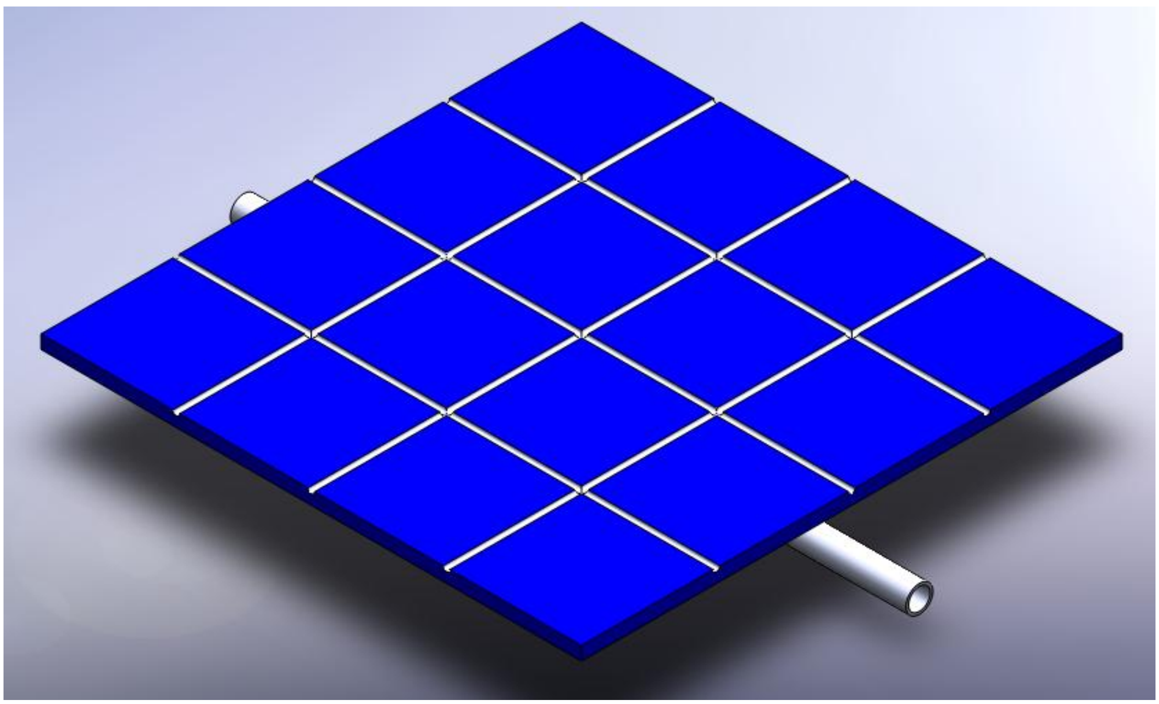

Figure 40 –Golf-bag design approach (self-designed)

The group members have resources for experienced work with fiberglass, and had envisioned a glossy fiberglass covering encasing all circuits safely attached within, with a cut out for our visual display, and cables to attach to a rotating attachment around the mid-section of the device, which would serve to rotate the PV panel through the use of an actuator. This seemed to be a solid design that would meet and exceed our needs, but it included putting the PV panel through an incredible amount of potential risk of physical damage during transport and storage, as the group deals with a fragile, rather expansive surface area. The group characterized it as expansive due to the size ratio of the small elongated cylindrical unit, compared to the large photovoltaic panels that would extensively protrude on its sides, as rather expensive wings that could be easily damaged.

The frailty of the Photovoltaic panel and the fact that air circulation was no longer of imperative magnitude when dealing with circuitry components (due to the practicality of Heat Sinks paired to our design), ultimately led the group members to agree that the design needs called for an enclosure that would not only protect the electrical components from climatologically unsound conditions, but would also physically protect the photovoltaic attachment, a fundamental feature of the project. The group immediately thought of seeking some form of pre-fabricated sturdy enclosure that would also present an ease in mobility, and settled on a conventional cooler to meet its needs –which would also present the added quality of being seemingly inconspicuous amongst the various objects the user would carry along in outdoors excursions of varying natures. The cooler seemed to be the perfect portable enclosure in which to place the product, with a photovoltaic panel that would simply prop up to a diagonal slant on a rotating base once the cooler's top was opened; and thus, the vision for the module had come into place.

Consequently, once we realized that a medium-sized cooler would satisfy the design needs, an added feature was proposed and warmly accepted into the project scheme: The group would utilize a larger cooler, and attach all of the designed components to this cooler's side and top panels, while still maintaining its original functionality. First, the group would manufacture a box in which to place all the circuitry components along with the battery, which would safely encase and seal all components away from detrimental outside agents. Said box would be attached to the back panel of the cooler, opposite the side with the handles.

Also, the group decided to compartmentalize the motor, rotating base, and photovoltaic panel and affix these in a second lid-resembling enclosure atop the cooler's own lid. The point behind this design would be that the compartment could be flipped open and set next to the cooler as a form of attached table (with two foldable legs at the two protruding corners) leaving the cooler's own lid unobstructed for use. This "table" flap would present the rotating base along with a photovoltaic panel that will be physically propped up to the prime slanted angle, to keep it in a perpendicular position to the sun as it follows its path across the sky. This approach will match the generators' components with the cooler's structure in a completely non-invasive way, thereby maintaining functionality in the two completely uncompromised.

3.13.b Materials & Details

Applicable to all marketable engineering solutions appealing to a non-technical mass audience on the basis of practicality and portability –such as the product-, the rule of thumb that seems to always be attached to the marketable tag would be that “the beauty is in the details”; sadly, as engineering students working with a tight budget, the *beauty* must always loose out to the *guts* of the project. This senior design dogma of “application trumps aesthetics” was a recurring theme in the casings aspect of the project, and will be reflected in the guiding thought process when approaching the Design process of the module after the big picture was settled, and move on to material specifications in this section of our design paper.

3.13.b.i The Cooler

Ideally, the Solar Tracking Power Generator will come attached to what one would describe as an “full-sized” cooler, of dimensions preferably exceeding those of the PVC panel. Therefore, to encompass the needed area for the overhead “flap” that will house the PVC Panel, the rotating base (along with the motor and needed hardware to allow for proper motility), and the needed extendible legs, we are forecasting the need for a unit that will exceed a length of at least 3 feet, by a width of at least 2 feet. Usually such dimensions would belong with specialty companies geared towards catering for the fishing/hunting industry, and the research yielded a range of “industrial” coolers in that area that would not go under 4-5 feet in length alone. Such dimensions would render the whole scheme of attaching a cooler to the module completely obsolete, since such coolers would be far too large to serve the needs of the common beachgoer, tailgater, or average camping enthusiast; a segment of the population that makes up what we have defined to be the main target audience that is being catered to with the module.

Luckily, the team came across what one would define as a hybrid laying between the full-sized and industrial-sized cooler family with the 165-quart units. These coolers lay almost at the desired size range needed, but most manufacturers fall short, except for the *Igloo Manufacturing Corporation*. This well-established manufacturer provides 2 different models that would fit best to our design: the “Igloo All-Terrain Cooler” of 165 Qt capacity, and the “Yukon Cold Locker” of the 120 Qt variation, from their newly released line of ice chests.

Figure. 41 Igloo All-Terrain Cooler (Authorization pending)

From these two models, even though the Yukon provides a slightly larger top surface area for the panel addition, it does not have the wheeled functionality, which is highly desirable in our design due to the added weight of the PV Panel. Therefore, the wheeled design of the "Igloo All-Terrain Cooler" variation would be favorably regarded to address the portability aspect, which is one of the main non-technical features in the project.

Having settled on the quintessential picture of the non-technical side of the project by settling the main needs the module's body will entail, and then encountered the harsh reality facing our project's aesthetics on two fronts:
First of all, the funds that have been entrusted to the group are aimed towards the technical design and prototyping of a solar tracking power generating module from a technological point of view, which would make it asinine to even think that the funding organization would remotely desire the group to spend over 20% of the budget in the triviality that is aesthetics; the senior design group has been entrusted with a research and development task, not a marketing project.
And secondly, according to calculations on early budgeting endeavors, once the development of the main electrical components are finished, the group won't have enough left-over funding to buy such an expensive piece of non-vital equipment even if we deemed it essential to our project's success.

From this textbook case of marketing vs. engineering, the group had to evaluate all options before they could proceed. Once the budget was given a careful revision and it was certain that such expenditure would be as unwarranted as unaffordable, the team decided they would build a make-shift wooden cooler to simulate this costly component. Plywood will be used along with mundane hardware to build a wooden enclosure and hatch of the same specifications as the previously chosen cooler of 41.94” length by 23.69” in width, and 22.6” in height (106.53cm Length x 60.17cm Width x 57.63cm Height.) There will also be attached a wooden handle and a small ATC wheel kit (4” diameter) to sustain the module’s weight during transportation. These variouspieces of hardware should not run over $100 in total.

3.3.b.ii Fiberglass Casings

For the circuitry enclosure and PV panel-covering “flap” component, the group has settled on using textured fiberglass multi-layered enclosures, utilizing E-Glass (or electrical-grade glass) with an Epoxy matrix composite.

The matter was thoroughly researched through a wide range of materials before settling on E-Glass, but ultimately chose this fiber because of its readily availability durability features. In the Orlando area alone, there exist a multitude of car-customization businesses that work with the material, as well as surfboard manufacturing facilities and marine shuttle repair shops along the eastern Central Florida coast, which will give the team a chance to seek the best price on an already rather inexpensive material. Also, there are multiple online resources (such as fiberglasssupply.com), that could easily furnish us with relatively inexpensive fiberglass manufacturing kits, facilitating not only composite part generation but also for sheathing different equipment if we were to change the design materials for the overhead flap, resulting in a more dense component sheathed in E-glass for any of its numerous favorable properties. These kits range in price and functionality from $5 to $50 and above, and include enough material to meet and surpass any E-Glass component manufacturing and sheathing that may come up in our prototyping endeavor.

As shown in the research portion of the paper dedicated to materials research however, E-Glass presents itself as an optimal choice to meet the design needs not only from purely financial and schedule-related measures, but also due to multiple other favorable properties characteristic of this material. In juxtaposition to its more common counterparts in this area of application such as aluminum and plastic encapsulations, this is a material possessing such temperature resistance capabilities, that it presents the intrinsic added feature of safety in terms of equipment overheating and costumer handling. The tensile durability of the material makes it perfect for the circuitry box because it can be easily drilled and molded to attach it to the cooler without affecting its overall integrity due to its micro-porosity, which will also allow it to stand resonance and module vibrations during operation and transport, with the added possibility of a small metal infrastructure to back the inside if resilience is truly desired for an extensive period of time.

Also, from impact tests, we see the fiber toughness and deformation studies present it rather favorably even against other Glass Fiber types, offering the product added lifetime. All things considered, its physical properties, readily availability, and cost effectiveness make this material the best choice to meet our design needs.

IV. Physical Testing

4.1 Testing the Motor Efficiency:

Testing the tracking component of the system is an important aspect of the project. Although the tracking component of the system will be tested as a whole, the stepper motor movement and accuracy will be tested separately to ensure that the motors are operating at peak capacity and not drawing as much power as possible. The connection between the motor and motor controller will be checked to ensure that the motor is operating at less than 2A and is not over discharging the battery. A voltmeter will be place between the two and the current will be measured. Then the voltage coming from the motor controller to the microcontroller will be check to ensure that the microcontroller is operating at 5V required.

4.2 DC/AC inverting testing:

Regular weather conditions won't affect much in testing of the DC/AC but extreme weather conditions will do so. Extreme means very high humidity that always affects electrical connections. Chips are rated to a max of 65 degrees Celsius meaning 149 degrees Fahrenheit. DC/AC inverters in areas with greater solar radiation, places in states like New Mexico, Arizona and, California where solar radiation is almost double than states like Florida will require special insulation and more safety connected junctions. The DC/AC does not have to be at a certain height, although it is better if it position in such manner where air flows through the circuit. As it was explained before it needs to be cool enough for the efficiency to reach a maximum point, efficiency with temperature is similar to maximum power point tracking in such that there is a certain temperature where efficiency is at max. The mechanical design of this project explains how air flow is distributed and how maximum efficiency will be obtained from the mechanical part of the project. Determining how long a DC/AC inverter will work for is very hard to predict, but what can really be predicted is an amount of time depending on various factors one of them is the battery used, in this project a 12 VDC battery at 30 amp hours is used. The second component affecting the amount of time that the inverter will work for is the load; in this project the load is a 32 inch LCD TV has been chosen because of the fact that it uses about 2.2 amps of current, the DC/AC inverter will be able to supply power for about 2.5 hours now, this is a case where the battery is not recharged and using a full battery, as the battery charges and discharging, in really good conditions the battery can charge faster than is draining making this inverter virtually everlasting, now it is common sense that the battery will only charge when there is sunlight out there. A calculated of using up to 2.5 hours using the load described. In theory this DC/AC inverter printed circuit board won't need any cool down period. But in real life as described before, in order to maintain a very good efficiency the system’s temperature will be measured periodically and if temperature reaches over 120 degrees Fahrenheit, it will be shutdown and cooled off, there will be an exception when the inverter might reach such temperature and it is at start up, the reason why it might reach such temperature is because there is a surge current when a load is connected to the system, the surge current cannot be simulated and it is expected to be no more than 10 amps.

The elements of the DC/AC inverter are tested in two different ways, one of them using software like Multisim and the other one in real life. Computer simulation programs use infinite loops when testing parts or when running simulations, for sake of discussion and efficiency, components will be tested to make sure that connections are valid on software but to make sure everything is working fine, a list of what will be tested and how it will be tested is supplied below. Individual components like resistors and capacitors are tested with a digital multi-meter upon purchase to make sure that everything is working fine.

Measurements	Software/Multisim	Digital Multi-meter/Oscilloscope
Input voltage	✓	✓
Frequency in circuit	✓	✓
Output voltage	✓	✓
Output current	✓	✓
Output frequency	✓	✓
Efficiency	✓	✓
Total impedance		✓

Table 32 – DC/AC Component testing

Although modern electronics are rating to extreme weather conditions, it is important to understand that high currents generate heat, in electronics high currents, mainly when things are too close to each other decrease efficiency as it was explained before, thickness and spacing in the PCB will be tested by placing thermometers on the components just to make that current won’t generate just enough heat to decrease the efficiency of the DC/AC inverter. The inverter will be tested in different dates and at different times of the day, temperature, sun visibility and humidity will be taken into account and a separate chart for the DC/AC inverter will be created depending on the results achieved, the measurements described above will be used and results will be used to develop the results.

4.3 Testing MPPT

The testing of the MPPT won't be too different than the testing that will be done on the DC/AC inverter. By simulation only theoretical values are obtained. Theoretical and real –life values are expected to change by ± 5%, the chart below has a list of the things and values that will be tested. Tests will be done every day for a minimum period of five days; weather during testing conditions is expected to be clear in the mornings but cloudy and rainy in the afternoons. Temperatures are expected to be on the high 80's increasing efficiency. The group will also test the MPPT by varying the inputs current and voltages in a controlled manner, meaning in the lab, reason this is going to happen is because the group will test if the algorithm in the microcontroller will work at any voltages or currents. As stated before the fuzzy logic method will be used in this MPPT and theoretically it is going to work, the group will use a power supply and periodically change the values of the current and voltage pretty much simulating what a solar panel does on a daily basis and will check capabilities of the microcontroller.

Measurements	Software/Multisim	Digital Multi-meter/Oscilloscope
Input voltage	✓	✓
Output voltage	✓	✓
Output current	✓	✓
MPPT algorithm	✓	
Efficiency	✓	✓
Total impedance	✓	✓

Table 33- MPPT testing.

4.4.a Efficiency Testing

The main focus of testing will relate directly to the efficiency of the system. The testing would focus on the modified solar panel system versus an unmodified stationary panel of the same make/model. This test would be performed in an un shaded area such as a rooftop or the top of a parking garage. Both panels will be placed relatively close to each other and pointed in a southward direction. The testing would start at sunrise to sunset (6 am -9 pm). After each 30 minute interval the results will be recorded. The use of an autonomous solar tracking system is expected to provide around 15% - 20% more efficiency versus a stationary[2]. We will use the results of the stationary panel as a bench mark to compare with or modified system. If the results match or exceed the specified performance guidelines then our design would be considered a success. However if the results produce less efficiency than the 15% then the system must be corrected to find the problem as to why the system is not performing to our expectations. This can be measured by measuring the current and voltage coming from the solar panel and comparing that to the power coming out of the AC/DC converter. From the equation P = IV we can get the efficiency by the equation Efficiency = (P_{out}/P_{in}) * 100. The efficiency of the motor guided system will be compared to the system with no tracking mechanism. The following table shows the calculations necessary for the testing. These measurements will be taken for both test cases (with solar tracking, without solar tracking)

Measurements	From LCD
Input Voltage (From Solar Panel)	✓
Input Current (From Solar Panel)	✓
Output Voltage (From MPPT)	✓
Output Current (From MPPT)	✓
Output Frequency	
Efficiency	✓
Total Impedance	

Table 34 –Efficiency Testing Results

4.4.b Efficiency Test 2

This efficiency test is to test the system to meet the goals and specifications set forth when designing this project. The intended design is supposed to have an efficiency of over 90%. This calculation will be made from the power going into the panel and the power leaving the MPPT circuit. The required measurements needed are going to be the Current and Voltage from the panel and the Current and Voltage leaving the MPPT circuit, as per the equation P = IV. These two power readings will be compared to measure an efficiency. Efficiency = (Pout/Pin) * 100 which needs to be greater than 90% to meet our goals. This test will be carried out on a Sunny day starting at 7:00 PM to 7:00AM. In intervals of 30 minutes the input and output Currents and Voltages will be measured. From these measurements we will be able to calculate the input power and output power which will equate to our efficiency reading.

Measurements	From LCD
Input Voltage (From Solar Panel)	✓
Input Current (From Solar Panel)	✓
Output Voltage(From MPPT)	✓
Output Current (From MPPT)	✓
Output Frequency	
Efficiency	✓
Total Impedance	

Table 36 – Efficiency Testing 2

4.5 Tracking Testing:

An important aspect of our project is the use of a solar tracking mechanism which will be able to successfully track the sun as it travels across the sky, thus providing the solar panel with the most available sun light as possible. One aspect of the tracking mechanism is that the amount of energy used by the motor is minimized. The system will check the sun location in intervals of 30 minutes. When the solar tracker is not being used it will be in a low-power mode to ensure that energy consumption is being kept to a minimum. In contrast, by having a system which will constantly check and adjust the panel to the brightest source, we will be exerting a lot of energy on the motors as opposed to efficiently powering our battery. To ensure that the project is completely autonomous, it will be tested to ensure that it operates and the correct time intervals. The test procedure can take place over the course of a day. Starting at sunrise or about 6 AM til Dark or 9 PM. The testing will be performed without any interaction with the group members. The readings of the system will be recorded at the alotted time intervals so that we can observe the results and note any abnormalities from the solar panel. The battery is expected to continuously charge as their will be no load which is drawing energy from it.

4.6 Load Test:

The system is expected to charge a battery as well as allows the use of AC appliances at the same time. This test is to see whether the goal of 2 hours of television use is possible for the project. The test would be to simulate how the project would work in a recreational setting such as during a beach day or tail gate. We will start by setting the panel around noon. As the battery is charging it is expected that the system to be able to maintain a load which is equivalent to a televisions usage. If the television is able to maintain its performance over the two hour period specified by the goals, then the project can be considered successful in that aspect.

4.7 Solar panel Testing

Another test which can use to measure the performance of the Solar Panel is to test it under conditions of shading. This type of shading can be present if there are overcast condition or if the solar panel is placed in a position which is subjected to shading from objects such as light poles or trees. This test will be done over the course of 2 days which have similar weather conditions. The first day will be the control and measure the performance of our panels during normal working condition. The results will be recorded every 30 minutes reporting the voltage output of the panels. The second day will test the panels when being subjected to shading. Ten percent of the panel will be cover either by a casted shadow or physically covered by a sheet. The results will be over 30 minute intervals and compare them with the results from the first day. It is a known fact that the output of solar panels are drastically affected by shading, even in small amounts. This test will be able to exemplify that. The following table will show the variables which are going to be measured. The drop in efficiency caused by the shadow should be noticed.

Measurements	From LCD
Input Voltage	✓
Input Current	✓
Output Voltage	✓
Output Current	✓
Frequency in Circuit	✓
Output frequency	✓
Efficiency	✓
Total Impedance	

Table 37 –Solar Panel Testing

4.8 Environmental Testing:

The purpose of this test is to ensure the performance of the solar tracker under strenuous conditions. The design is intended for the solar power generator to be portable and have practical uses such as for tailgating or use at the beach since there is a cooler attached to it. The design must be able to withstand potential exposure to sand and dirt as well as any windy conditions which may be present. The testing conditions for this test will take place at a beach under sunny conditions. The beach has more windy conditions than inland weather which is ideal for this test. The wind will potential blow sand in and around our solar tracker as well. This test take place over a 12 hour span ranging from 7:00 AM to 7:00 PM. First the lid will be set up in its operating position and the solar panel will be securely mounted. Once the system is turned on and begins tracking, the design will be monitored in 30 minute intervals. The system will be evaluated upon its operation in solar tracking as well as power generation. The voltage and current readings from the panel will be recorded as well as the battery's charge and load monitoring. Once the battery is completely charged a load such as an appliance like a television can be connected to ensure the that the AC/DC converter will be operational as well. The test will be deemed successful if all components are working correctly under these environmental.

4.9 Structural Testing:

The purpose of this test is to ensure the structural capabilities of the encasement design. The proposed application of the solar power generator is to have it mounted on a cooler to serve as a portable means of power generation. In the proposed design the cooler lid will open and two legs will prop from this lid to make a platform much like a table. The lid and the supporting legs must have the structural integrity to withstand the estimated weight of about 30 pounds. The 30 pounds includes the 18 pounds from the solar panel, around 3 pounds for the motor and 5 pounds for the mounting materials. These are high estimates to ensure that the lid will be able to withstand any potential load from out system. It is also important that the design will be able to hold this weight for a given days worth of use. The testing will take place in the morning at 7:00 AM and will last until 7:00 PM which will simulate a full days use. The lid will be open for the solar panel to be positioned in its operating position. Once in position the system will be turned on and the panels tracking mechanism will begin to take place. The system will be monitored every 30 minutes to ensure that the lid or the legs don't collapse under the weight of the solar panel and its mounting pieces.

V. Budget Used

This latest version of the Budget forecast reflects parts ordered and received, as well as parts to be ordered but already decided upon. The group's aggressive beginning schedule plan was somewhat held back due to delays in sponsor responses. However, once resources were clearly established, requisition procedures got well under way.
Items that have already been received by the group include the Lead Acid Battery unit, all tracking components and auxiliaries to the unit are already in the group's position.

For more complete information regarding prices along with parts physical properties, information on manufacturers, and shipping information, please refer to the Design section.

Solar Tracking Generator Budget			
		Sponsored Budget	$1,010.00
Store	**Purchase**	**Individual part Cost**	**Total Including Shipping**
Tracking Portion			
SparkFun.com	ATMEGA3280	$4.30	($46.56)
SparkFun.com	PIC Development Board	$37.95	
Ebay	Male & Female Pin Headers	$6.40	($9.89)
Ebay	Photo Resistors	$0.99	
Ebay	HD44780 20X4 LCD module	$7.88	($7.88)
SparkFun.com	Arduino Uno R3 Board	$29.95	($29.95)
AllTronics.com	NEMA 23 Stepper Motor	$19.95	($19.95)
Sparkfun.com	BigEasy Driver	$19.95	($19.95)
Best Global Source inc.	Bare bone PCB	$50.00	($50.00)
MPPT PCB Portion			
Microchip	PIC-16F88	$1.33	($1.33)
RadioShack	LM 358 (op-amp)	$2.19	($2.19)
ON Semiconductor	MBR-20100(Schottky Diode)	$0.98	($0.98)

Resistors	RadioShack (five-pack)	$1.19	($1.19)
RadioShack	Capacitors	$1.23	($1.23)
Texas Instruments	TL499 (voltage regulator)	$1.17	($1.17)
RadioShack	NPN Transistors	$2.49	($2.49)
RadioShack	Zener Diode	$1.59	($1.59)
RadioShack	Diode	$1.19	($1.19)
RadioShack	Power Mosfet	$3.38	($3.38)
RadioShack	10k Ohm Potentiometer	$1.99	($1.99)
RadioShack	Inductor	$1.49	($1.49)
Best Global Source Inc	Bare bone PCB	$50.00	($50.00)

Voltage Current sensing Portion

ebay	TEKTRUM	$129.98	($129.98)
RadioShack	ZenerDiode 1N4733A	$1.59	($1.59)
Digikey	**ACS714**	$9.95	($9.95)
Ebay	Temperature Sensor TMP 36	$4.30	($4.30)
Futurlec.com	TO220 Heat Sink	$8.80	($8.80)
Digikey.com	Op Amp TLV2302	$2.58	($2.58)

Project Budget Continues

Battery component

Ebay	Battery	$74.95	($74.95)

DC/AC PCB portion

Texas Instruments	LM348D (op-amp)	$0.50	($0.50)
RadioShack	Potentiometer 100Kohms	$3.19	($3.19)
RadioShack	Resistors (five pack)	$1.19	($1.19)
RadioShack	Capacitors	$1.23	($1.23)
Renco electronics	Step up Transformer	$28.00	($28.00)
RadioShack	Inductor	$1.49	($1.49)
Best Global Source inc.	Bare bone PCB	$50.00	($50.00)
RadioShack	NPN Transistor	$2.49	($2.49)

Miscellaneous Components		$200.00	($200.00)
Construction Estimate		$200.00	($200.00)

Total Spent	$967.83	-$974.64
Net Total		$35.36

Table 38 –Revised Budget

This final budget estimate includes a foreseen cost for three Barebone PCBs, 1 PCB of which will be implemented in the MPPT design, another unit will be included in the design for the DC/AC Inverter, with the third PCB being utilized for the circuit in the tracking component. The estimated price for PCB assembly – including hand labor-, has been included in the “Construction” Estimate portion of the budget.

VI. Conclusion

6.1 Research Summary

There are numerous reference designs where a student can get ideas and a helping hand from. Websites like e2eti.com, ieee.org offer the user explanations and even some schematics on designs; it does explain to young engineers and users how many electrical components behave, and what kind of effects can be achieved with such things as low pass filters. Research did explain a lot about advancements in technology, it is certain that companies like TI do have new developments almost every month. From voltage regulators to MCU's to logic chips, it is hard to try to choose a part because of the fact that newer parts are based from older ones so a person might assume the behavior of a specific component from the results of an older one. When it comes to a maximum power point tracking device it is important to understand the basics, and it is very simple, the fact of the matter is that the voltage will increase and the current will maintain stable up to a certain point then it will decrease. The point maximum point where the current and the voltage meet is called maximum power point, to make this concise and clear it is very important for the user to come up with an strategy to maintain this point constant even though the income of current and voltage might vary the trick of this circuit is to keep tracking these changes in order to keep power to a maximum.

DC/AC Summary

DC/AC inverters are very popular on the market and companies are not willing to show 'schematics' because of the fact that this is their money making secret, although reference designs where obtained, it is important to recall that modified sine waves is what rules the market right now. A portable power inverter that produces a pure sine wave will be very profitable and in very efficient. While doing research, it was found that a lot of the power losses occur mainly in the IC parts i.e. diodes, Mosfet transistors, Zener diodes, the principle behind efficiency is power in should be the same as power out. Modern power regulators offer efficiency up to 95% with a modified square wave. As it was explained before there are three main types of power inverters, they are square wave power inverters, modified sine wave inverters, and pure sine wave inverters, although pure sine wave inverters are very expensive, many of them only come with an output of 10-12 volts in the form of a sine wave at 60 hertz. There are different types of rechargeable batteries, but after an extensive research it was understood that the best fit for this project would be a lead acid battery, although one might think that a brand wont' really matter when it comes to batteries reviews show otherwise. Brands like Eaton, General Electric and

Westinghouse have better reviews than other less known brands, this is a clear indication that brand names do matter when it comes to results.

Motor

The motor for this project will allow us to efficiently rotate the solar panel to effectively track the path of the sun. The type of motor chosen for this project was a stepper motor. This motor was chosen because of its ability to rotate based on predefined angle steps. Several different motors were researched but in the end the motor chosen was based on availability, power usage, torque output and cost.

LCD

The LCD will allow the user to monitor the status of the system such as PV Panel temperature, power output, current usage, etc… The LCD display chosen was based on cost and number of character lines and size. A 20x4 character LCD display was chosen because it was low cost, required as much power as 16X2 or any lower character displays. It would allow more information to be displayed on the screen in comparison to a 16X2 or 8X2 character LCD display

Microcontroller

The microcontroller is an integral aspect of the project. Two microcontrollers will be used for this project. One microcontroller will be used to help determine the maximum power point of the PV panel. The other microcontroller will be used to monitor the status of the system. The two microcontroller type chosen are the PIC microcontroller from Microchip and the Atmel Atmega328. Both microcontrollers will satisfy the speed and memory needed for this project.

Solar Panel Summary

Since our objective is to have an efficient solar power generator, we have determined that the Monocrystalline solar panels would be best for our project. Although the cost of the panel may be a little more than Polycrystalline or Thin film solar panels, Efficiency is the main attribute we are looking for when we are designing this project.

Solar Tracking Summary:

In our project we will be use a Photo resistor Guided Tracking System. This method will be more precise in tracking the sun as it travels across the sky. It is not location dependent unlike the Fixed Interval which helps serves our goal of portability. This type of tracking system is also going to be a cheaper method compared to using an IR camera.

6.2 Design Summary

Designing explained that real life engineering is way different than schematics and design. For example design software comes with infinite harmonics when a waveform is produced. Now in real life when a battery and a motor produces a waveform i.e. an AC motor produces a sine wave at a certain frequency but it does have finite amount of frequencies. Simulation and real life results change dramatically, although numbers are mostly similar when it comes to theoretical values and real life values they match most of the time but waveforms do change dramatically because of noise, dealing with high power (meaning greater than 35 volts) became noisy, results do vary depending on what type of transformer is used, although many resistors, capacitors, are made of similar materials, transformers are not and depending on what company, depending on factors like if it was sliced or no, also the ratio of the wires wrapping the transformer has a lot to do with the results achieved. A design of an MPPT was achieved by using a PIC microcontroller, the way it works is that the microcontroller will receive a voltage and current from the solar panel and with an algorithm programmed into the chip it will keep tracking both voltage and current to maintain a maximum point. As it was explained before the microcontroller will be programmed in PIC assembly language. The code has different loops to maintain a stable income/output of power.

As it was explained before DC/AC inverter can be built in different ways, numerous designs were made in a desire to reach a frequency, voltage and, current that will fit the project. After obtaining a square wave inverter at 114 Volts and 59 Hertz it was discovered that the step down response of the inverter was way too steep and this will blow up items. A pure sine wave was achieved after inputting a DC voltage into an eight order low pass filter, the main problem with this design was the fact that after inputting the transformer the signal will be distorted so much that a lot of noise would be acquired making the output of the transformer unusable. Finally a design was achieved by doing a modified sine wave. It does have the closure to 60 hertz and an alternating voltage of 120 volts. The advantage of this inverter is that the step down response was steep enough to be able to power the desired television and everyday use electronics. This power inverter is cable of outputting up to 4 amps of current and it is efficient up to an 80%.

There wasn't much designing to be done with the battery although it was important to understand the steps involved with the inputs and outputs of the battery, meaning how much current and voltage the battery will produce, it was important to understand how much current the battery was able to receive when charging, and most importantly understand the different scenarios involved charging discharging the battery. The fact of the matter is that the battery can't be left to discharge completely if not it would be damaged; the price for a good branded battery is about 80 dollars. Transformer will be custom made by a company called Renco electronics.

Testing Summary

Testing has been theoretical so far, but numerous days with different climate conditions will be used due to the fact that this will increment our data, therefore giving the costumer reliable information to use the inverter and at what positions, height climate conditions the panel and the tracking will work better.

Microcontroller Development Boards

To familiarize with programming the microcontroller two development boards will be used for initial programming. The 40 Pin PIC development board will be used to program the PIC microcontroller and the Arduino Uno R3 board will be used to program the Atmel328P Microcontroller. The microcontrollers will be transferred to the main PCB circuits later on. The 40 pin PIC board cost $37.95 and the Arduino Uno board cost $29.95 from Sparkfun.

40 pin PIC Board - $37.95
Arduino Uno Board - $29.95

LCD

The LCD chosen for this project will the generic 20X4 character LCD from Ebay. The LCD uses the HD4780 chipset to control and drive the LCD. The LCD cost $7.88 and was brought with free shipping.

20X4 Character LCD - $7.88

Stepper motor

The stepper motor chosen for this project will be a size 23 stepper motor. The motor will be purchased from Alltronics.com and will cost $19.95. Based on the motors spec and size, it should be big enough to sustain the PV Panel weight and size.

Lin Engineering Stepper Motor - $19.95

Motor Controller
The stepper motor controller chosen for the project will be the BigEasy Driver and it will be purchased from Sparkfun. The motor controller will have a max current rating of 2A and will be able to step down the 12V coming from the battery to a manageable 5V for the PIC controller.
Big Easy Driver motor controller - $19.95

Solar Panel:

A 60 W 12V Solar panel will be used for the project. The panel will be purchased on Ebay and price will include the shipping and handling. The panel was chosen because of its cheap price. It has an operating current of 3.34 A and a Maximum/peak voltage of 18V.Most other panel which were 60W and 12 V cost more but had very similar specs, so we decided to pick the cheapest one. The final cost will be $129.98.

Zener Diode:

Our Chosen Zener Diode will be the 1N4733A made by Vishay. It was chosen because it is rated for 5.1V which is necessary because the Microcontroller can only take up to 5V. This part is available through RadioShack. The online price is listed as $1.59 but has a $6.99 shipping price. A local RadioShack will be consulted first to alleviate the shipping expense.

Current Sensor:

The ACS714 will be used because it is rated for -5 A to +5 A usage and outputs between 1.5V and 3.5V with a linear gradient. The panel has an operating current of 3.34 which is in the range of this current sensor. The output of this sensor will be no more than 3.5V which will not overload the microcontroller which it will be interfacing with. The formula to find the original current from the circuit is $I_{panel} = (V_{data} - 2.65V)/(0.185VA^{-1)}$ since the sensitivity is 185mv/A and an output of 2.5V when 0A. This will be purchased from digikey.com. Each unit costs $4.73. Shipping is about $9.00 so we intend on having one larger order from digikey to avoid having to pay for shipping all separately.

Temperature Sensor:

The TMP36 will be chosen for our design. This sensor is appealing because of its large temperature range which encompasses any normal outside weather temperature. It is also low voltage and has very high accuracy. This will be purchased on Ebay.com for $4.30 a unit and includes free shipping.

Heat Sink:

The TO220 is going to be selected for the design because our other proposed heatsink does not meet the intended needs of the project. The heat sink will be applied to the back of the solar panel. At a cheap price of $0.40 a unit, they can be purchased in high volume. The intended design will have this heat sink attached behind each solar cell in the design. The shipping will be $4.00 from futurlec.com. We intend to purchase 12 of them equaling a total of $8.80.

Op Amp:

The differential Op Amp which we will be using is the TLV2302 because it has it both operational amplifier and comparator in one. The price for this part is $2.58 on digikey.com. All parts ordered from this site will be together to lessen the shipping prices.

Current and Voltage Circuit:

Below is the prototype of the current and voltage circuit which we will implement. The voltage is measured through the voltage divider which was designed. The zener diode, 1N4733A, ensures that the voltage will not exceed the threshold of 5V for the microcontroller. The Op Amp, TLV2302, will help ensure the accuracy of the signal. The current sensor circuit will measure the current which is leaving the solar panel through the ACS714 part. By using the reference design given in the datasheet we built this prototype circuit.

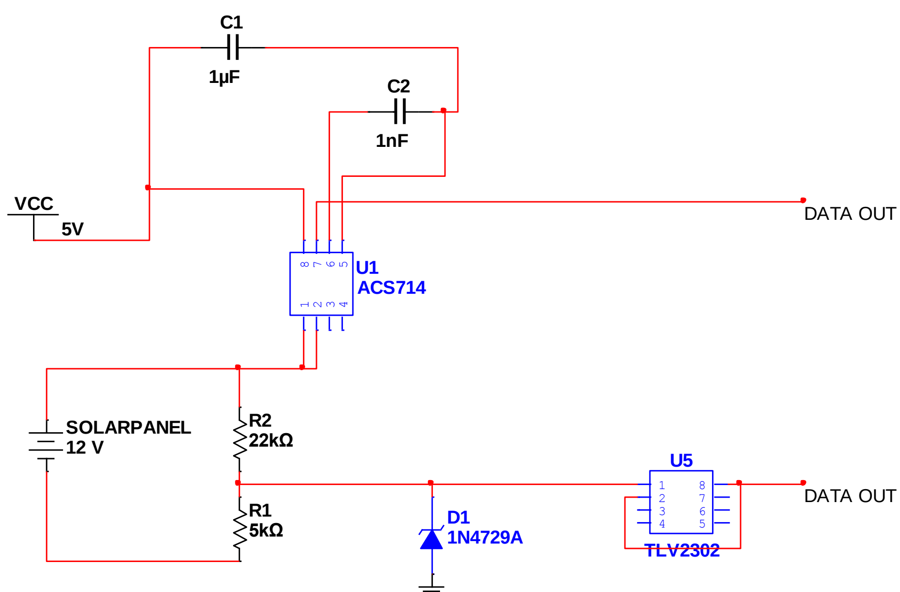

Figure 42. Group's own design for a Voltage Current sensor.

VII. Appendices

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