Alternative Solar Energy Generation

Andy Bryan, Beau Eason, Rob Giffin, Sean Rauchfuss

School of Electrical Engineering and Computer Science, University of Central Florida, Orlando, Florida, 32816-2450

***Abstract* — The news is constantly filled with stories about the energy crisis being faced by the world. In times like these there is a significant need for new sources of energy to halt the crisis. In addition most current forms of energy cause damage to the environment when exhausting them. To cease further damage to the earth new energy sources need to be clean. The solution which this project presents is to utilize solar thermal energy generation. This paper's primary focus is to describe each system related to the project and finally how each system works in unison to form a functioning device. Some of the systems include power generation, tracking, power storage, and charge control.**

***Index Terms* — Control engineering, Microcontrollers, Power integrated circuits, Solar energy, Stirling engines**

I. Introduction

In today's world the desire for alternative forms of energy is ever growing, especially for those which do not harm the environment. This sparked the mindset for this project; to generate an alternative form of solar energy collection. This alternative form is to move away from the popular use of photovoltaic cells because their production is expensive and involves many toxic chemicals. Also they can be fragile and require expertise for setup and maintenance. Instead this project utilizes a Fresnel lens and a Stirling cycle engine. Then the mechanical output of the Stirling cycle engine will be transformed into electrical energy and stored in a battery. Further motivation to take on this project has come from the amount of potential solar energy available in Florida. The need for new, innovative methods of renewable energy is in high demand and is a major contributing factor in the motivation to seek out this solution. The project is graciously being funded by Progress Energy.

Completing this project will achieve a reliable source of sustainable energy with a minimal carbon foot print. The project is to be scaled as a proof of concept that this method can be reliable, efficient, cost effective, and safe. The function of the project begins by concentrating solar energy using a Fresnel lens. The converging solar rays will be used as a heat source to power a Stirling cycle engine. The mechanical output of the Stirling cycle engine will then be transformed into electrical energy using an electric generator. Because the Fresnel lens focal point is very small, a feedback system is used to control precisely where the focal point sits and to adjust the position as the sun moves throughout the day. This will both greatly boost the efficiency of the product and also make it so that it can operate for an entire day without human interaction.

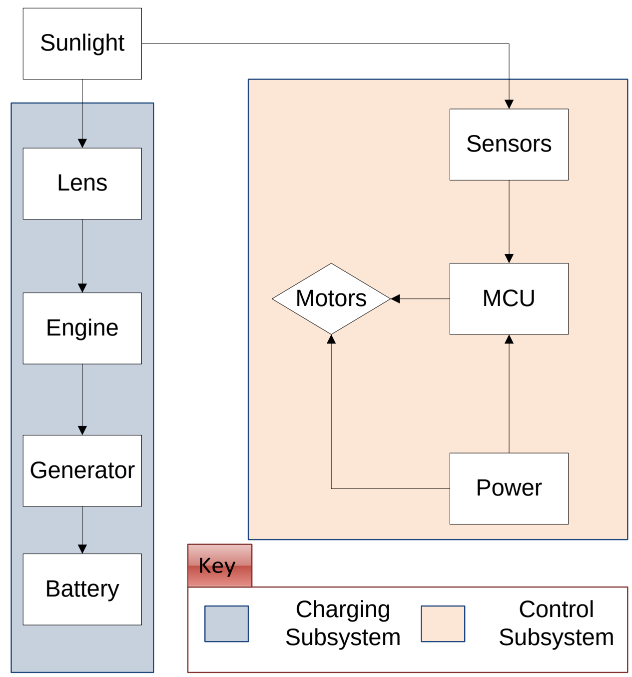

Fig. 1. Flowchart of Alternative Solar Energy Generation

II. Specifications

For the alternative solar energy generation system to function properly, a very specific set of requirements must be met. The following list holds the requirements for the alternative solar energy generation system.

1) The system is to weigh no more than 50 kilograms and is to occupy a volume no greater than 2 meter^3

2) The system is to be capable of operating continuously under ideal conditions for at least a 2 hour period

3) A 12V supply battery will be able to properly power the control system

4) The generator output will be capable of efficiently and safely charging a 12V battery

5) The tracking system will be able to keep the focal of the Fresnel lens precisely on the heat element of the

Stirling engine as to avoid damage to other parts of the system and to maximize energy generation

6) Fresnel lens will be capable of producing focal point with enough heat to properly operate Stirling cycle engine

7) A microcontroller will control the tracking system as well as be responsible for battery and charge control management

8) The system will utilize two 12V batteries that will be interchangeable in function. The microcontroller will be responsible for switching between battery functions

9) Switching regulators will be used to provide proper power for the microcontroller and tracking system motors from the 12V battery

III. Input Sources

The most important input source of this project is Earth's closest star, the sun. This is because the sun is the key to success for the Alternative Solar Energy Generation project. The sun's rays are to be focused using a Fresnel lens. The decision to use Fresnel lenses was made due to their availability in large sizes at relatively low prices. The two main focal patterns of Fresnel lenses are linear and spot. The former focuses the light into a thin beam about five inches long and an inch wide, while the latter focuses the light into a roughly 0.5 inch diameter circle. The project uses a 40 inch by 28 inch spot Fresnel lens. The spot lens was chosen for its small focal point which can be placed exactly where needed. The focal spot of the lens is capable of producing temperatures up to 2000 degrees Fahrenheit.

Fig. 2. Stirling cycle engine used for Alternative Solar Energy Generation

The focal point of the lens is aligned precisely to fall on the heat element of the Stirling cycle engine. A Stirling cycle engine was chosen over other types of heat engines, such as a steam engine, for its high efficiency, safety, and ease of use with virtually any heat source. The project utilizes a beta type Stirling cycle engine purchased from greenpowerscience.com, a picture of this engine can be seen above. Beta type engines are made up with two pistons, a power piston and displacer piston, both inside a single cylinder. The cylinder has a heat element on one end to absorb heat and heat sinks on the other end to dissipate heat. Shafts from the pistons are able to rotate a flywheel outputting rotational mechanical energy. The engine weighs roughly 5 pounds and is 10 inches in length.

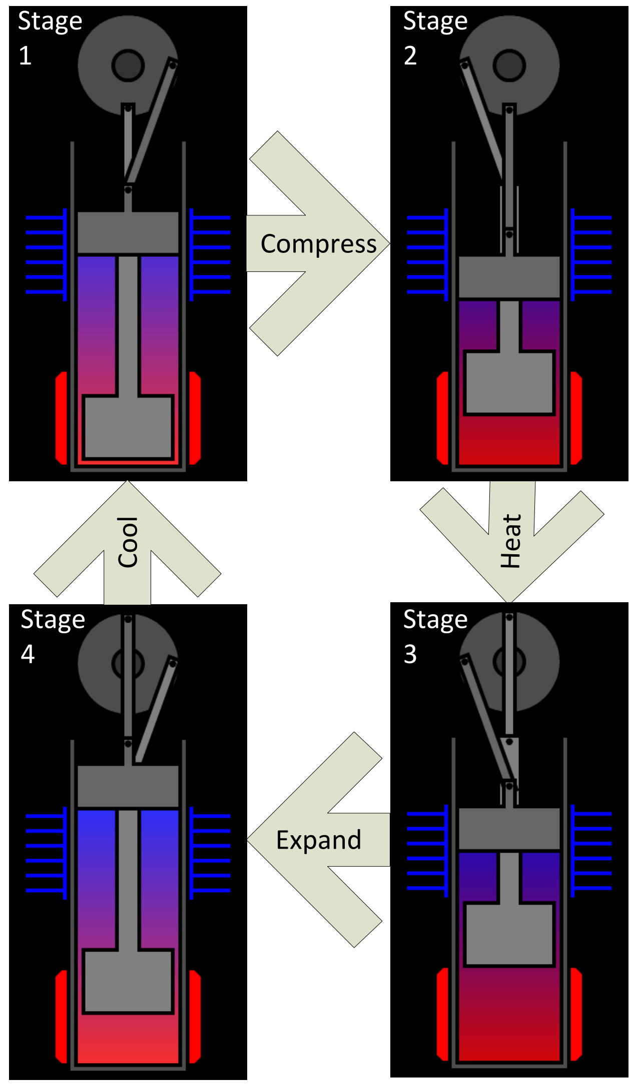

Fig. 3. Stirling cycle engine stages

The Stirling cycle engine operates based on the carnot cycle of thermodynamics to drive a piston which in turn spins a flywheel [4]. Figure 3 shows the four different stages of the Stirling cycle engine. From the first to second stage the displacer piston raises moving the air inside the engine from the cool region towards the heat region. Also the power piston compresses the air varying the pressure-volume inside the engine. From the second to third stage the air that was moved into the heat region begins to expand driving the power piston. Between stages three and four the expansion continues and the displacement piston moves the heated air to cool region of the engine. Finally the engine resets from stage four to one, the displacement piston has pushed all the air towards the heat sinks to begin cooling.

IV. POWER GENERATION

Because the ultimate goal of the project is to actually generate and store usable energy a generator is needed. The generator used utilizes brush permanent magnets and is rated to run up to 24 VDC. This specific generator was chosen for its low starting and running torque. The flywheel of the Stirling cycle engine is attached to the generator using a direct coupler. Through testing it was found that the generator typically outputs between 5 and 7 Volts when under ideal operating conditions. This is due to the limited availability of large Stirling cycle engines, which would have been better suited for the project's needs.

V. TRACKING SYSTEM

A. Tracking System Overview

A major component in achieving the goal of sustainable power generation through an extended period of time relies on successfully tracking the sun. The purpose of any solar tracking system is to keep the payload correctly oriented towards the sun. The measure of success is to keep the focal point of the Fresnel lens consistently on the heating element of the Stirling cycle engine for an extended amount of time. To meet the needs for precision the project will utilize a method known as azimuth-altitude dual axis tracking (AADAT). This tracking technique has its primary axis vertical to the ground with a secondary axis normal to the primary system. The major advantage of an AADAT system is that the system will allow for rotation around a central point, the heat element for this project.

B. Sunlight Sensor

Active solar trackers utilize photo detector arrays to take advantage of the short wavelength and vast distance from the source of sunlight to earth or in other words the fact that light waves are nearly parallel to one another. By doing so they are able to detect the direction of the sun compared to the direction in which the array is facing. The sensor array is constructed from a balsa wood base 4inches by 4 inches. Connected to the base and placed in an X formation with all 90 degree angles between each piece are 4inch walls. A sensor will be placed in each quadrant of the X. The array will be connected to the lens such that when all four sensors are receiving light the focal point of the lens will be precisely on the heat element of the Stirling cycle engine. The sensors to be used will be high powered red LED's. The LED's were chosen for their accuracy and the fact that they don't need a supply voltage. Instead they are plugged into the system with the cathode connected to ground and the anode will be connected directly to the microcontroller. The following table shows the output voltage of the LED's in varying amounts of sunlight.

TABLE I
OUTPUT VOLTAGE OF LED IN VARYING SUNLIGHT

Sunlight	Output Voltage
Direct	1.5V
Partial	0.6V
Ambient	0.02V

D. Tracking motors

Two motors will be needed for the adjustment of the payload one to rotate the entire system about the Stirling cycle engine; this will adjust the azimuth angle. The second will be responsible for raising and lowering the lens, this movement will change the altitude angle. To control the azimuth angle the HT23-260-4 stepper motor will be used. The torque of the motor is 260 Oz In. The motor has a step size of 1.8° or 200 Steps per revolution and requires 2.5 Amps Current Per Phase. The altitude angle will be controlled using the FA-PO-150-12-12 actuator with a built in 10 kOhm potentiometer built in. Additional details as to how these motors will be implemented can be seen below in tracking system functionality.

E. Microcontroller

The microcontroller will be the brains of the solar tracking system. The primary responsibility of the microcontroller is to take in the sensor data and make appropriate adjustments to the position of the payload. Texas Instruments MSP430 has been selected for its cost, low input voltage and low power modes. During most of the operation of the system no control will be needed. This downtime allows for taking advantage of the MSP430's low power modes (LMPX), specifically LMP3. In this mode the CPU, Mclock, and SMclock are turned off. Leaving only the auxiliary clock active, this clock is used for the delay between readings from the sensors. Figure 4, below, shows the operating cycle of the MSP430.

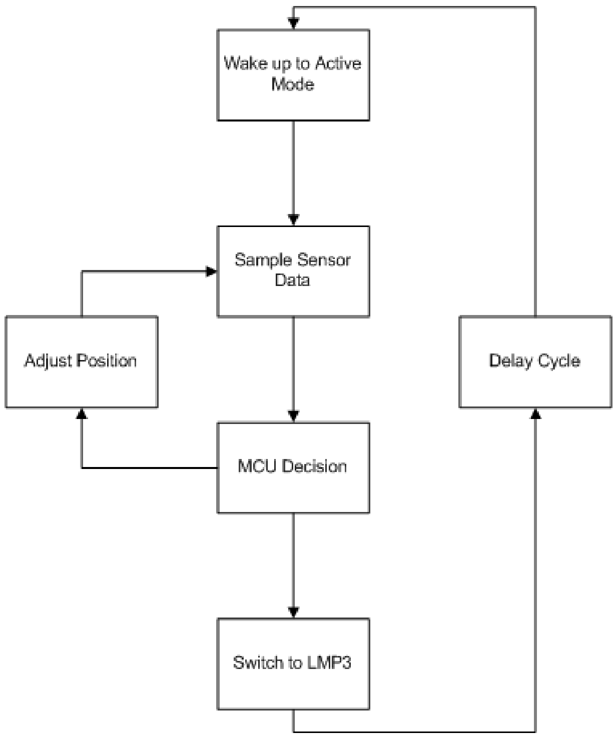

Fig. 4. MSP430 decision flowchart

F. Tracking System Functionality

The control procedure has two main parts, data acquisition, and motor control. First, we will discuss how data is read by the microcontroller. The MSP430F2212 has numerous inputs that are capable of performing analog to digital conversion. The LEDs will be connected to four of these inputs to find the position of the lens in relation to the sun. Even during this step a low power mode will be utilized. The MSP430 will go into this low power mode during the analog to digital conversion. Directly upon completion of the conversion the microcontroller will go back into active mode to continue with control procedures. It should be noted that this conversion does not take a tremendous amount of time but every bit of power that can be save should be since the overall goal of the project is to create and store energy. Once all four LEDs have been read adjustments to the lens position can be made.

As mentioned before two different control motors will be used to position the lens. The first to be discussed is the actuator. This actuator will be controlled by the microcontroller. The positive and negative leads to the actuator will be connected to the outputs of two switches on the printed circuit board. These switches will be turned on and off by the microcontroller based on whether the actuator needs to be extended or retracted. The amount of time that the actuator will be turned on will be fairly short then another sensor read will be conducted to determine if additional movements will be required. The switches are being used because the voltage level of the output of the microcontroller is too low. The output of the switches is high enough to turn on the actuator.

There is another aspect of this actuator worth mentioning, the potentiometer. This potentiometer will allow us to know the position of the actuator which helps with two important things. The first is determining the highest position of the lens. During a day's operation there will be a transition from the sun rising in the sky then it descending. The actuator must also know when to transition from extending to contracting. The potentiometer will help us know when this transition happens and how to adjust the control procedure. The second way the potentiometer helps is with overextension protection. A threshold can be set up so, should there be a position that could damage the apparatus, protection can be implemented in the software. The fact that this actuator has this potentiometer built in was an important criterion during selection.

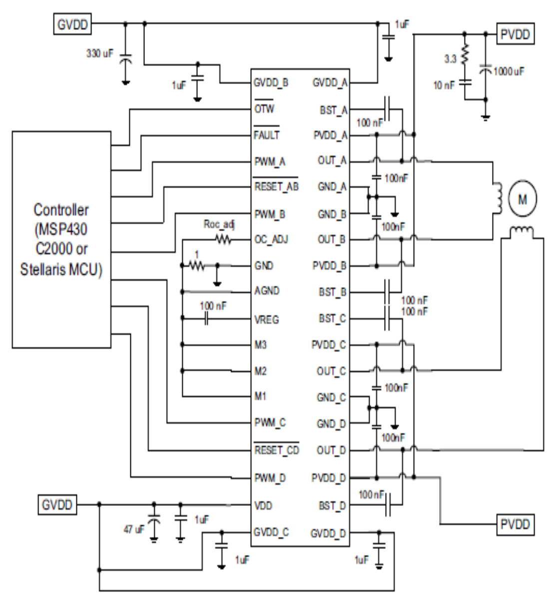

Fig. 5. DRV8312 schematic

The final component of the control procedure is the stepper motor. This motor is being used to rotate the base of the apparatus. This motor is also being controlled be the microcontroller but not directly. There is an intermediate driver circuit to step up the power of the control signal.

The IC being used for this is the DRV8312 from Texas Instruments. This portion of the circuit can be seen in the figure above. The stepper motor being used is of the bipolar permanent magnet motor type. As with the actuator the motor will be turned on for a very short amount of time then more sensor reads will be made. This is easily implemented with a stepper motor because of its ability to rotate in discrete steps.

The decision as to whether to move the actuator or the stepper motor is made based on the results of the LED readings. The values read by the LED inputs will be compared with an on/off threshold determined through experimentation. If the LED is found to be on it is given a value of one, otherwise it will be changed to zero. The four readings are grouped into four variables in two groups of two; two for rotations, and two for angle adjustments. Each of the four variables will be the sum of two of the LED reads. The values of the variables are going to be zero one or two. These values along with the actuator potentiometer readings are then sent through a set of conditional logic statements to determine which motors should be used and in which direction.

The data read and position adjustment process discussed above will occur several times in succession until correct alignment is achieved. Once this happens the microcontroller will return to low power mode 3 and wait for a predetermined amount of time. During this time the apparatus will be held in a constant position. After the low power mode cycle the control loop will begin anew; sampling data them making necessary adjustments to the position of the lens. It will be up to the operator to shut the device down at the end of a day's operation by disconnecting the batteries form the control board.

VI. Switching Regulators

Alternative solar energy generation utilizes three switching regulators for its voltage adjustment needs. Two of Intersil's ISL8502s will be used to go from the 12Volt supply battery and buck the input voltage to be lower at the output. The first ISL8502 will supply an output voltage of 3 Volts with a current of 1milliamp. This will be used to power the MSP430. The second ISL8502 will supply 3 Volts with a current of 2Amps. This second output will be used to power the actuator. The final component of the system which needs to be powered is the stepper motor. The motor controller has an input of 12 Volts so this will come directly from the battery.

The third switching regulator is an ISL98012 this will be used to boost the output of the generator from its output to the 12Volts needed to by the charge controller to properly charge the battery. The component values of all three regulators were chosen based on the datasheet provided by Intersil. The figure below is the schematic of the three switching regulators.

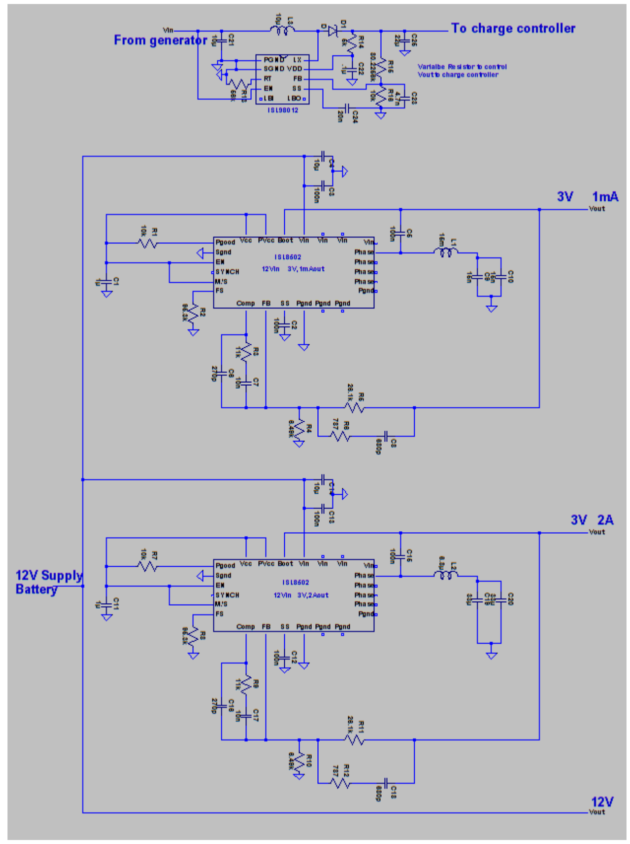

Fig. 6. Schematic of the three switching regulators

VII. Storage of Electric Potential

The system will utilize two batteries for storing the electric potential output from the generator. The first is referred to as the source battery. This battery will be used anytime that the system needs to power something. Examples of where it will be used are the tracking motors and microcontroller. The second of the two batteries will be getting charged by the charge controller system. The batteries are manufactured by Leoch and are lead acid in chemistry. Each battery is 12Volts with a capacity of 7AmpHours. The function which each battery holds will be switchable via two control line from the MSP430. To properly handle the switching the system relies on four LTC4412 low loss power path controllers. The power path controllers function very similarly to logic multiplexers, with the advantage of they work well for circuits where logic components would burn up due to overcurrent. Below in the figure the placement and hookup of the power path controllers can be seen.

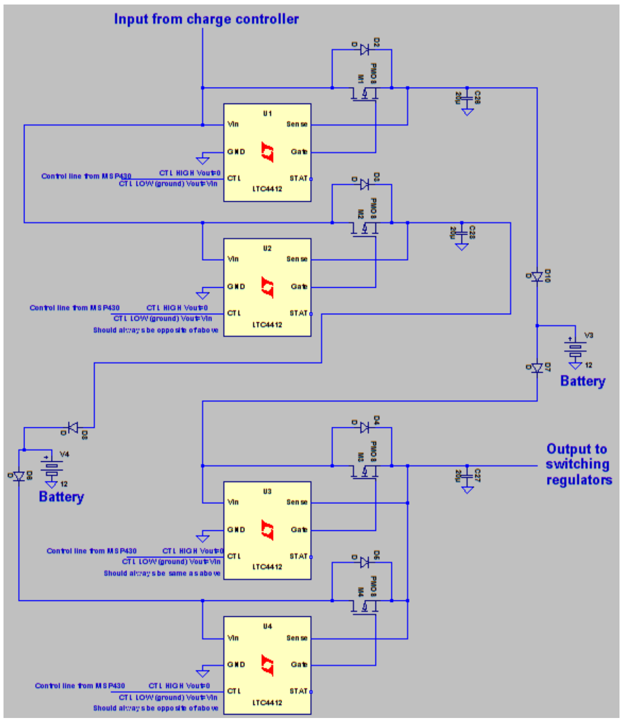

Fig. 7. Schematic of the four power path controllers

VIII. Charge Controller

The charge controller system is critical for both safety and efficiency when it comes to charging the battery. The best way to charge a lead-acid battery is by using a three-stage device. The first stage is the constant current charge and this applies the bulk of the charge and takes up roughly half of the total charge time (voltage rises at constant current). The second stage is the topping charge, and this continues at a lower charge current and provides saturation (voltage peaks while current decreases). The third and final stage called the "float charge" compensates for the loss caused by self-discharge (voltage is lowered, trickle charge for loss of self-discharge). These three stages are essential for the battery to be able to accept a full charge and will help to prevent any performance decrease due to sulfation.

A Texas Instruments BQ24450 integrated charge controller for lead acid batteries is used as the brains of the charge controller. The decision to use a manufactured charge controller over designing one was made in the interest of maximizing efficiency. The BQ24450 used as the charge controller is optimized with several external components to fit the needs of the project. These optimized external components were all selected based on the datasheet provided by Texas Instruments. The internal components include voltage and current regulating amplifiers as well as comparators to monitor the charging voltage and current.

Along with the regulating amplifiers and comparators there is also a temperature-compensated built-in precision voltage reference which allows for accurate charging voltage over an extended temperature range without using any external components. The BQ24450 can also be configured to a very wide range of battery sizes and can be configured as a simple constant-voltage float charge controller (two stage charging controller) or a dual voltage float-cum-boost charge controller (three stage charging controller). The charge controller system is able to precisely control the charging current as well as charging voltage to safely and efficiently charge the battery. This process is able to maximize the batteries capacity and life. For the design of the external components the following equations were used, with R_c being standard at 46kΩ.

$$V_{FLOAT} = V_{REF} \times (R_A + R_B + R_C) \div R_C \qquad (1)$$

$$V_{BOOST} = V_{REF} \times (R_A + R_B + R_C//R_D) \div R_C//R_D \qquad (2)$$

$$V_{TH} = V_{REF} \times (R_A + R_B + R_C//R_D) \div (R_B + R_C//R_D) \qquad (3)$$

$$I_{PRE} = (V_{IN} - V_{PRE} - V_{DEXT} - V_{BAT}) \div R_T \qquad (4)$$

$$I_{MAX\text{-}CHG} = V_{ILIM} \div R_{ISNS} \qquad (5)$$

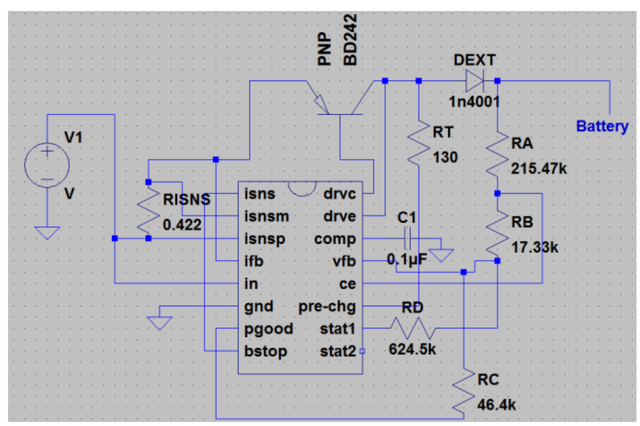

Fig. 8. Charge controller circuit

The figure above is the design of the charge controller with the external components attached. The circuit and IC layout were designed using LTSpice with the external components values calculated using the equations above that were supplied through the datasheet of the BQ24450. The 12VDC input is on the left with the output to the 12V battery on the right. The output to the battery will be giving a bulk voltage of about 13.8V. When the charge on the battery is at a minimum it will give a low voltage charge of about 10.5V in order to protect the battery.

IX. Printed Circuit Board

To fabricate our circuit we decided to use the website 4pcb.com because of their cheap student deals and fast turn over times. We took advantage of their $66 special for a four layer board. The decision to use a four layer board was made because it allowed a dedicated ground plane, which reduces noise significantly, and simplifies the challenge of routing all the connections. Several programs were considered to layout the board, specifically Eagle and Orcad/Allegro. After attending the Eagle seminar, we decided to use Orcad/Allegro since a group member was already familiar with it and had access to a licensed copy.

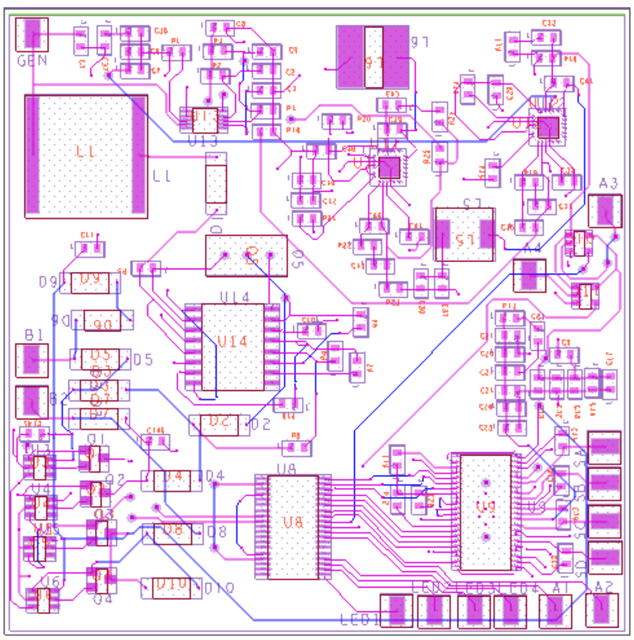

Fig. 9. Printed Circuit Board Image

The area allotted for board design was 3”x3”, so surface mount technology was selected to minimize wasted board space. For capacitors and resistors 0603 size was selected, and several IC’s are sot-23 standard sizes. Some components, such as diodes and bipolar junction transistors, were selected to be through hole, simply because of the greater availability of through hole for those parts, and minimal number of them required in our design. A minimum line width of 6 mils was used, with some lines which carry more current up to 25 mils. The standard via size was 15 mils diameter, with some larger ones for power lines. The top and bottom layers were the primary routing layer, with layer three available for additional routing options, and layer two being the ground plane. For the input and output connections of the board, a centimeter long pad was created to solder the wires directly to, rather than attaching connectors. This decision was made to reduce the number of unnecessary components on the board, and because of the permanent nature of the connections. The inputs of the board will be the generator output, the led sensor array, the actuator’s potentiometer, and the batteries. The outputs of the board are the actuator control and power, and stepper motor control and power. The figure below shows the final printed circuit board layout.

X. Framing

Each of the subsystems for the project will be combined onto an aluminum frame with a wooden base. The aluminum frame will house the Fresnel lens, sensor array and actuator. This aluminum frame will be placed atop wheels which will rotate in grooves on the wooden base such that the heat element of the Stirling cycle engine is always at the exact center. The Fresnel lens rests inside a wooden frame with support arms that extend to its focal length. The lens support arms are connected to the aluminum frame with pins such that the lens can freely rotate about the pin axis. The actuator is connected from a crossbeam across the arms of the Fresnel lens support to an aluminum crossbeam on the rotating frame. Aluminum was chosen to build the frame for its light weight and strength. The stepper motor is connected to a riser from the wooden base with a gear attached to its shaft. This gear interfaces with a permanent gear attached to the bottom of the aluminum framing. The permanent gear is placed such that its center is in the exact center of the aluminum framing as well as the exact center of the wooden base to ensure the gear stays perfectly aligned as the aluminum frame rotates. The wooden base is built of two quarter inch pieces of plywood laminated together with a groove routed out of the top piece for the wheels to sit in and keep the system centered. In addition to the stepper motor the wooden base will also house the remaining parts of the total system including the batteries, PCB, generator, and Stirling cycle engine. All of these components are securely placed within the circular grooves to avoid obstacles in the path of rotation of the aluminum frame. Additionally the wooden base was chosen for its strength, its ease to work with, and cost effectiveness. The finalized design of the aluminum frame with wooden base can be seen in the figure below.

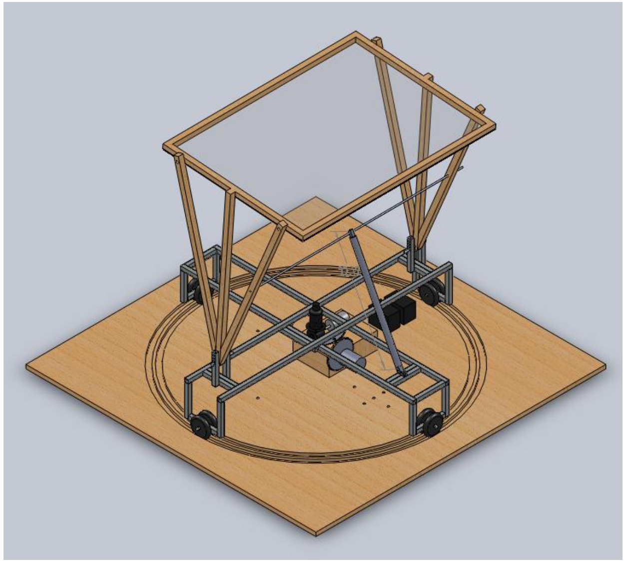

Fig. 10. 3-D rendering of the framing

XI. Conclusion

The Alternative Solar Energy Generation project utilizes the energy of the sun to heat a Stirling cycle engine. The mechanical output of the engine is converted into electric potential which is carefully controlled to safely and efficiently store the charge to a battery. Meanwhile a second battery is powering a control system to maintain the alignment of the focused sunlight on the heat element of the Stirling cycle engine. The energy stored on the battery can later be used just as any other battery would be. The main purpose of this project is to prove with a working prototype that there are alternative methods of generating energy which are renewable and do not damage the environment.

XII. Acknowledgment

The entire Alternative Solar Energy Generation team would like to thank Progress Energy for graciously funding this project. The team would also like to thank Dr. Samuel Richie for his continuous support in Senior Design.

XIII. Reference

[1] Buchman, Isidor. "Charging Lead Acid." Charging Information For Lead Acid Batteries â□“ Battery University. Cadex Electronics Inc. Web. 28 Mar. 2012. <http://batteryuniversity.com/learn/article/charging_the_lead_acid_battery>.

[2] W. H. Cantrell, "Tuning analysis for the high-*Q* class-E power amplifier," *IEEE Trans. Microwave Theory & Tech.*, vol. 48, no. 12, pp. 2397-2402, December 2000.

[3] W. H. Cantrell, and W. A. Davis, "Amplitude modulator utilizing a high-Q class-E DC-DC converter," *2003 IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 3, pp. 1721-1724, June 2003.

[4] "Working Principles." Logic System Technology. Web. 18 Mar. 2012. <http://www.logicsys.com.tw/wrkbas.htm>.

XIV. The Engineers

Andy Bryan, an Electrical Engineering major from Melbourne. He interned at Aeronix Coroporation. He privately tutors math, physics, and engineering courses, in addition to programming flash games and websites on the side.

Beau Eason is a senior electrical engineering student at The University of Central Florida. He also has a minor in computer science. He has worked for his university as a tutor and as an undergraduate admissions ambassador. Upon graduation he will begin his career at Texas Instruments.

Robert Giffin is an electrical engineering student from Miami, FL. After graduating from Miami Dade college with his AA he transferred to the University of Central Florida to pursue his bachelor's degree. Upon graduation, he will be joining Siemens in Houston, TX as a Wind Engineer in Training.

Sean Rauchfuss is an electrical engineering student in his senior year at the University of Central Florida. During his time as a student he worked as an RA in the on campus dorms in addition to interning with Intersil Corporation. Following graduation, he will be joining Texas Instruments in Dallas, TX as a Technical Sales Associate.