Portable Nano-Hydro Power Generator for the DC House Project

by

Andrew Aw

James Biggs

Senior Project

ELECTRICAL ENGINEERING DEPARTMENT

California Polytechnic State University

San Luis Obispo

2013

TABLE OF CONTENTS

Section *Page*

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

This senior project report explains the construction and design of a small, portable water generator that converts kinetic energy flowing in small creeks to electrical energy as a renewable source of energy for the DC House. The DC House, in short, is a project to build a self-sustainable house for Third World countries that utilizes only DC electricity. The system consists of two converters and a charge controller for a 12V lead-acid battery. The first converter converts the hydro generator voltage output to 15 Volts for safe and proper charging of the lead-acid battery by the charge controller. The second converter provides power output for the DC House by converting the 12V lead-acid battery to 48 Volts at a maximum of 60 Watts. The charge controller contains a bi-directional connection to the 12V lead-acid battery that can store the energy generated by the hydro generator for future use during light loads or deliver additional power during heavy loads. Since the system uses DC electricity, interfacing with the DC House eliminates costly and inefficient conversion from DC to AC, and vice versa, normally implemented in conventional methods. Also, assuming the user of the system owns a vehicle, the user can use his/her existing battery without having to buy additional expensive equipment. The Portable Nano-Hydro Power Generator provides a cheap and versatile renewable source of energy that can provide electricity to the unfortunates without depleting the earth's natural resources.

I. INTRODUCTION

In today's world, the demand for electricity in the United States increases annually as more people continue buying products that run on electricity. In the early 1990s, the average household owned at most 1 computer and 1 mobile phone. Now, in the year 2013, an average person owns 2 computers, 1 mobile phone, and 1 portable music player. Consumers use all of these products on a daily basis, which require greater electricity demand as seen in Figure 1.

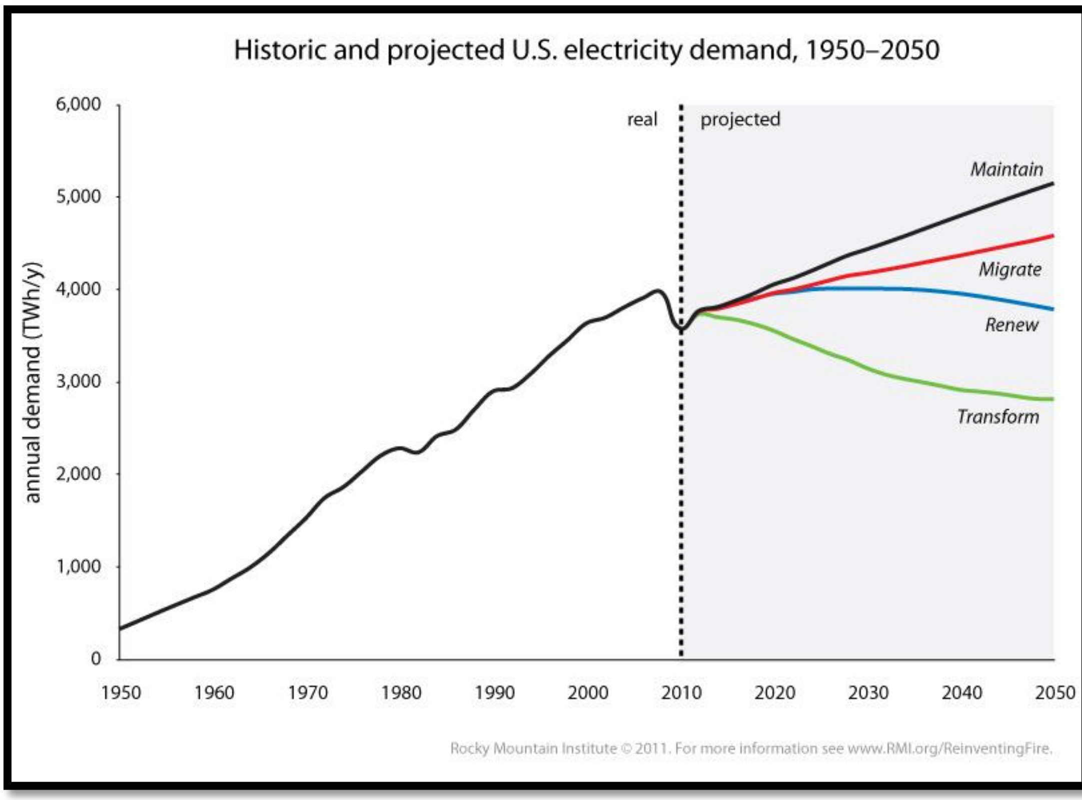


Figure 1: Historic and projected U.S. electricity demand [1]

Since 1950, the annual demand for electricity continues to increase linearly unless the U.S. migrates, renews, or transforms the annual demand as illustrated in Figure 1 [1]. However, as the electricity demand increases, natural resources used for electrical generation by power plants will begin to deplete and require industries to search for alternative forms of electrical generation.

Current renewable sources of energy include solar, hydro, and wind power are slowly being implemented in the U.S. to curb the trend.

Unfortunately, in other parts of the world, growing Third World countries, such as China and India, are becoming more modern and industrialized without regard for sustainability and the environment. Natural resources begin to deplete much more rapidly and cause greater greenhouse gas emission. Soon, these Third World countries will experience the same problem of high annual electricity demand as the U.S. and could potentially create a global issue when earth's natural resources are depleted.

As an innovative and sustainable system, the Portable Nano-Hydro Power Generator is created in order to preserve earth's natural resources while generating electrical energy in a sustainable manner. The system can safely be placed into the water without damaging the habitat or harming the living organisms living within the habitat. The turbine of the generator rotates naturally with the water flow and converts the kinetic energy into electrical energy without consuming any water resource. Also, the system requires only a small amount of materials to create it, making it small and portable for a single person to operate.

People worldwide can benefit from the Portable Nano-Hydro Power Generator by reducing greenhouse gas emissions and consumption of natural resources for electrical generation. Natural resources can be used more effectively and efficiently through renewable energy sources by creating projects like the Portable Nano-Hydro Power Generator and promoting its use.

II. BACKGROUND

i. DC House

The DC House is simply a house whose electricity is provided by direct current (DC) power. About 1.6 billion people in the world do not have access to electricity because many of them live on or below the poverty line. Some may also be geographically isolated from access to the utility grid. The DC House project aims to utilize renewable energy sources directly, such as solar panels, that output DC power without the need for intermediate energy conversions, i.e. DC to AC conversion. The elimination of the intermediate conversion process increases efficiency and reduces cost, while simultaneously providing electricity to the less fortunate [2]. The Portable Nano-Hydro Power Generator is just one of the various renewable sources of energy for the DC House project as shown in Figure 2.

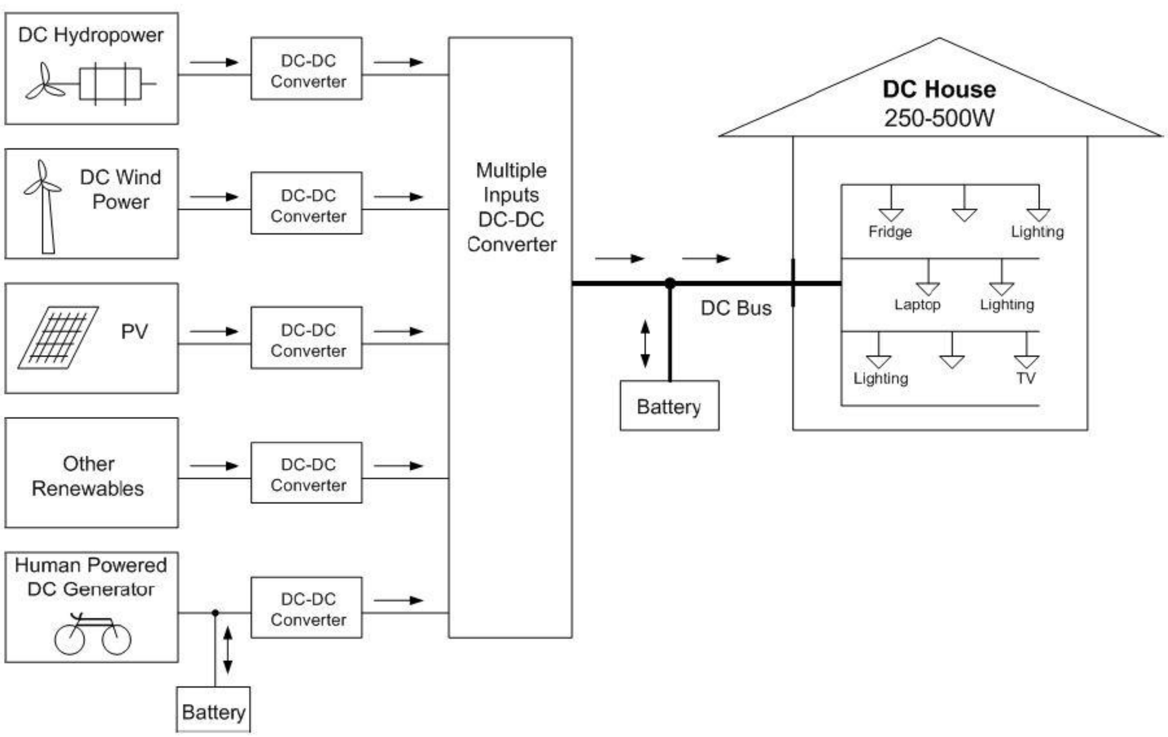


Figure 2: Various components of the DC House project [3]

ii. Portable Nano-Hydro Power Generator

The Portable Nano-Hydro Power Generator consists of a water turbine, controller, and battery as seen in Figure 3. When placed in a small stream, the water turbine rotates and converts the kinetic energy of the water flow into electrical energy for charging a battery or supplying power to the DC House. The controller/charger block consists of DC-DC converters and a battery charge controller. DC-DC converters are power electronic circuits that modify voltage or current by using semiconductor devices as switches. These converters are necessary to step up the output DC voltage of the water turbine for proper charging of a 12V lead-acid battery and to step up the DC voltage to 48 Volts for the DC House. The charge controller is also necessary because unsafe practice of charging a lead-acid battery can lead to bodily injury or even death. Without a charge controller, the battery could overcharge and produce hydrogen gas, known as gassing, which presents a safety hazard [5]. The system is rated at 60 Watts to provide power for lighting appliances, which is the majority of electricity demand for people residing in developing countries.

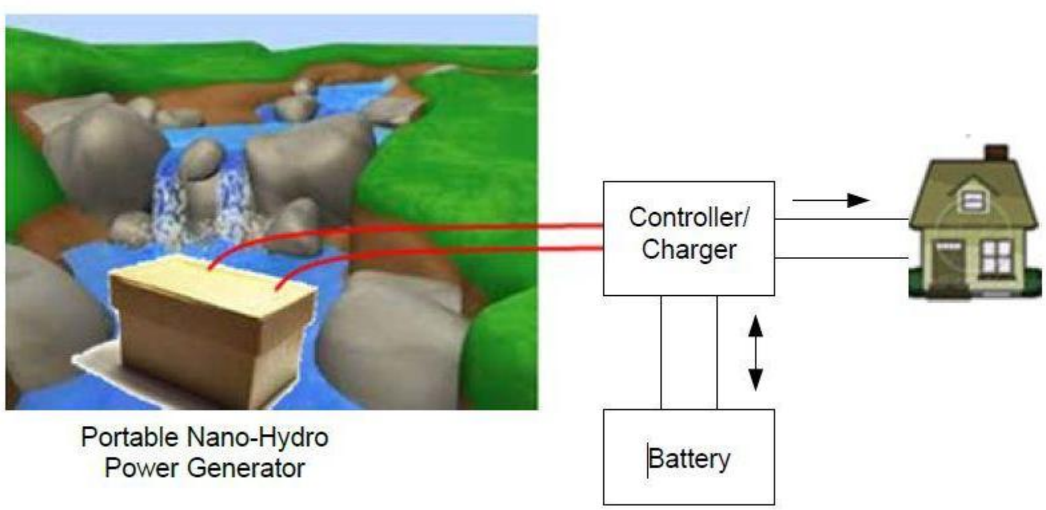


Figure 3: Pictorial diagram of the Portable Nano-Hydro Power Generator [4]

III. REQUIREMENTS AND SPECIFICATIONS

TABLE I [6]
PORTABLE NANO-HYDRO POWER GENERATOR REQUIREMENTS AND SPECIFICATIONS

Marketing Requirements	Engineering Specifications	Justification
2,5	The hydro generator generates a maximum of 60 Watts.	The 60 Watt maximum provides sufficient amount of power for the consumers' needs. Lighting consists of the majority of the electricity demand for Third World countries which ranges from 50 Watts to 100 Watts. The hydro generator can help supply that electricity demand.
4	The charge controller contains a bi-directional connection for charging and discharging a standard 12 Volt lead-acid battery.	The system requires a portable battery to store the energy generated by the generator along with providing a local energy source to the load. When a power deficit occurs, the battery discharges to power the load. When excess generation occurs, the battery stores the energy.
4,5	The electrical system outputs voltages of 15 and 48 Volts, and receives inputs from the battery and hydro generator.	The system receives its source from either the hydro generator or the battery, or both. The 48 Volt output will connect to the DC House main bus voltage of 48 Volts, while the 15 Volt output connects to the lead-acid battery for proper charging.
2	The electrical system is rated at 60 Watts.	With the capability to operate at 60 Watts, the components of the electrical system must operate safely in the worst case scenario and have protection from potential faults.
2,3,6	A protective cover with a Type 6P NEMA rating encases the electrical components.	Since the product operates underwater, the Type 6P NEMA rated enclosure protects against electrical shock from accidental user and/or wildlife contact while preventing water and dirt from damaging the system.
1,3	The dimensions for the enclosure for the converters and charging components should not exceed 12in. x 9in. x 7in. (~304mm x 229mm x 178mm)	Transportation to remote and/or distant locations requires portability of product. The dimensions for this enclosure mimic the typical size of a standard 12V battery, which consumers consider portable.

Marketing Requirements

1. Portable
2. Safe to use
3. User friendly
4. Versatile with the capability of charging and discharging a car battery
5. A renewable source of energy
6. The product can withstand outdoor elements.

The marking requirements and engineering specifications for the Portable Nano-Hydro Power Generator are listed and tabulated above in Table I. Marketing requirements are a collection of engineering and marketing requirements that a system must satisfy in order to meet the demands of the customer or end user. Conversely, engineering requirements are technical requirements of a system to meet standards and functionality. Each engineering specification comes with justification and its correlating marketing requirement(s). The engineering requirements must be verifiable and traceable to the marketing requirement(s) in order to create a successful system. The marketing requirements and engineering specifications table format derives from [6], Chapter 3

IV. DESIGN

i. Initial Design Considerations

In order to develop the Portable Nano-Hydro Power Generator, a block diagram is planned out to determine each component's functionality and its relationship with other components within the overall system. The first proposed block diagram contains two simple blocks, a DC-DC converter and charger controller, shown below in Figure 4. This system block diagram minimizes power losses and component count and promotes greater efficiency.

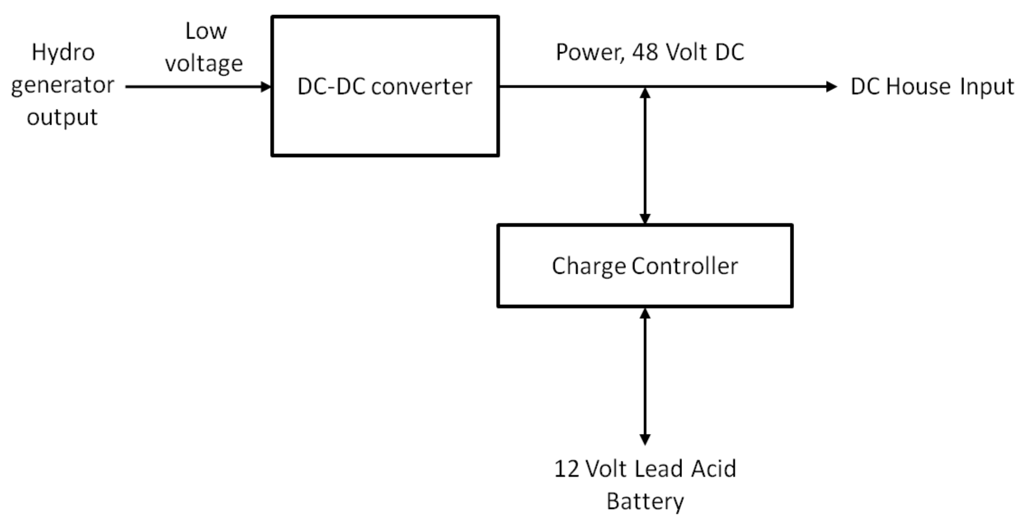


Figure 4: Proposed Block Diagram of Portable Nano-Hydro Power Generator

However, the problem with the block diagram in Figure 4 is the receiving input of 48 Volts for the charge controller. No charge controller exists to handle an input voltage nearly 4 times greater than the nominal battery charging voltage level without having to step down the voltage. The maximum voltage for charging a 12V lead-acid battery is approximately 14.5 Volts, or else the battery could overcharge and release toxic chemicals [5]. Also, the connection to the lead-acid battery fails to meet the engineering requirement of a bi-directional connection for charging and discharging. For those reasons, two separate converters are created: one converter to produce the proper voltage for charging the lead-acid battery and the other converter to produce for the proper voltage for the DC House.

Both DC-DC converters initially are chosen as non-isolated topologies, or more commonly known as boost converters, schematically drawn in Figure 5.The derived mathematical equation for a boost converter is given as

$$V_o = \frac{V_s}{1-D} \tag{4.1}$$

where V_o is the output voltage, V_s is the input voltage, and D is the duty cycle. The DC component of the output voltage is controlled by adjusting the duty cycle D, which is the fraction of the switching period that the switch is closed [7].

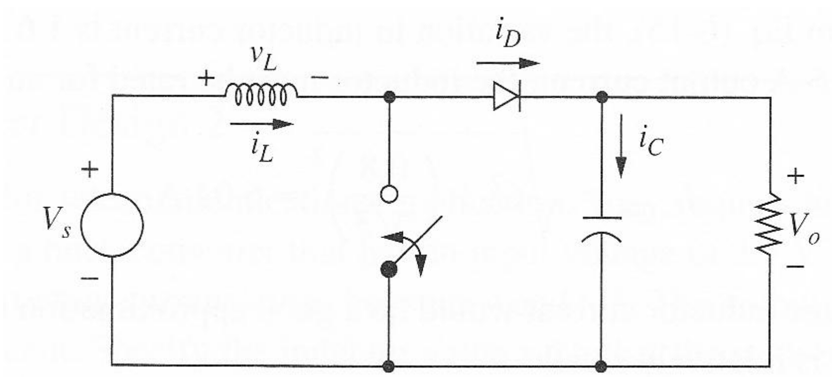


Figure 5: Circuit Diagram of a Boost Converter [7]

Based on the given information provided by the mechanical team, a two-phase stepper motor with a 5.5 Volt rating is chosen as the hydro generator with an average flow rate of 50 RPM. The voltage output from the hydro generator depends on the flow rate of the stream; the faster the stream flows, the higher the output voltage. The first boost converter converts the hydro generator output of approximately 5 Volts to 15 Volts for the charge controller, while the second converter converts the 12V lead-acid battery to 48 Volts for the DC House. However, according to equation 4.1 and rearranging to solve for D, the 5-15 boost converter's and 12-48 boost converter's duty cycles are 66.67% and 75%, respectively. The existence of small inductor resistance, especially at high duty cycles, affects the performance of the boost converter by increasing power loss and decreasing efficiency [7]. Ideally, design of the converters calls for a duty cycle less than 50% to reduce the drawbacks. The trend as duty cycle increases can be seen below in Figure 6. Therefore, isolated DC-DC converters that utilize transformers are ideal topologies for the design of the Portable Nano-Hydro Power Generator to include the transformer's turns ratio as a design parameter and reduce the duty cycle of the MOSFET switch.

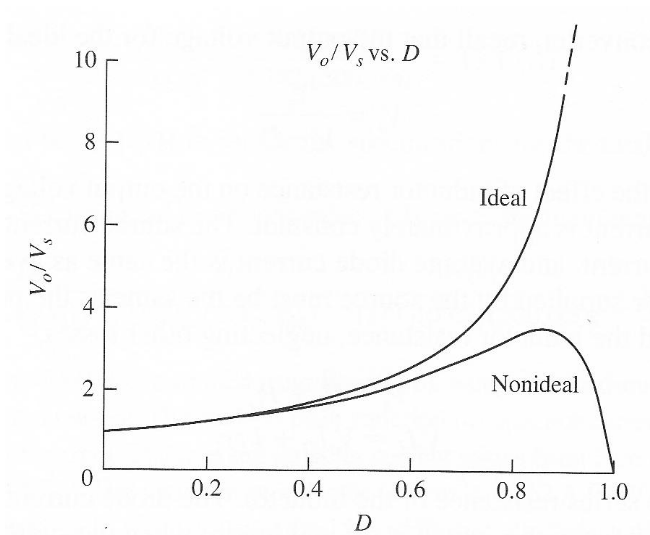


Figure 6: Output and Input Voltage Ratio versus Duty Cycle performance trend for Ideal and Nonideal Boost Converter [7]

ii. Block Diagram

The block diagram for implementation of the Portable Nano-Hydro Power Generator is illustrated in Figure 7 using isolated DC-DC converter topologies. Isolated converters include forward, flyback, and push-pull topologies with each isolated topology consisting of its own advantages and disadvantages. After investigating each topology, the flyback converter, shown in Figure 8, best meets the design specifications for an output of 60 Watts. The flyback converter is widely used for output powers from 150 Watts down to under 5 Watts and is the frequent choice for a supply with many output voltages in the region of 50 to 150 Watts. The push-pull topology is typically used in up to 300 Watts, while the forward topology is most widely used for output power under 200 Watts when the maximum DC input voltage is in the range of 60-200 Volts. Below the maximum input of 60 Volts, the required primary input current becomes too large for practical implementation [8]. All controllers chosen for the Portable Nano-Hydro Power Generator are made by Linear Technology to design and simulate in their free software tool, LTspice.

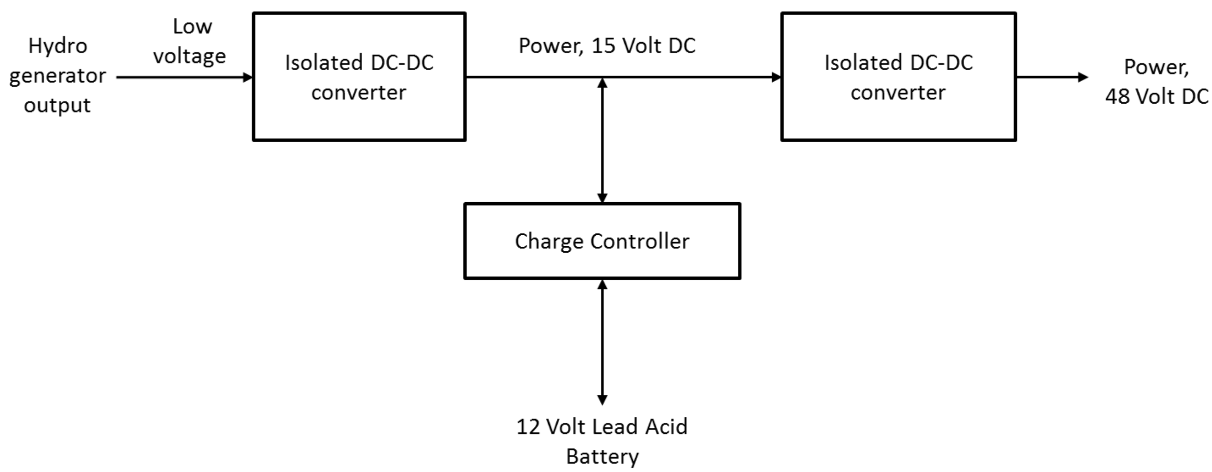


Figure 7: Block Diagram of the Portable Nano-Hydro Power Generator

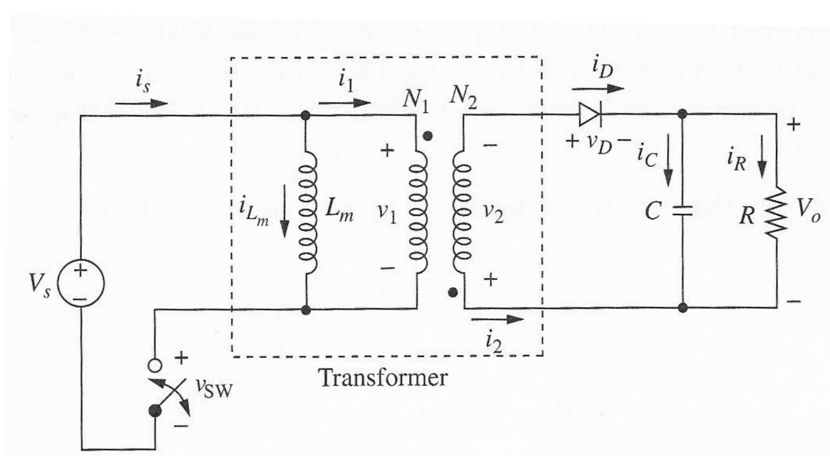


Figure 8: Circuit Diagram of a Flyback Converter [7]

iii. Charge Controller

After carefully searching through all of the different charge controllers by Linear Technology, the LTC4000-1 charge controller is chosen because it is compatible with lead-acid battery chemistries and designed to simplify the conversion of any externally compensated DC-DC converter into a high performance battery charger with PowerPath control [9]. Linear Technology offers very few lead-acid battery charge controllers, but offers a plethora of charge controllers designed for lithium-ion, nickel-metal-hydride, and nickel-cadmium battery chemistries. The proper charge controller must be selected for a lead-acid battery chemistry because lead-acid batteries require a different charging method and voltage per cell than for the other battery chemistries. A 12 Volt lead-acid battery typically contains 6 cells with a float charge voltage commonly specified at 2.25 V/cell at 25°C, or 13.5 Volts, and a -3.3 mV/°C per cell temperature coefficient, or -19.8 mV/°C [9]. The most common charging method for a lead-acid battery is called 3-step charging depicted below in Figure 9.

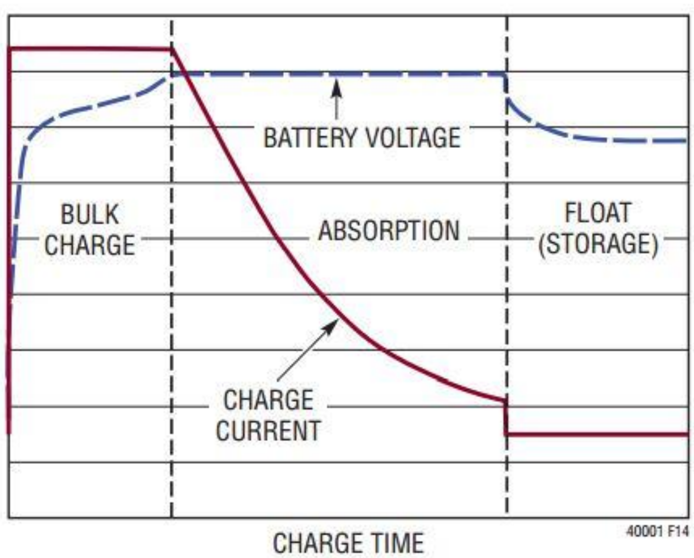


Figure 9: Lead-Acid 3-Step Charging Cycle [9]

The 3-step charging involves bulk charge, absorption, and float stages. In the bulk charge step, the charge controller charges the lead-acid battery at a constant current until the battery voltage reaches the programmed absorption voltage. Once the absorption voltage is reached, the programmed absorption voltage level is held constant as the charge current gradually decreases in the absorption stage. The absorption stage terminates when the charge current falls to the programmed C/X level and enters the float stage of the charging process. Once in the float stage, constant voltage is held indefinitely at the programmed float voltage with a small trickle charge to maintain the battery's state of charge. When the battery voltage drops below a certain level, the whole 3-step charging cycle is reinitiated beginning with the bulk charge stage. Other battery chemistries charge up in a similar manner but require different steps [9].

The LTC4000-1 provides many special features such as regulation loops and status indicators. Some of the features available on the LTC4000-1 will not be used to avoid discrepancies with interfacing system components and/or is not necessary for the design of the charge controller. These unused features include the enable charging pin (Pin 1), $\overline{\mathrm{FLT}}$ pin (Pin 7), $\overline{\mathrm{CHRG}}$ pin (Pin 8), output feedback voltage pin (Pin 17), input current sense negative input (Pin 22), voltage monitor input (Pin 25), $\overline{\mathrm{RST}}$ pin (Pin 26), input current monitor (Pin 27), and input voltage feedback pin (Pin 28). The enable charging, $\overline{\mathrm{FLT}}$, $\overline{\mathrm{CHRG}}$, and $\overline{\mathrm{RST}}$ pins are digital input and output pins which requires a microcontroller to interface with these pins. The output feedback voltage, input current sense negative input, voltage monitor input, input current monitor, and input voltage feedback pins are unnecessary features for monitoring the DC-DC converter's input and output. The pins are either left open or tied to a specified pin to disable its feature as stated in the datasheet [9].

In order to perform the 3-step charging, the LTC4000-1 recommends configuring the controller as shown in Figure 10. When a charging cycle begins, the charger enters the bulk charge step and the $\overline{\text{CHRG}}$ pin is pulled low. The battery voltage rises to the absorption voltage level programmed by [9]

$$V_{ABSRP} = \left(\frac{R_{BFB1}(R_{BFB2}+R_{BFB3})}{R_{BFB2}R_{BFB3}} + 1\right) * 1.136V \quad (4.2)$$

As the charge current drops to the programmed C/X level according to the equation [9],

$$I_{CLIM} = \frac{(0.25\mu A * R_{CX}) - 0.5mV}{R_{CS}} \quad (4.3)$$

the $\overline{\text{CHRG}}$ pin turns high impedance and the charger enters the float stage charging the battery voltage at a constant float voltage level programmed by [9]

$$V_{FLOAT} = \left(\frac{R_{BFB1}}{R_{BFB2}} + 1\right) * 1.136V \quad (4.4)$$

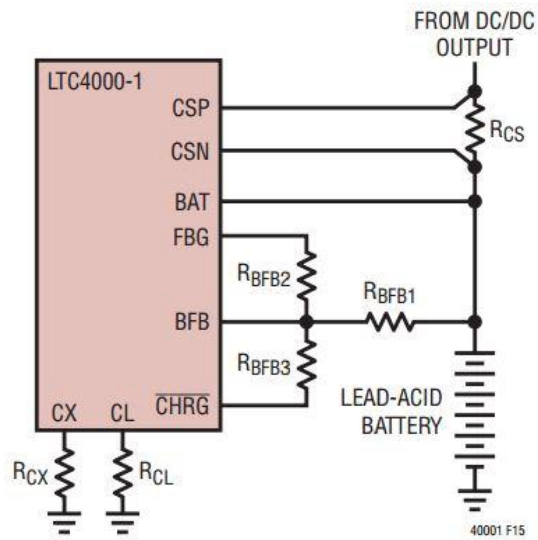


Figure 10: Recommended 3-Step Charging Circuit Configuration [9]

Beginning with equation 4.4, the float voltage is programmed at 13.5 Volts, as specified in the datasheet for the proper float charge voltage at 25°C, by choosing standard resistor values for R_{BFB1} and R_{BFB2}. The resistor values chosen for R_{BFB1} and R_{BFB2} are 97.6 kΩ and 8.98 kΩ, respectively. Substituting the R_{BFB1} and R_{BFB2} resistor values into equation 4.2 with an absorption voltage programmed at 14.5 Volts, the resistor value of R_{BFB3} is 106 kΩ. The CL (charge current limit programming) pin is left open and equation 4.3 simplifies to

$$I_{CLIM(MAX)}(A) = \frac{0.050V}{R_{CS}(\Omega)} \tag{4.5}$$

where R_{CS} is the charge current sense resistor connected across the CSP (charge current sense positive input/input ideal diode cathode) and CSN (charge current sense negative input/battery ideal diode cathode) pins [9]. Since the engineering specification requires a 60 Watt rating, the charge current limit is programmed at 4 Amps with the first flyback converter outputting 15 Volts and R_{CS} equates to 12.5 mΩ using equation 4.5. The first flyback converter output is designed for an output of 15 Volts due to the instant-on voltage dependencies of the LTC4000-1 and to account for any potential voltage drop. As shown in Figure 11, the output voltage should neither be too high for the PMOS to be driven in the linear region, where it is less efficient, nor programmed less than 105% of float voltage to ensure the battery can be fully charged. The battery charge to terminate once the charge current drops to the programmed C/X level in equation 4.3, which is programmed at 0.4 Amps and R_{CX} equates to 22 kΩ [9].

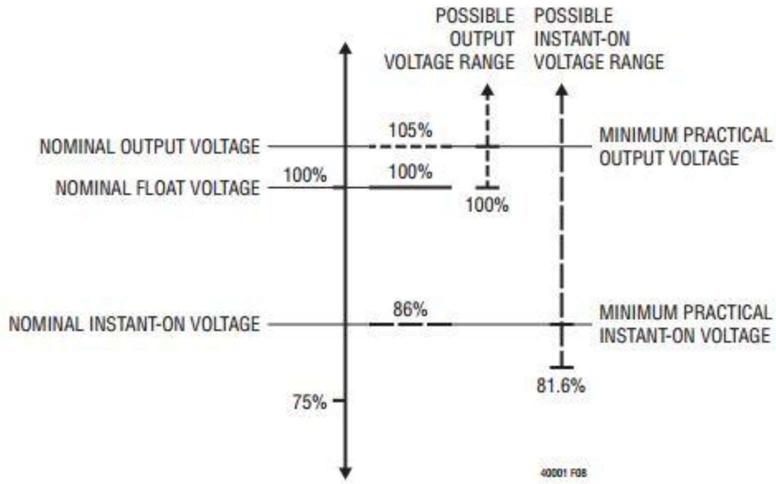


Figure 11: Output Voltage Dependencies for the LTC4000-1 [9]

Next, the LTC4000-1's battery temperature qualified charging feature is implemented by configuring the controller as recommended and shown in Figure 12. This feature allows for programmable hot and cold threshold levels for the charge controller to pause charging of the lead-acid battery until it is deemed safe. Lead-acid batteries have a charging temperature operating range of -10°C to 60°C and should be properly temperature compensated to prolong battery life and prevent reduction of charge acceptance [9].

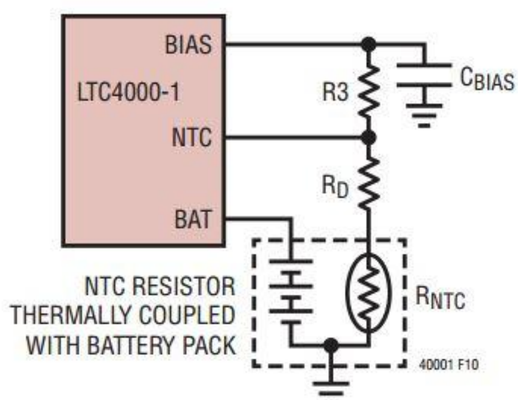


Figure 12: NTC Thermistor Circuit Configuration [9]

The resistors R3 and R_D in Figure 12 are determined by the given equations provided by the datasheet

$$R3 = \frac{R_{NTC}\ at\ cold\_threshold - R_{NTC}\ at\ hot\_threshold}{2.461} \tag{4.6}$$

$$R_D = 0.219 * R_{NTC}\ at\ cold\_threshold - 1.219 * R_{NTC}\ at\ hot\_threshold \tag{4.7}$$

where the R_{NTC} is a thermistor that increases in resistance as temperature decreases or decrease in resistance as temperature increases [9]. The hot and cold thresholds are chosen at 0°C and 50°C, respectively, where R3 is calculated at 11.8 kΩ using equation 4.6 and R_D is calculated at 2.77 kΩ using equation 4.7 for a 150 kΩ NTC thermistor.

The remainder of the pins of the LTC4000-1 are connected to various positions on the first flyback converter or to a specified connection stated in the datasheet.

iv. 5-15 Volt Flyback Converter

The first flyback converter is designed to receive a nominal input voltage of 5 Volts and output 15 Volts for the LTC4000-1 charge controller. After viewing all the possible flyback controllers manufactured by Linear Technology, the LTC1871 is chosen because the controller provides a wide voltage input range suitable to connect with the hydro generator. The input to the first flyback converter will vary based on the RPM of the turbine and water flow. A high RPM correlates to a high voltage output from the hydro generator, while a low RPM correlates to a low voltage output from the hydro generator. The LTC1871 controller also allows the designer to program the operating frequency and attach external components to promote greater flexibility in designing the converter. High switching frequency is desired to reduce the inductors and capacitor sizes, but the tradeoffs for high switching frequency are increased power loss in the switch and heat produced. More heat produced decreases the converter's efficiency and may offset the reduction in component sizes [7]. The ability to attach external components does not limit the designer to work within the capabilities of the discrete internal components integrated in the chip.

The LTC1871 controller comes available in two different operating modes: Burst Mode operation and Pulse-Skip Mode operation. For applications in maximizing efficiency at very light loads, the Burst Mode operation should be applied by connecting the MODE/SYNC pin to ground. For applications where fixed frequency operation is more critical than low current efficiency or lowest output ripple is desired, the Pulse-Skip Mode operation should be used by connecting the MODE/SYNC pin to the $INTV_{CC}$ pin. The $INTV_{CC}$ pin contains an internal 5.2V regulated output voltage which is locally bypassed with a capacitor. The Burst Mode operation is disabled once the MODE/SYNC pin senses a DC voltage above 2 Volts and allows the I_{TH} pin to directly control the current comparator from no load to full load condition [10]. The Pulse-Skip Mode is selected because the controller operates mainly with large currents.

The LTC1871 uses a constant frequency architecture that can be programmed over a 50 kHz to 1 MHz range by simply attaching the corresponding external resistor, or timing resistor, value from the FREQ pin to ground. The resistance value of the timing resistor for the desired operating frequency is determined by viewing the graph given in the datasheet and depicted below in Figure 13. By careful inspection of Figure 13, the programmed operating frequency at 500 kHz is approximately 47 kΩ. 500 kHz is chosen as the operating frequency of the LTC1871 because some designers consider it the best compromise between small component size and efficiency [7].

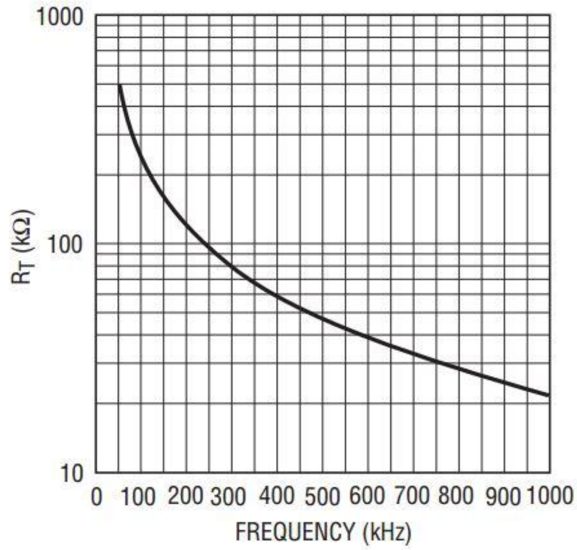


Figure 13: Timing Resistor Value [10]

In comparison to conventional current mode controllers, the LTC1871 operates its current control loop by sensing the voltage drop across the power MOSFET switch instead of across a discrete sense resistor. This sensing technique improves efficiency, increases power density, and reduces the cost of the overall solution as long as the voltage on the SENSE pin is less than 36 Volts [10]. According to the theoretical calculation of the voltage across the switch of a flyback converter, the equation is

$$V_{SW} = V_s + V_o\left(\frac{N_1}{N_2}\right) \tag{4.8}$$

where V_S is the input voltage, V_O is the output voltage, and N_1 and N_2 are the number of turns on the primary and secondary sides of a transformer, respectively [7]. The manufacturer Coiltronics makes configurable, multi-winding surface mount transformers ideal for flyback applications. The transformers are made with ferrite core material and provide a power range from 1 Watt to 70 Watts [11]. The derived mathematical relation between input and output for a flyback converter given as

$$V_o = V_s\left(\frac{D}{1-D}\right)\left(\frac{N_2}{N_1}\right) \tag{4.9}$$

where V_O is the output voltage, V_S is the input voltage, D is the duty cycle, and N_1 and N_2 are the number of turns on the primary and secondary sides of a transformer, respectively [7]. For a 15 Volt output, 5 Volt input, and 50% duty cycle in equation 4.9, the Coiltronics transformer can be configured with a 1:3 turns ratio. Substituting the turns ratio into equation 4.8, the voltage across the switch is 10 Volts, which is well below the maximum rating of the SENSE pin. Thus, the SENSE pin can be connected to the drain of the MOSFET switch without the need for a sense resistor to operate with greater efficiency.

Next, the turn-on threshold input voltage must be programmed using a resistor divider using the given equation in the datasheet

$$V_{IN(ON)} = 1.348V * (1 + \frac{R2}{R1}) \tag{4.10}$$

where the center node is connected to the RUN pin of the LTC1871 [10]. The controller contains an internal comparator detection circuit to determine when the converter will turn on or off to save power. By programming the turn-on threshold input voltage at its minimum voltage of 2.5 Volts, the resistor values for R1 and R2 are calculated to be 5 kΩ and 4.27 kΩ, respectively. A separate resistor divider is also implemented to program the output voltage using the given equation in the datasheet

$$V_o = 1.230V * (1 + \frac{R2}{R1}) \tag{4.11}$$

where the center node is connected to the FB pin [10]. This resistor divider is connected to the output of the flyback converter and fed into an error amplifier internal to the controller to program the desired output voltage. For an output voltage of 15 Volts, the resistor values for R1 and R2 are calculated to be 5 kΩ and 56 kΩ, respectively.

The remaining pins of the LTC1871 are configured according to the proper connections explained in the datasheet. The output capacitance, though, is determined by the theoretical mathematical equation

$$\frac{\Delta V_o}{V_o} = \frac{D}{RCf} \tag{4.12}$$

where ΔV_o is the output ripple voltage, R is resistance of the load, and f is the operating frequency [7]. For a power rating of 60 Watts and output voltage of 15 Volts, the resistance equates to 3.75 Ω. Substituting in the resistance, duty cycle of 50%, and frequency of 500 kHz, the output capacitance equates to approximately 27 μF for output voltage ripple of 1% using equation 4.12. The computed theoretical output capacitance, though, does not take into account of the equivalent series resistance, or ESR, of the capacitor, which can significantly affect the output voltage ripple [7]. The ESR of a capacitor can be minimized by connecting multiple capacitors. According to basic circuit theory, multiple resistors connected in parallel equates to a small equivalent resistance and multiple capacitors connected in parallel increase in equivalent capacitance.

For added protection from large voltage transient spikes during the switching cycle, a resistor-capacitor-diode (RCD) snubber is configured as shown in Figure 14. Energy is stored in a non-magnetic gap in series with the transformer core, but the multiple windings cannot be all equally well coupled to the core due to the physical separation between the windings. A small amount of energy is stored within and between the windings and is represented as a leakage inductance. Because of this, the flyback topology has the disadvantage of large transient voltage spikes at the drain of the power switch and at the secondary rectifier, where the spikes are a function of the leakage inductance in the flyback transformer.

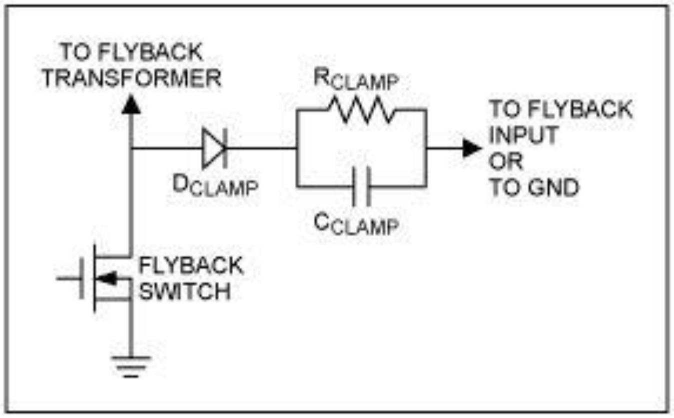


Figure 14: Snubber Circuit Configuration [12]

By placing the snubber circuit, the effects of the leakage inductance can be controlled and improve the reliability of the power supply. There are two possible configurations for a RCD snubber: voltage clamp snubber and rate-of-rise voltage snubber. Figure 14 represents a voltage clamp snubber that clamps the voltage during turn-off of the MOSFET, which will discharge the energy stored in the parasitic inductance into the RC network during each cycle [12]. In order to determine the proper RC component values, the following equations are used

$$\frac{1}{2}CV_{in(\max)}{}^{2}f = Watts \tag{4.13}$$

$$t_{on} = DT > 5RC \tag{4.14}$$

Equation 4.13 accounts for the rated wattage of the dissipation of the RC circuit, while Equation 4.14 allows for the proper RC time constant to allocate sufficient time for the RC circuit to fully discharge. Designing for 2 Watts and assuming a maximum input voltage of 36 Volt, the capacitance is 6.2 nF according to equation 4.13. Substituting the capacitance into equation 4.14 with a maximum operating 92% duty cycle by the LTC1871, the resistance is 60 Ω.

v. 12-48 Volt Flyback Converter

The second flyback converter receives a 12 Volt input from the lead-acid battery and outputs 48 Volts for the DC House using the same LTC1871 controller as in the first flyback converter. The controller is set to Pulse-Skip Mode to allow for the minimum amount of output voltage ripple. This is done by connecting the MODE/SYNC pin to the INTVCC pin. As stated for the 5-15 volt flyback converter, by careful inspection of Figure 13, the programmed operating frequency at 500 kHz is approximately 47 kΩ. Similarly to the 5-15 Volt converter, the SENSE pin is connected to the drain of the MOSFET. No sense resistor is needed because, by using equation 4.8, the maximum switch voltage is calculated as VSW = 24V, which is below the 36 Volt maximum mentioned previously. Using a 50% duty cycle, Vs=12V, Vo=48V, and equation 4.9, the necessary transformer turns ratio is calculated to be N2/N1=4/1. This is accomplished by connecting two windings in parallel on the primary side and four windings in series on the secondary side.

The turn-on threshold input voltage is set to 11.8 Volts so that the converter does not draw current from a drained battery. This voltage is set using a resistor divider where R1 is chosen as 10kΩ and R2 is calculated to be 78.7kΩ using equation 4.10. Output voltage is regulated using a feedback voltage from a resistor divider from the converter output. Using equation 4.11, R1 is chosen to be 5kΩ and R2 is calculated to be 191kΩ.

The minimum value for the output capacitor is calculated using equation 4.12 to be 2.6uF. However, due to the large inductance on the transformer, we increase this value to

Cout=44uF in order to have a properly compensated output. In order to reduce ESR, two 22uF capacitors are placed in parallel instead of one 44uF capacitor. The snubber resistance and capacitance are calculated using equations 4.13 and 4.14 to be 60Ω and 39nF. The remaining pins of the LTC1871 are configured according to the proper connections explained in the datasheet.

V. TEST PLANS

The flyback converters are tested to find parameters common for DC-DC converters. Both converters are tested with an open circuit load and many of the bias voltages are checked to verify the functionality of the LTC1871 controllers. Line regulation, load regulation, efficiency and output voltage ripple are measured for both converters. Input voltage, current, and power are measured on an AC power meter. Output voltage and current are measured from an electronic load. These measurements are obtained for low, nominal, and high input voltages while setting the electronic load from 0% to 100% of the max load current in steps of 20%.

Line Regulation

Line Regulation is calculated for each converter using the equation shown below [8].

$$\%\boldsymbol{LineRegulation} = \frac{\boldsymbol{V_{out(high\ input)}} - \boldsymbol{V_{out(low\ input)}}}{\boldsymbol{V_{out(nominal\ input)}}} * \mathbf{100}\% \tag{5.1}$$

Load Regulation

Load Regulation is calculated for each converter using the equation shown below [8].

$$\%\boldsymbol{LoadRegulation} = \frac{\boldsymbol{V_{out(low\ load)}} - \boldsymbol{V_{out(high\ load)}}}{\boldsymbol{V_{out(high\ load)}}} * \mathbf{100}\% \tag{5.2}$$

Efficiency

Efficiency is calculated using the equation shown below [8].

$$\boldsymbol{Efficiency} = \boldsymbol{\eta} = \frac{\boldsymbol{P_{out}}}{\boldsymbol{P_{in}}} * \mathbf{100}\% = \frac{\boldsymbol{V_{out} I_{out}}}{\boldsymbol{P_{in}}} * \mathbf{100}\% \tag{5.3}$$

Output Voltage Ripple

Output voltage ripple is found by measuring the peak to peak output voltage on an oscilloscope for value of input voltage and output current.

In addition to testing the electronics, the hydro generated is also tested to determine its functionality and performance. The hydro generator selected by the mechanical team is a two-phase stepper motor as shown in Figure 15. The stepper motor can still perform as a generator by rotating shaft and take the output from each phase. Based on the name plate information, the expected power output of the stepper motor is approximately 5 Watts.

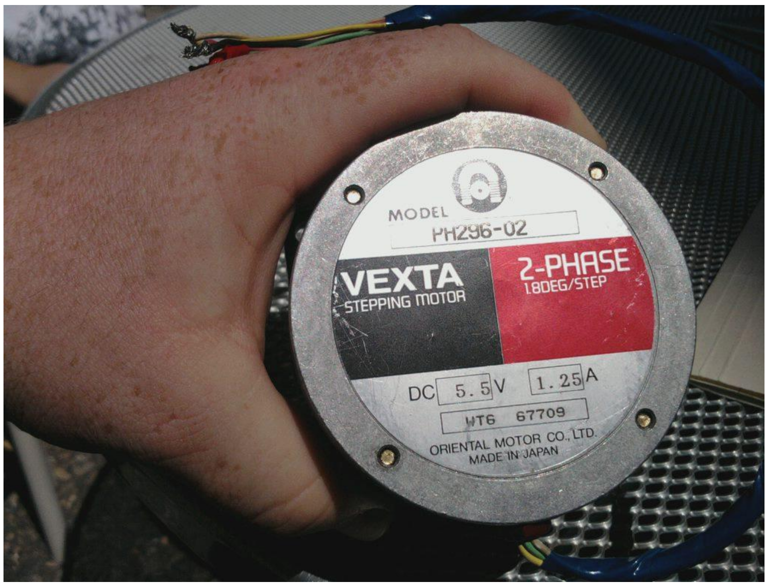


Figure 15: Capture of Stepper Motor

VI. DEVELOPMENT AND CONSTRUCTION

The two flyback converters and the charge controller are developed and tested in LTspice individually. The flyback converters are tested at full load and open load to verify that the controllers properly maintain the correct output voltages. The 5-15 Volt flyback converter is then combined with the battery charge controller in order to test if the 3-step charging cycle is performed on the lead-acid battery. The LTspice schematic for the 5-15 Volt flyback converter and charge controller are shown below in Figure 16 and Figure 17, respectively.

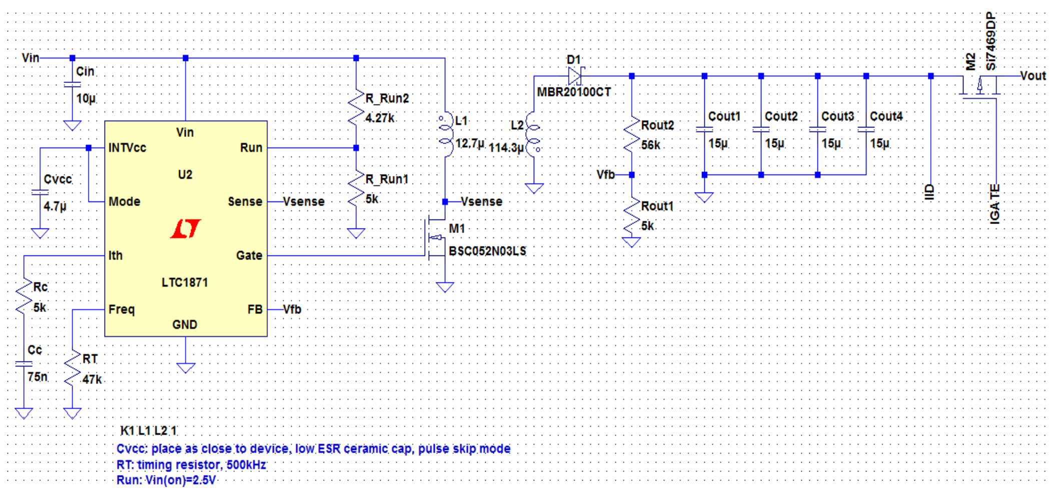


Figure 16: LTspice Schematic of 5-15 Volt Flyback Converter

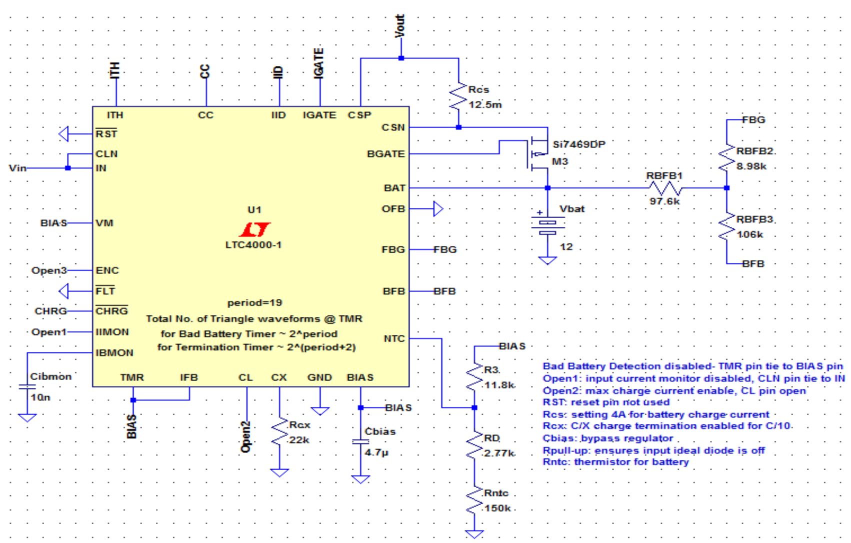


Figure 17: LTspice Schematic for the Battery Charge Controller

The LTspice schematic for the 12-48 Volt flyback converter is shown below in Figure 18.

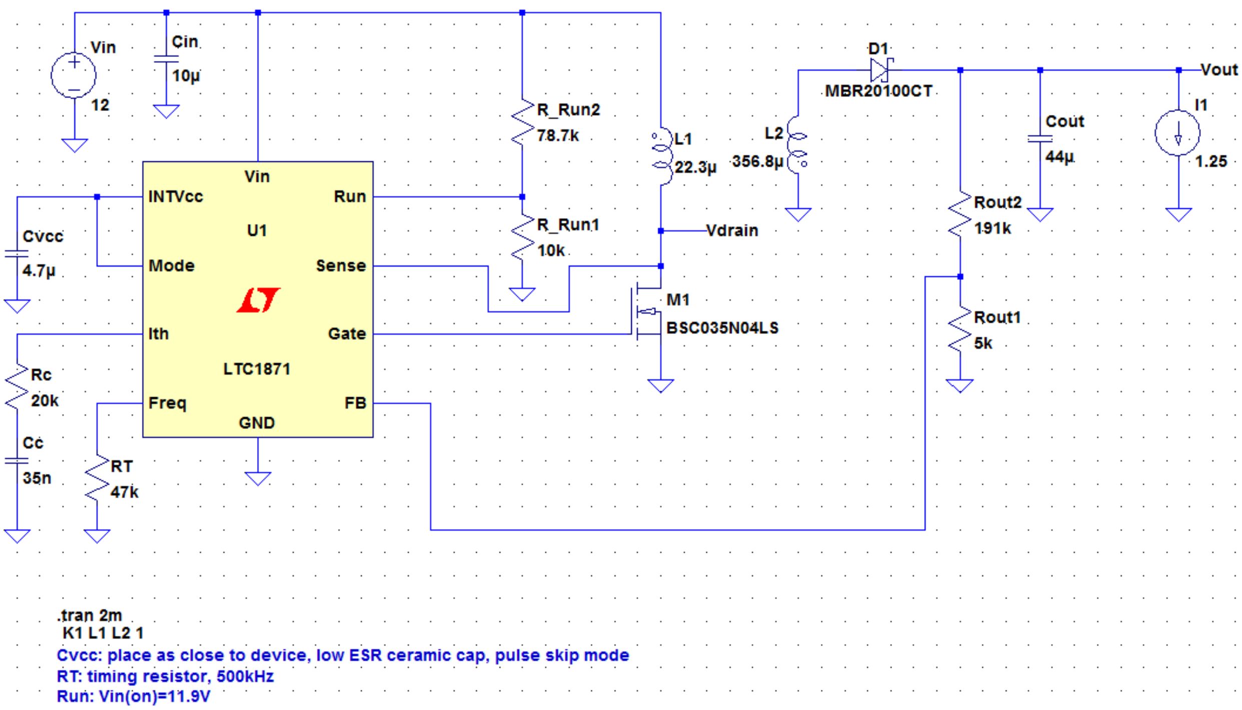


Figure 18: LTspice Schematic of 12-48 Volt Flyback Converter

After the simulated versions of the circuit are functional, the circuits are transferred into a PCB layout. Our layout is designed for a 2.5"x4" board layout from expresspcb.com. All components are sized and assigned appropriately sized pads on the layout. The trace widths are chosen based on the recommended widths for expected current values in the help section of the ExpressPCB program. Most of the components are of standard sizes with pre-set pad arrangements in the ExpressPCB program component library. The transformers, MOSFETs, and the LTC1871 controllers, however, require custom made pad arrangements which are based upon recommended layouts from their respective datasheets. The layout for the original board construction is shown below in Figure 19.

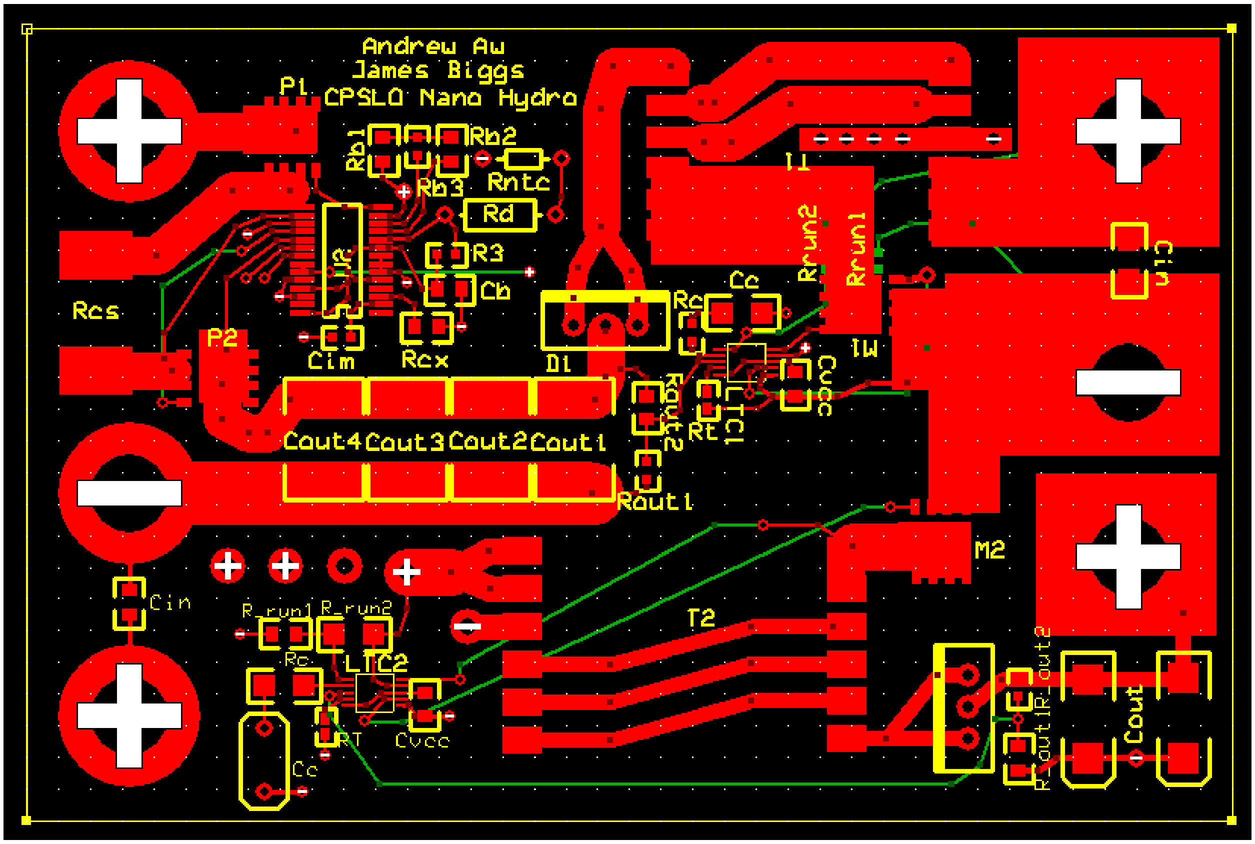


Figure 19: Layout for Original Circuit Board Configuration for ExpressPCB

The second design for the PCB layout is shown below in Figure 20. This version of the layout design is an attempt to fix some issues present in the previous layout. The second design includes spaces for flyback snubber circuits used to control the large voltage transient spikes during the switching cycle of the MOSFET switches. In addition, the layout is designed to improve power flow from the system input and output due the thermal heat generated by the circuit components. The controllers are also placed in a close proximity within each other for easy identification and close to its external components to reduce trace lengths.

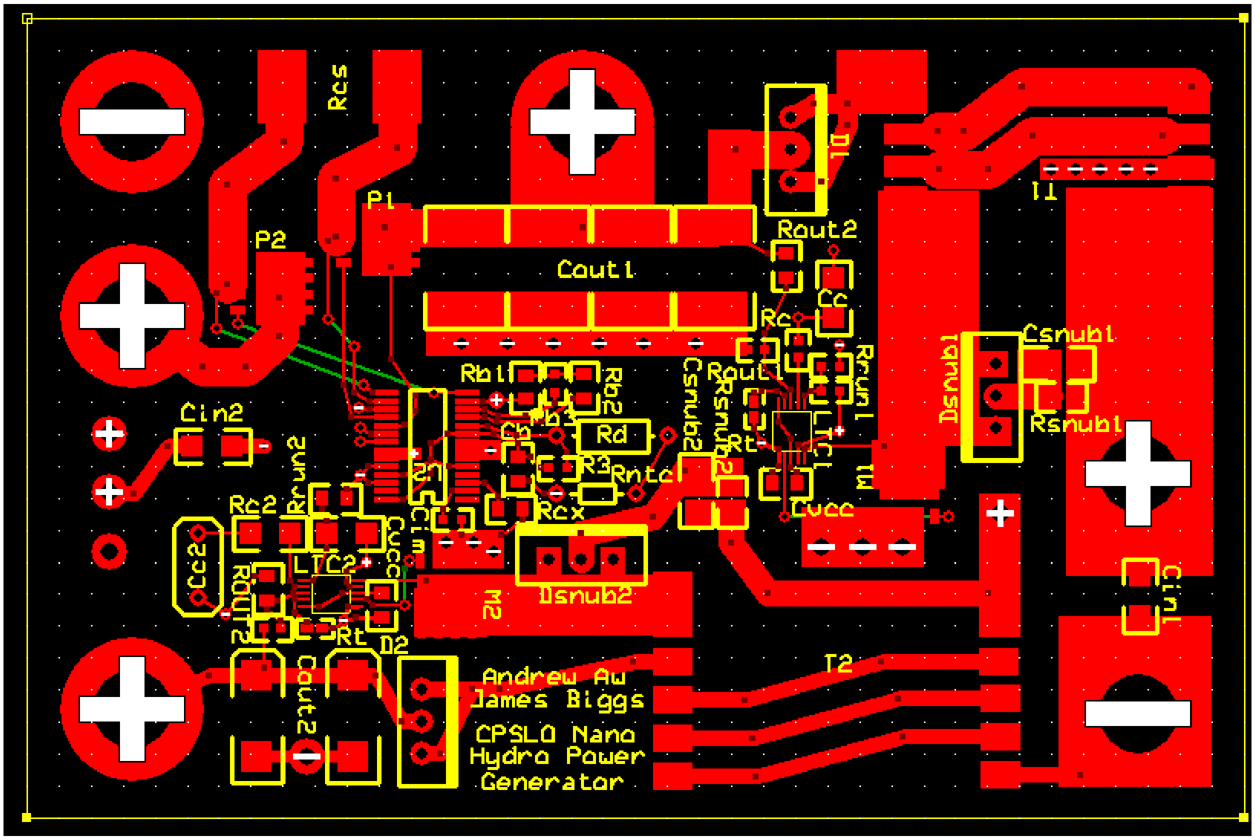


Figure 20: Layout for Revised Circuit Board Configuration for Express PCB

After designing the board layout, each of the three components are built and tested individually before being integrated. This is done to simplify the troubleshooting process by isolating the problems to specific components as opposed to searching for a problem within the entire system. The 5-15 Volt converter is tested first by verifying the proper output voltage and the correct turn-on voltage. This ensures that the LTC1871 controller, among other components, is connected and functioning properly. This test is then repeated for the 12-48 Volt converter.

VII. INTEGRATION AND TEST RESULTS

i. Simulation of Circuit

The data shown below in Table II and Table III represent the results from simulating both flyback converters in LTSpice. The measurement parameters listed are consistent with the hardware test plans shown previously in chapter five so that the load current is varied at high, low, and nominal input voltage values. Table II below lists the simulated results for this test plan on the 5-15 Volt flyback converter (circuit is shown in Figure 16).

TABLE II
SIMULATED RESULTS FOR 5-15 VOLT FLYBACK CONVERTER

Vin=5V							
%Load	Load Current (A)	Iin (A)	Pin (W)	Vout (V)	Pout (W)	Vopp-ripple (V)	Power Efficiency
20	0.8	2.69	13.45	15	12	0.032	89.22%
40	1.6	5.76	28.8	15	24	0.066	83.33%
60	2.4	9.56	47.8	14.93	35.832	3.6	74.96%
80	3.2	13.47	67.35	14.99	47.968	1.31	71.22%
100	4	14.51	72.55	11.96	47.84	0.164	65.94%
Vin=9V							
%Load	Load Current (A)	Iin (A)	Pin (W)	Vout (V)	Pout (W)	Vopp-ripple (V)	Power Efficiency
20	0.8	1.43	12.87	15	12	0.023	93.24%
40	1.6	2.99	26.91	15	24	0.047	89.19%
60	2.4	4.64	41.76	15.01	36.024	0.07	86.26%
80	3.2	6.45	58.05	15.01	48.032	0.1	82.74%
100	4	8.39	75.51	15.01	60.04	0.123	79.51%
Vin=12V							
%Load	Load Current (A)	Iin (A)	Pin (W)	Vout (V)	Pout (W)	Vopp-ripple (V)	Power Efficiency
20	0.8	1.07	12.84	15	12	0.019	93.46%
40	1.6	2.12	25.44	15	24	0.041	94.34%
60	2.4	3.52	42.24	15	36	0.063	85.23%
80	3.2	4.96	59.52	15	48	0.086	80.65%
100	4	6.04	72.48	15	60	0.103	82.78%

The results shown above in Table II are obtained using Vin=5V for minimum input, Vin=9V for nominal input, and Vin=12V for high input. Using these values, the parameters listed in the Test Plans section can be obtained. Using Equation 5.1, the Line Regulation at full load current is 20.33%. Using Equation 5.2, the Load Regulation at nominal input is 0.067%.

Table III below lists the simulated results for this test plan on the 12-48 Volt flyback converter (circuit is shown in Figure 18).

TABLE III

SIMULATED RESULTS FOR 12-48 VOLT FLYBACK CONVERTER

Vin=12V							
%Load	Load Current (A)	Iin (A)	Pin (W)	Vout (V)	Pout (W)	Vopp-ripple (V)	Power Efficiency
20	0.25	1.07	12.84	48.18	12.045	0.006	93.81%
40	0.5	2.08	24.96	48.32	24.16	0.011	96.79%
60	0.75	3.18	38.16	48.26	36.195	0.016	94.85%
80	1	4.28	51.36	48.28	48.28	0.022	94.00%
100	1.25	5.4	64.8	48.27	60.33875	0.028	93.12%
Vin=13.5V							
%Load	Load Current (A)	Iin (A)	Pin (W)	Vout (V)	Pout (W)	Vopp-ripple (V)	Power Efficiency
20	0.25	0.95	12.825	48.18	12.045	0.005	93.92%
40	0.5	1.88	25.38	48.24	24.12	0.01	95.04%
60	0.75	2.82	38.07	48.25	36.1875	0.015	95.06%
80	1	3.85	51.975	48.22	48.22	0.021	92.78%
100	1.25	4.78	64.53	48.22	60.275	0.026	93.41%
Vin=15V							
%Load	Load Current (A)	Iin (A)	Pin (W)	Vout (V)	Pout (W)	Vopp-ripple (V)	Power Efficiency
20	0.25	0.856	12.84	48.18	12.045	0.005	93.81%
40	0.5	1.69	25.35	48.22	24.11	0.009	95.11%
60	0.75	2.54	38.1	48.22	36.165	0.013	94.92%
80	1	3.42	51.3	48.22	48.22	0.018	94.00%
100	1.25	4.29	64.35	48.22	60.275	0.023	93.67%

The results shown above in Table III are obtained using Vin=12V for minimum input, Vin=13.5V for nominal input, and Vin=15V for high input. Using these values, the parameters listed in the Test Plans section can be obtained. Using Equation 5.1, the Line Regulation at full load current is 0.1%. Using Equation 5.2, the Load Regulation at nominal input is 0.083%.

ii. Motor Testing

The stepper motor is tested by rotating the shaft at a certain RPM and determining the proper connections to receive the proper output. After measuring all the possible wiring configurations, one phase of the stepper motor belongs to the red, white, and blue color coded wires and the other phase of the stepper motor belongs to the black, yellow, and green color coded wires. The white and yellow color coded wires are the center taps of its corresponding phase. A visual picture of the testing can be seen in Figure 21.

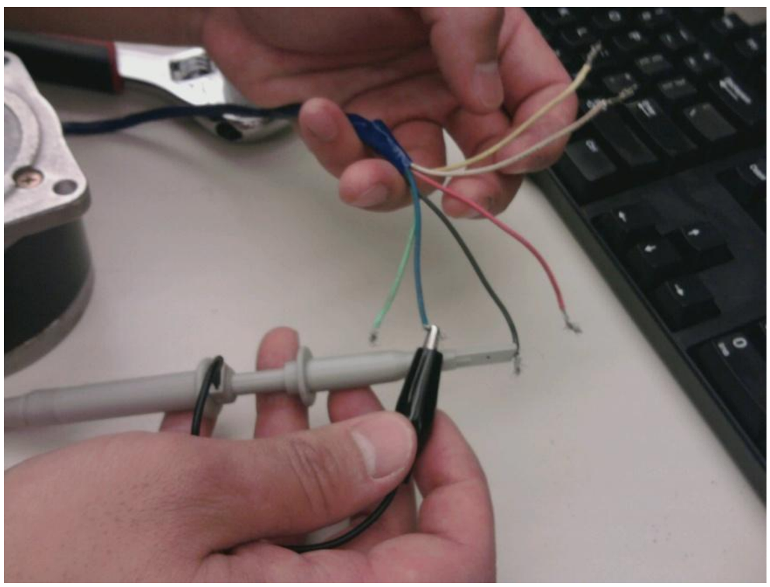


Figure 21: Capture of Wiring for Stepper Motor

Initially, the two phases of the stepper motor are connected in a parallel configuration to synchronize the two phases. In this configuration, the stepper motor produces a peak-to-peak voltage of around 2 Volts rotating at 60 RPM as measured in Figure 22. Since the minimum input voltage of the flyback controllers require at least 2.5 Volts, the two phases of the stepper motor are connected in a series configuration. In the series connection, the stepper motor is found to already be in synchronous phase and produces a greater voltage output approximately 9 Volts at the same RPM after rectification. Although the stepper motor produces a greater voltage output in a series configuration, the short-circuit testing of each configuration shows that the series configuration produces a much smaller current output than in the parallel configuration. Nonetheless, the power output of the stepper motor is much less than 60 Watts and does not meet the engineering specification.

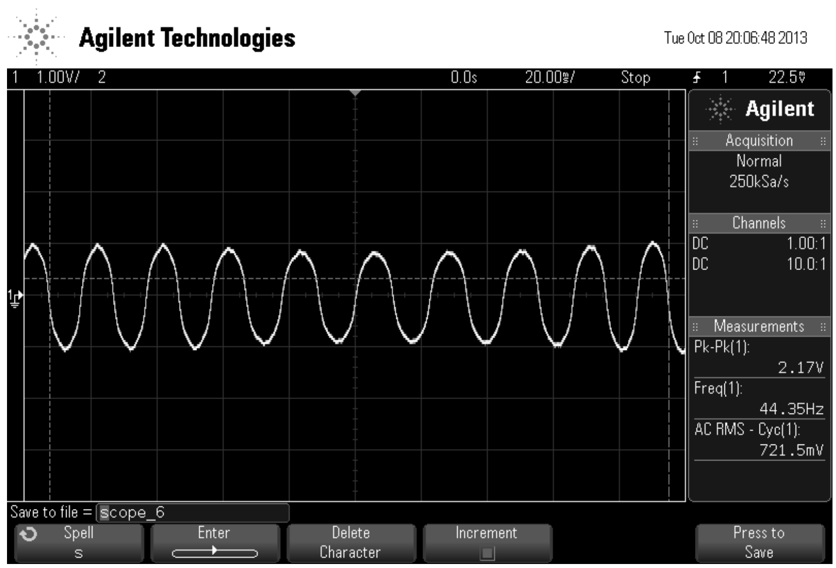


Figure 22: Capture of one phase output of Stepper Motor at 60 RPM

iii. Hardware Testing

After the simulated versions of the circuit are functional, we transfer the circuit into a PCB layout shown previously in Figure 19 of the Development and Construction section. After designing the board layout, we built the 5-15 Volt flyback converter and tested it with no load. The converter turns on with an input as low as 2.5V and produces the desired 15V output. The initial PCB layout does not include an output jack for this converter, so there was no safe method of testing output current. After testing the 5-15 Volt converter, we test the 12-48 Volt converter. This converter turns on at an input of 12.1V and produces a 47.3V output with no load attached. However, when the electronic load was attached, the added current caused a short from in input connection to ground.

Per Dr. Taufik's recommendation, we re-designed our board layout to that shown in Figure 20. This version of the layout allows for better power flow within the circuit and to better separate the controller circuitry from the power conversion circuitry. Additionally, this design included an additional banana jack at the output of the 5-15 Volt converter for testing purposes and snubber circuits for both flybacks.

After ordering the second version of the board, we assembled both flyback converters and tested them at no load conditions to see that they were still functional. The 5-15 converter turned on at 2.5V and provided an output of 16V. 12-48 converter turned on at 11.8V and provide an output of 48V. After the open circuit testing confirmed that both converters were functional, we then tested them with the electronic load. Unfortunately, both converters failed within 20% if their rated load current and additionally showed very poor output voltage regulation. The first test was for the 12-48 Volt converter and the results are shown below in Table IV.

TABLE IV

HARDWARE RESULTS FOR 12-48 VOLT FLYBACK CONVERTER

Iout (A)	Vout (V)
0	48
0.1	3.33
0.2	2.199

Since the first converter failed after only three data points we decided to use a finer resolution for the test on the second converter. The results of this test are shown below in Table V.

TABLE V

HARDWARE RESULTS FOR 12-48 VOLT FLYBACK CONVERTER

Iout (A)	Vout (V)
0	48
0.1	5.26
1.5	3.354
0.2	3.182
0.25	2.805
0.3	2.638
0.35	2.55
0.4	2.444
0.45	2.29
0.5	2.276
0.55	0.015

iv. Discussion of Test Results

While the simulation of the circuits in LTspice do not indicate any potential problems with voltage regulation, the results from the hardware testing indicated otherwise. Both flyback converters failed when drawing less than 20% of the designed rated load current. Additionally, the controller was not properly regulating the output voltage when a load was applied. When the converter failed, a short was caused somewhere in the system creating a connection between the power plane and the ground plane of the PCB. We first suspected that the short was within the MOSFET. However, after removing the MOSFET from the board, the short was still present. Since the MOSFETs and other components were all still functional, we suspect that the core of the transformers were saturating, which in turn does not allow for energy transfer within the circuit. The transformer datasheet states that the rated current values listed would only cause a 30% saturation of the core [11]. This relationship is shown below in Figure 23.

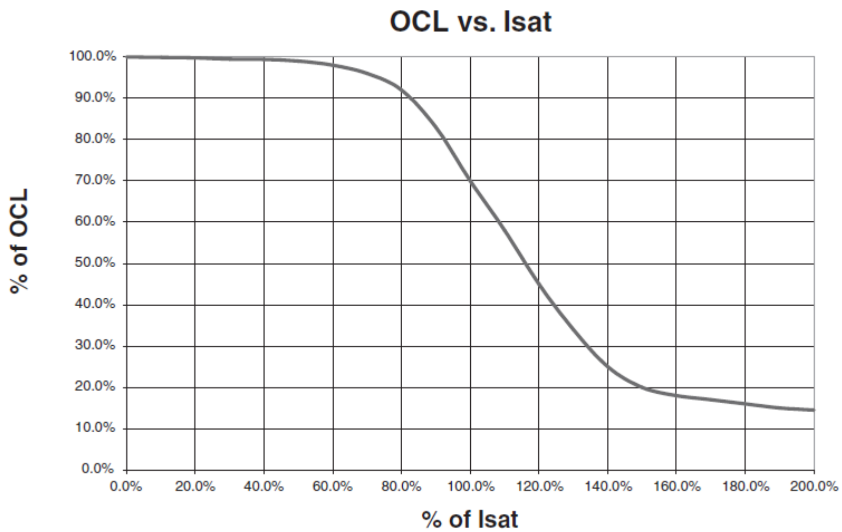


Figure 23: Inductance Characteristics for Coiltronics Transformers [11]

As seen in Figure 23, even for higher current values, the transformers should still behave in a relatively ideal manner. Since the flyback converters provide the correct values during open load testing, we suspect that the problem lies within energy transfer of the energy in the circuit. Because of these reasons, we removed the transformer from the board and the short was no longer present. The transformer terminal connected to the input voltage power plane is located next to the terminal connected to the ground plane. Due to the saturation issues mentioned earlier and the proximity of the input and ground terminals, we believe that the short was developed within the transformer windings. Additionally, the charge controller is designed to be used for 4 Amp charging. Since the 5-15 Volt flyback converter was never operational at full load, there is no way to test the charge controller within the project timeframe.

VIII. FUTURE IMPROVEMENTS

The most challenging aspect of the Portable Nano-Hydro Power Generator project is the lack of technical knowledge in the field of power electronics. Neither of us had taken power electronics courses prior to accepting this project as our senior project. Despite this disadvantage, we still accepted the project because we liked the project idea and wanted to challenge ourselves in learning a new field of electrical engineering on our own. As a recommendation to future students pursuing this project as an improvement design, we strongly encourage taking power electronics course in order to avoid basic pitfalls commonly encountered in power electronics. For example, our first mistake was creating the converters on a transistor level when controllers for the converter have already been systematically made.

A possible future improvement design of the project is to custom build the transformers of the flyback converters. By customizing the transformers instead of purchasing a pre-made transformer, students may gain a better understanding of how transformers function and the various characteristics of a transformer. After testing the two flyback converters, we believe the core of the transformers saturated prematurely which contributed to the low output voltages on the secondary sides.

A different generator should be chosen to produce the correct power requirement. The stepper motor is chosen by the mechanical team because the generator is small and light enough to be carried onto their raft design. A larger power output from a generator would have required a larger sized generator and be heavier for the raft to support, which could potentially cause the raft to sink. Also, the generator should output a DC output versus an AC output in order to decrease the loss from rectification and be operable with the DC-DC converter.

Another possible future improvement design is to implement a temperature sensor on the charge controller to properly set the correct float charge voltage for the lead-acid battery. For the LTC4000-1 charge controller, the datasheet did recommend a particular circuit configuration to compensate for the temperature change as illustrated in Figure 24. Because the lead-acid battery contains a -3.3 mV/°C per cell temperature coefficient, or -19.8 mV/°C, the temperature sensor suggested would have produced a temperature compensation scheme of battery float voltage [9].

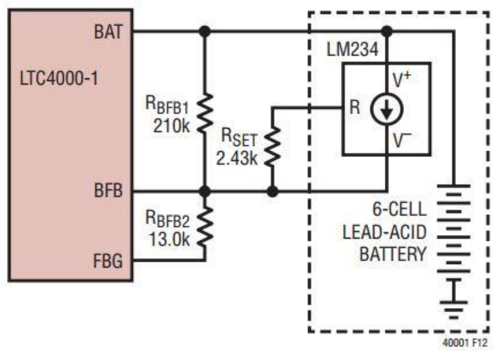


Figure 24: Float Charge Voltage Compensation Circuit Configuration [9]

Finally, our last possible future improvement design is to create the system using just one converter. As mentioned in the Initial Design Considerations section of the Design chapter, the charge controller could not receive the output voltage of a DC-DC converter beyond a certain percentage above the float voltage value. However, in the future, advances in technology could have been realized and be able operate with the high voltage. In this way, efficiency can be greatly improved and reduce the complexity of the system.

IX. CONCLUSION

The objective of this project is to create a product which can use electricity generated by a small hydro generator and convert it into power for the DC House. Our proposed design uses a flyback converter to convert from a low voltage output of the generator into a 15 Volt output to charge a lead-acid battery. Another flyback converter is used to convert the voltage from the 12V lead-acid battery into a 48 Volt output for the DC House. This design uses LTC1871 controllers to regulate the output of the flyback converters and uses a LT4000-1 controller to regulate the charging of the battery. The designs for each component were developed and tested in LTspice and the circuit was transferred into a printed circuit board layout and fabricated by ExpressPCB. The results from the simulations seemed promising, however testing on the physical board proved otherwise. Both converters were functional during open circuit testing, but performed very poorly once a load was applied. After inspection of the circuit, we conclude that the problem lies in the transformers we used. Since the voltages were correct during open circuit testing, we suspect that the improper energy transfer is a result of the type of transformer we used. As a future improvement of the project, custom-made transformers should be created in order to prevent premature saturation of the transformer. All in all, the engineering specifications may not have been met, but a significant amount of knowledge was gained in the power electronics field and its design process from our initial starting point.

X. BIBLIOGRAPHY

[1] Rocky Mountain Institute. “Historic and projected U.S. electricity demand, 1950-2050” [Online]. Available: http://www.rmi.org/RFGraph-US_electricity_demand

[2] Dr. Taufik. (2010, Sept. 13). “The DC House Project: Providing access to electricity for the unfortunates" [Online]. Available: http://www.calpoly.edu/~taufik/dchouse/index.html [Mar. 2, 2013].

[3] Dr. Taufik. (2013, Jan. 4). "Taufik Senior Projects 2012-2013." Personal email.

[4] Dr. Taufik. (2013, Jan. 4). "Fwd: Proposal submission for Chevron Fund." Personal email.

[5] R.A. Messenger and J. Ventre, *Photovoltaic Systems Engineering*. Boca Raton, FL: CRC Press, 2010.

[6] R. Ford and C. Coulston, *Design for Electrical and Computer Engineers*, McGraw-Hill, 2007, p.37.

[7] Daniel W. Hart, *Power Electronics*. New York, NY: McGraw-Hill, 2011.

[8] Taufik and D. Dolan, *Introduction to Power Electronics*, San Luis Obispo: California Polytechnic State University, 11th Revision 2013.

[9] Linear Technology, "High Voltage High Current Controller for Battery Charging with Maximum Power Point Control," LTC4000-1 datasheet, 2012 [Online]. Available: http://cds.linear.com/docs/en/datasheet/40001fa.pdf [May 26, 2013].

[10] Linear Technology, "Wide Input Range, No RSENSE Current Mode Boost, Flyback and SEPIC Controller," LTC1871 datasheet, 2001 [Online]. Available: http://cds.linear.com/docs/en/datasheet/1871fe.pdf [May 26, 2013].

[11] Coiltronics - Cooper Industries, "Versa-Pac Inductors and Transformers," VPH4-0075-R & VPH5-0155-R datasheet, 2007 [Online]. Available: http://www.cooperindustries.com/content/dam/public/bussmann/Electronics/Resources/product-datasheets/Bus_Elx_DS_PM%204301_VERSA-PAC(VP1_2_3_4_5_VPH1_2_3_4_5).pdf [May 26,2013].

[12] Maxim Integrated, "Snubber Circuits Suppress Voltage Transient Spikes in Multiple Output DC-DC Flyback Converter Power Supplies," Appl. Note 848, 12 Nov. 2001 [Online]. Available: http://www.maximintegrated.com/app-notes/index.mvp/id/848 [November 25, 2013].

[13] D. Barashev and A. Thomas, *GanttProject* [Software]. GanttProject Team: 2003-2013.

APPENDIX A - Senior Project Analysis

TABLE A-I
ANALYSIS OF SENIOR PROJECT DESIGN

Project Title: Portable Nano-Hydro Power Generator for the DC House Project

Students' Name: Andrew Aw & James Biggs
Students' Signature:

Advisor's Name: Dr. Taufik
Advisor's Initials:
Date:

● 1. Summary of Functional Requirements
The Portable Nano-Hydro Power Generator generates a maximum of 60 Watts and outputs a voltage of 48 Volts. The electrical system contains a bi-directional connection with a 12V lead-acid battery for charging and discharging, depending on the generation. Table I contains detailed listings and justifications of the marketing requirements and engineering specifications.

● 2. Primary Constraints
The lack of technical knowledge for the majority of the project's engineering specifications and similar designs provide significant challenges for the design and implementation of the project. Without similar designs to model from, the solutions to the problems we encounter contain no references to learn from. We plan to document any unprecedented problems for future references and share to the engineering community.

● 3. Economic
The Portable Nano-Hydro Power Generator requires lots of human capital due to its innovative design. We generated the gantt chart for the duration of the project using the GanttProject software as shown in Figures A-1, A-2, and A-3 [13]. Figure A-1 shows the intense planning, research, and preparation performed for the project. As seen in Figures A-2 and A-3, the gantt charts also demonstrate designing, simulating, building, and testing the three modules require at least 14 weeks before interfacing with the mechanical system. Chevron provided financial capital for the materials of the project. This financial capital assists in purchasing real capital necessary for the project such as the car battery and power electronics. Fortunately, the senior project room already provides the measurement tools and bench equipment which helps relieve the real capital. The hydro generates uses water as its natural capital for electrical generation.

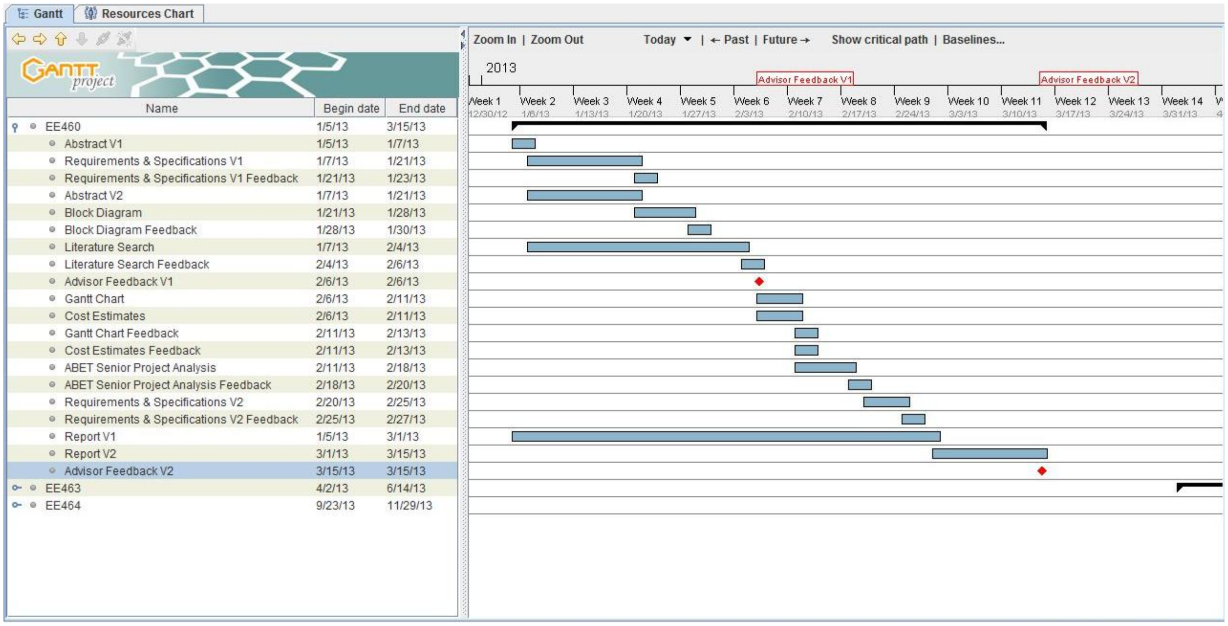
A typical engineering project lifecycle consists of seven phases: proposal, requirement, design, build, integration, test, and operations and maintenance. Labor costs accrue during all seven phases. Materials and parts cost accrue during the design and integration phases. Benefits accrue during proposal and operations and maintenance phases.

The experiment requires inputs from the hydro generator and the car battery. The project cost approximately $600 in parts as calculated in Table A-II. The anticipated prices may vary according to the quality and performance of the item. As stated prior, Chevron funds the majority of the cost.

TABLE A-II: COST ESTIMATES		
Item	**Anticipated Price ($)**	**Justification**
12 V Car Battery	125	Car batteries cost between $100-$200 plus a core charge, or state mandate tax. We plan to purchase a low end or used car battery for the project.
Car Battery Connections Kit	30	The car battery requires specific cables to connect to its terminals which cost about $5. However, purchasing additional adapters and terminal protectors also necessitate the complete connection needed for the DC-DC converter.
PCB	50	The PCB, or printed circuit board, ranges from $5 to $100 depending on the size and quality. For this project, we use a medium size PCB of sufficient quality.
Circuit Components	300	The circuit components range from resistors to MOSFETs to ICs which vary from a few cents to a couple bucks. The few extra components purchased serve as a backup or replacement of defective part(s).
Housing Unit Components	80	The housing unit protecting the electrical components from water and/or human contact consists of mainly plastic material. Plastic material cost a couple bucks and the fasteners and sealers add to the cost of the complete housing unit.
Subtotal ($)	585	
Labor ($24/hr for 150 hrs.)	3600	The $24/hr rate for the average engineering intern wage.
Total ($)	4185	

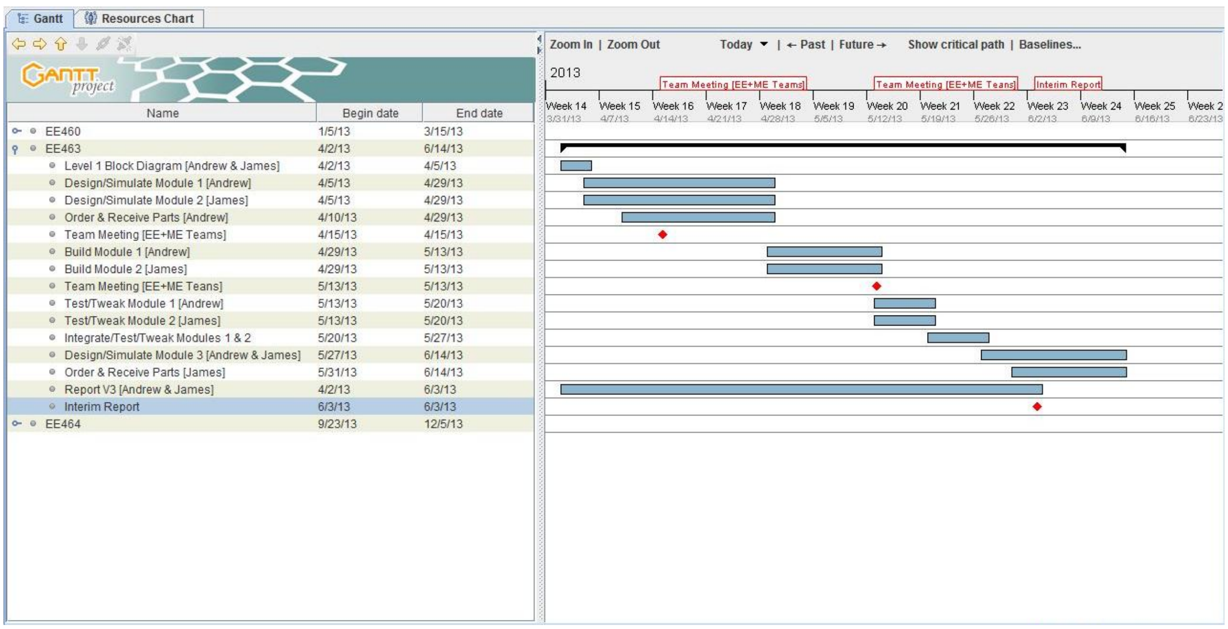
This project targets areas without access to an electrical grid and nonprofit endeavor sponsored by companies or organizations. From a commercial basis, the manufacturers and designers profit from the earnings of the project by including the labor costs into the material cost.

The product should emerge by the end of 2013 as required by the senior project completion date. The product should exist for about 25 years with minimal maintenance. The maintenance mostly consists of cleaning and maintaining the hydro generator rotor from buildup of algae and/or dirt. After project completion, the project may undergo improvements or revisions for interfacing with the DC House.



Name	Begin date	End date
EE460	1/5/13	3/15/13
Abstract V1	1/5/13	1/7/13
Requirements & Specifications V1	1/7/13	1/21/13
Requirements & Specifications V1 Feedback	1/21/13	1/23/13
Abstract V2	1/7/13	1/21/13
Block Diagram	1/21/13	1/28/13
Block Diagram Feedback	1/28/13	1/30/13
Literature Search	1/7/13	2/4/13
Literature Search Feedback	2/4/13	2/6/13
Advisor Feedback V1	2/6/13	2/6/13
Gantt Chart	2/6/13	2/11/13
Cost Estimates	2/6/13	2/11/13
Gantt Chart Feedback	2/11/13	2/13/13
Cost Estimates Feedback	2/11/13	2/13/13
ABET Senior Project Analysis	2/11/13	2/18/13
ABET Senior Project Analysis Feedback	2/18/13	2/20/13
Requirements & Specifications V2	2/20/13	2/25/13
Requirements & Specifications V2 Feedback	2/25/13	2/27/13
Report V1	1/5/13	3/1/13
Report V2	3/1/13	3/15/13
Advisor Feedback V2	3/15/13	3/15/13
EE463	4/2/13	6/14/13
EE464	9/23/13	11/29/13

Figure A-1: Proposed Gantt Chart for EE 460 [13]



Name	Begin date	End date
EE460	1/5/13	3/15/13
EE463	4/2/13	6/14/13
Level 1 Block Diagram [Andrew & James]	4/2/13	4/5/13
Design/Simulate Module 1 [Andrew]	4/5/13	4/29/13
Design/Simulate Module 2 [James]	4/5/13	4/29/13
Order & Receive Parts [Andrew]	4/10/13	4/29/13
Team Meeting [EE+ME Teams]	4/15/13	4/15/13
Build Module 1 [Andrew]	4/29/13	5/13/13
Build Module 2 [James]	4/29/13	5/13/13
Team Meeting [EE+ME Teans]	5/13/13	5/13/13
Test/Tweak Module 1 [Andrew]	5/13/13	5/20/13
Test/Tweak Module 2 [James]	5/13/13	5/20/13
Integrate/Test/Tweak Modules 1 & 2	5/20/13	5/27/13
Design/Simulate Module 3 [Andrew & James]	5/27/13	6/14/13
Order & Receive Parts [James]	5/31/13	6/14/13
Report V3 [Andrew & James]	4/2/13	6/3/13
Interim Report	6/3/13	6/3/13
EE464	9/23/13	12/5/13

Figure A-2: Proposed Gantt Chart for EE 463 [13]

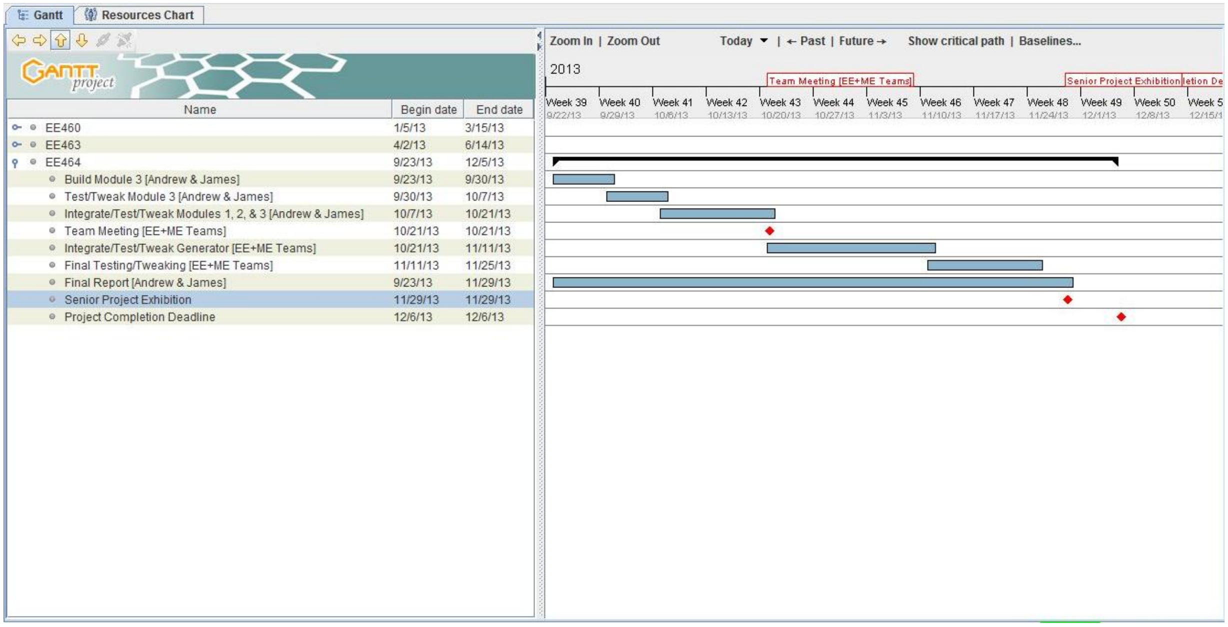


Figure A-3: Proposed Gantt Chart for EE 464 [13]

● **4. If manufactured on a commercial basis:**
The number of devices sold per year would likely range from 50-100 and cost approximately $600 for materials as estimated in Table A-II. The cost of each unit sold should not exceed $3,500 which produces a profit of about $250,000 per year. Labor to transport the device comprises of the majority of the operation cost. Depending on the user’s point of view for labor, the operation cost varies from person to person. Limiting factors of operation cost include the life of the user's car battery and possibly circuit level components within the product.

● **5. Environmental**
This system should provide a source of free electricity to a customer without access to an electrical grid. However, the device would likely interfere with the organisms living in the stream or water source in which the user places it. Alteration in the water flow of the stream also presents an environmental impact associated with the use of the Portable Nano-Hydro Power Generator. If place in a narrow stream, the device may impede the flow of water and cause water to back up. The device restricts access to water, vital for all known forms of life, for the animals and plants downstream and potentially destroying the habitat. Other environmental impacts include the materials used and emissions from manufacturing and transporting the device. The materials for production may be toxic and/or non-degradable.

● **6. Manufacturability**
Manufacturing the seal-tight case presents an issue associated with manufacturing the Portable Nano-Hydro Power Generator. Since the product submerges in water, a seal-tight case encloses the electrical system to prevent water from entering and shorting the circuit. However, complications could occur which allow water to come into contact. Also, mounting components on PCB has become increasingly common in today's industry. Therefore, manufacturing the generator box should prove more complicated than manufacturing the converter box. Manufacturing the product in other countries outside the United States presents another issue of manufacturing. If not made in the United States, other countries may not possess strict regulation of quality control for manufacturing their products.

● **7. Sustainability**
As a source of renewable energy, the project comprises of a sustainable background. Both the generator box and the converter box function interchangeably with replacement or improved parts easily. The selected individual components designed for longevity eliminate the need for frequent replacement. Making the product compatible with 12V lead-acid batteries provides opportunities for recycling and reuse. However, durability against

environmental factors may present an issue associated with maintaining the completed system. The primary consumers reside in developing countries with harsher environmental hardships than in developed countries.

- **8. Ethical**

The manufacturer needs to produce and transport the device as efficiently and responsibly as possible. The ethical implication of designing the system without regard for safety affects both the users and its surrounding environment. This correlates to the ethical framework of The Platinum Rule, treat others as they would like you to treat them. The users could experience electrical shock or even death when operating the device. Insulating all conductive components should prevent such hazards. Wildlife may also experience electrical shock or death if water comes into contact with the electrical system. The water can create a short in the system and become a conductor, shocking wildlife such as live fish and birds currently in contact. As stated in the IEEE Code of Ethics, members of the IEEE community agree to avoid injuring others and take responsibility for the safety of the public.

- **9. Health and Safety**

The device contains high powered electronics and, when left unattended, presents a potential hazard for users, children, and animals near the device. The user may experience electrical shock from accidental contact of the electrical system. A protective case encloses the electrical system of the Portable Nano-Hydro Power Generator, but the user may accidentally leave the case open and come into contact. Electrical shock can also occur when the user connects the device with the car battery. Manufacturing and transporting the product also produces emissions which would require regulation.

- **10. Social and Political**

Environmental degradation creates a social issue with the design of the project. The generator may obstruct the flow of water due to its size and prevent water from reaching downstream, destroying the habitat below. The potential for renewable energy sources to dominate creates a political issue with power utility corporations. The power utility corporations may see a loss of business and profit if their customers remain off the grid and depend solely on this product to obtain electricity.

The project benefits the less fortunate and those who can't obtain electricity due to geographic isolation. The direct stakeholders comprises of manufacturers, designers, delivery workers, electronic industries, and consumers, while the indirect stakeholders comprises of utility companies, diplomats, and government. The various electronic industries, delivery workers, manufacturers, and designers receive profit from the sale of the project. The consumers benefit from the product itself by generating electricity for use. The utility companies may feel threatened by the decrease of demand for electric service. Diplomats and government for the consumer's corresponding nation could threaten its nation's economy. The extent in which stakeholders benefit equally depend on the response of the corresponding nation; otherwise, inequalities for the stakeholders remain.

- **11. Development**

The project requires general power electronics concepts, principles involving boost converters, and charging circuits. Project planning and organization techniques facilitate the completion of the project. The following sources helped develop an understanding of these concepts. The PSIM software simulation program also provides helpful simulation and analysis of power electronics and power systems.

APPENDIX B - Parts List and Cost

TABLE B-I
12-48 VOLT FLYBACK CONVERTER COST

Component	Per item cost	# of items	Cost
Rt	$0.28	1	$0.28
R_run1	$0.34	1	$0.34
R_run2	$0.26	1	$0.26
R_fb1	$1.40	1	$1.40
R_fb2	$0.47	1	$0.47
Rsnub	$0.93	1	$0.93
Rc	$1.96	1	$1.96
Cvcc	$0.36	1	$0.36
Cin	$0.76	1	$0.76
Cc	$1.06	1	$1.06
Csnub	$0.39	1	$0.39
Cout	$2.06	2	$4.12
Transformer	$7.26	1	$7.26
Mosfet	$1.11	1	$1.11
Diode	$1.18	2	$2.36
LTC1871	$4.38	1	$4.38
Component Total			**$27.44**

TABLE B-II
5-15 VOLT FLYBACK CONVERTER COST

Component	Per item cost	# of items	Cost
Rt	$0.28	1	$0.28
R_run1	$2.52	1	$2.52
R_run2	$0.75	1	$0.75
R_fb1	$2.52	1	$2.52
R_fb2	$0.47	1	$0.47
Rsnub	$0.93	1	$0.93
Rc	$2.52	1	$2.52
Cvcc	$0.36	1	$0.36
Cin	$0.64	1	$0.64
Cc	$0.73	1	$0.73
Csnub	$0.29	1	$0.29
Cout	$2.52	4	$10.08
Transformer	$8.11	1	$8.11
Mosfet	$0.80	1	$0.80
Diode	$1.18	2	$2.36
LTC1871	$4.38	1	$4.38
Component Total			**$37.74**

TABLE B-III
BATTERY CHARGE CONTROLLER COST

Component	Per item cost	# of items	Cost
Rb1	$0.85	1	$0.85
Rb2	$0.85	1	$0.85
Rb3	$0.75	1	$0.75
Rntc	$4.01	1	$4.01
Rd	$0.82	1	$0.82
R3	$0.59	1	$0.59
Rcx	$0.75	1	$0.75
Rcs	$1.92	1	$1.92
Cim	$0.35	1	$0.35
Cb	$0.36	1	$0.36
Mosfet	$2.68	2	$5.36
LTC4000-1	$6.43	1	$6.43
Component Total			**$23.04**

TABLE B-IV
ADDITIONAL COMPONENTS COST

Component	Per item cost	# of items	Cost
Banana Jacks	$1.65	6	$9.90
Switch	$6.40	1	$6.40
PCB (3 copies)	$118.00	1	$118.00
Component Total			**$134.30**

TABLE B-V
TOTAL SYSTEM COST

Component	Cost
12 to 48 Flyback	$27.44
5 to 15 Flyback	$37.74
Battery Charger	$23.04
Other	$134.30
Total Cost	**$222.52**

APPENDIX C - PC Board

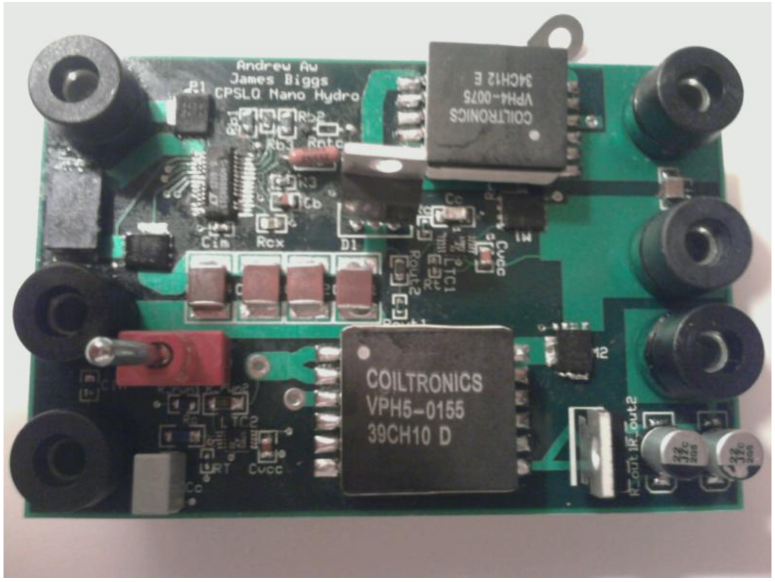


Figure C-1: Original PCB Layout

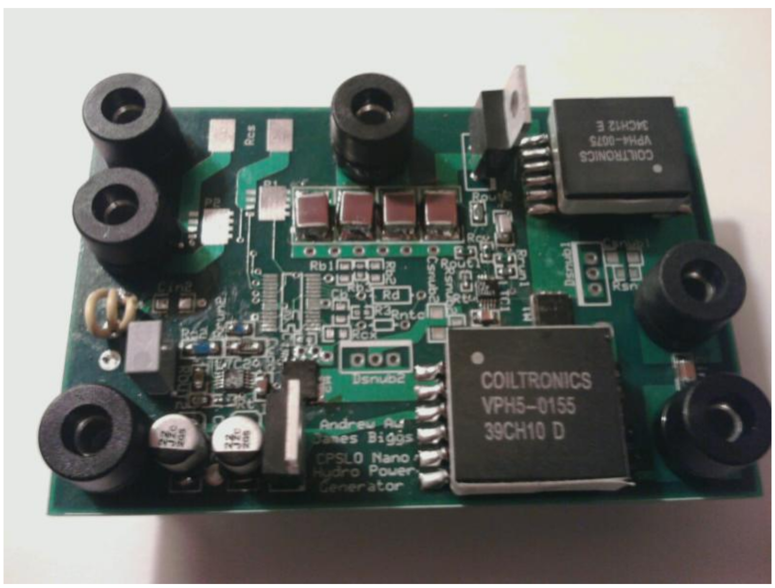


Figure C-2: Revised PCB Layout