



Enota Hydroelectric Power Generation Plant

Proposal

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Abstract



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This proposal focuses on the solution to Enota's high electric bill by developing and designing a micro hydroelectric generator with low flow and low head parameters. The design approach, project cost, and project management are included in the proposal.

1.0 Introduction

“In 2005, more than 3/4 of total world energy consumption was through the use of fossil fuels.” [1] With the current state of the environment, it is essential to explore all the possibilities for renewable energy. The main forms of renewable energy are wind, solar, biomass, and hydroelectric [2]. “Hydroelectric power plants are the most efficient means of producing electric energy.” [3]

Since water is the most abundant resource in the world, it is important to utilize the power of flowing water. The most efficient way to harness the power of water is to collect the potential energy. This is done by damming up a body of flowing water. A dam is an object that restricts the flow of water. In today's hydroelectric dams, the restricted water is diverted to a turbine using a penstock and exits the turbine through the tailrace. [5]

The turbine is made up of a shaft with blades attached. As a fluid flows through the blades a rotational force is created. This force causes a torque on the shaft. The turbine shaft is coupled to a generator, where electricity is produced.

The backbone of most power generation system is the generator. An electric generator is “any machine that converts mechanical energy into electricity for transmission and distribution.” [4] The generator works by spinning a rotor that is turned by a turbine. The rotor is a shaft that has field windings. These windings are supplied with an excitation current or voltage. As the rotor turns, the excitation current creates a magnetically induced current onto a stator. The stator is a cylindrical ring made of iron that is incased by another set of field windings and is separated from the rotor by a small air gap.

Hydroelectric generations can vary from 1 watt to 100's mega-watts. With today's technology it is possible to generate power with small scale parameters. With low flow



and low head parameters a micro generator can be used to produce electric power. From the source of the flowing water, a weir, small scale dam, can be used to restrict the flow of water. From this the water can be piped to a turbine. Since the turbine is coupled to the generator, a micro generator can generate about 1 watt to 100 kilowatts. [18] This generator can be used to power residential loads.

2.0 Literature Survey

2.1 Case Study 1

Coulter Lake Guest Ranch installed a hydroelectric system that has a low flow and low head parameters. The system is DC and capable of producing approximately 400 watts, and was installed to power the ranch's lodge. With the 400 watts of constant production, 9.6 kilowatt hours per day were generated. Enough to power the ranch's lodge or a typical home with the exclusion of demanding appliances such as an electric stove, electric water heater, or electric clothes dryer. The system consists of a turbine with DC generator, batteries, inverter, and load controller, which are the main components of the proposed system. The proposed systems advantages in its ability of producing more power with up to 1200 watts and it will allow for automatic transfer to the grid in the event the hydro system is incapable of powering the load. [10]

2.2 Case Study 2

Bill Kelsey of Sharon, CT has built a micro hydroelectric system on a site similar to the proposed site. This turbine is fed by a mountain brook of unstated flow, a head of approximately 30 feet over 275 feet through a four inch diameter PVC pipe. The turbine was produced by Harris Hydroelectric. Kelsey averages 3.6 kW hours per day. One issue Kelsey ran into while building his system was the effects of pipe loss. In the first attempt the use of two 2" PVC pipes resulted in high losses due to pipe friction. Upon increasing to a 4" PVC pipe, the output was increased by nearly 50%. Another issue that was encountered was the exposure of the pipeline. Due to the harshness of New England weather Kelsey was forced to bury the pipeline nearly 15' deep to maximize the head and to keep the pipeline from freezing. From Kelsey's example, it is seen that it is important to plan and design for pipe-loss. Kelsey also ran into problems using an alternator with



brushes, the brushes were always wearing out. Since switching to brushless permanent magnet alternator and maintenance issue have been drastically reduced. From this, it is easy to see that a brushless system is ideal for the micro generation. [12]

2.3 Case Study 3

Joseph Hartvigsen of South-East Idaho has built his own hydroelectric system. Hartvigsen's system makes benefit of 95' of head using a 6" diameter PVC pipe. The intake used by Hartvigsen is an 18" diameter pipe with hundreds of ½" holes drilled in it as the pipe rest at the bottom of a diverted section of the stream. A version of this is an acceptable solution for the intake. This pipe should be wrapped in a thin wire mesh to keep out debris and animals. Again we see that the pipeline had to be buried to keep it from freezing and to maintain the grade. Hartvigsen has his pipeline buried at an average depth of 4', but this depends on the terrain. The turbine used in this system is an ES&D Pelton Runner connected to a 3 hp 208 V induction motor powering his battery charger. Hartvigsen has destroyed many battery sets due to overcharging; from this a charge controller must be used to stop charging the batteries and also a "shunt" load to dissipate unused power. This shunt load for Hartvigsen was an element from electric clothes dryer; in the proposed solution the heaters currently in place at the site can be used or install a new high wattage heater coil to dissipate energy safely. This system produces an average of 800 watts at his power house after 800' of #10 wire from the generator. [11]

3.0 Conceptual Design

For the project site of Enota Mountain Retreat, this proposal has been designed for a low-flow, low-head hydroelectric generator. The proposed equipment is used to provide an efficient alternative power source. This system is also designed to be an educational tool that is simple and easy for the general public to understand and relate to people own life experiences. The following is a detailed description of the proposed conceptual design and justification of design choices.

3.1 Hydro System Overview



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The purpose of this design is to provide a renewable energy source for Enota Mountain Retreat. This design will implement the use of the available water sources on the property to produce electricity. The project also requires that an educational display is present to inform the public on the type of energy produced and the effects on the environment.

It was necessary to obtain flow and elevation data from Gurley Creek. This data was needed to approximate the power that is available from the creek. To protect the ecosystem of the creek, it is necessary to take a maximum of fifty percent of the stream. [7] The power output of the creek is determined by the equation [6]:

$$kw - hr = \frac{q(H - h_f)eT}{11.8}$$

Where q = the discharge of a stream in cubic feet per second;
 H = the gross head, in feet;
 H_f = the head lost in the conduit system and tailrace;
 e = the station efficiency, expressed as a fraction;
 T = a period of time in hours;

At the time the data was collected, the flow obtained was around the base flow for the creek. This flow found to be 0.64 f³/s or approximately 290 GPM. From this data, the minimum power was calculated to be 400 W, which will allow for the sizing of a generator and determine the size of the pipe and nozzles. From tables in energy systems and design, it was determined that the maximum flow from a four nozzle generator is 428 GPM [8]. From this, it was determined that the maximum power output is 1.2 kW. These calculations were determined using an efficiency of 50 percent for the generator.

In order to complete this design, it is necessary to have a 4" supply pipe from the property corner of Gurley Creek to the powerhouse, where the generator will be placed. The intake of the pipe should be covered by a grate or a filter to insure that no debris enters the supply line. The pipe should also have a shut off valve at the intake to allow for pipe or generator maintenance. It is also suggested that the intake be supplied by some



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form of a weir. **These are the suggested requirements to be met by Enota prior to installation date.** Figure 1 is a pictorial representation of the proposed generation system



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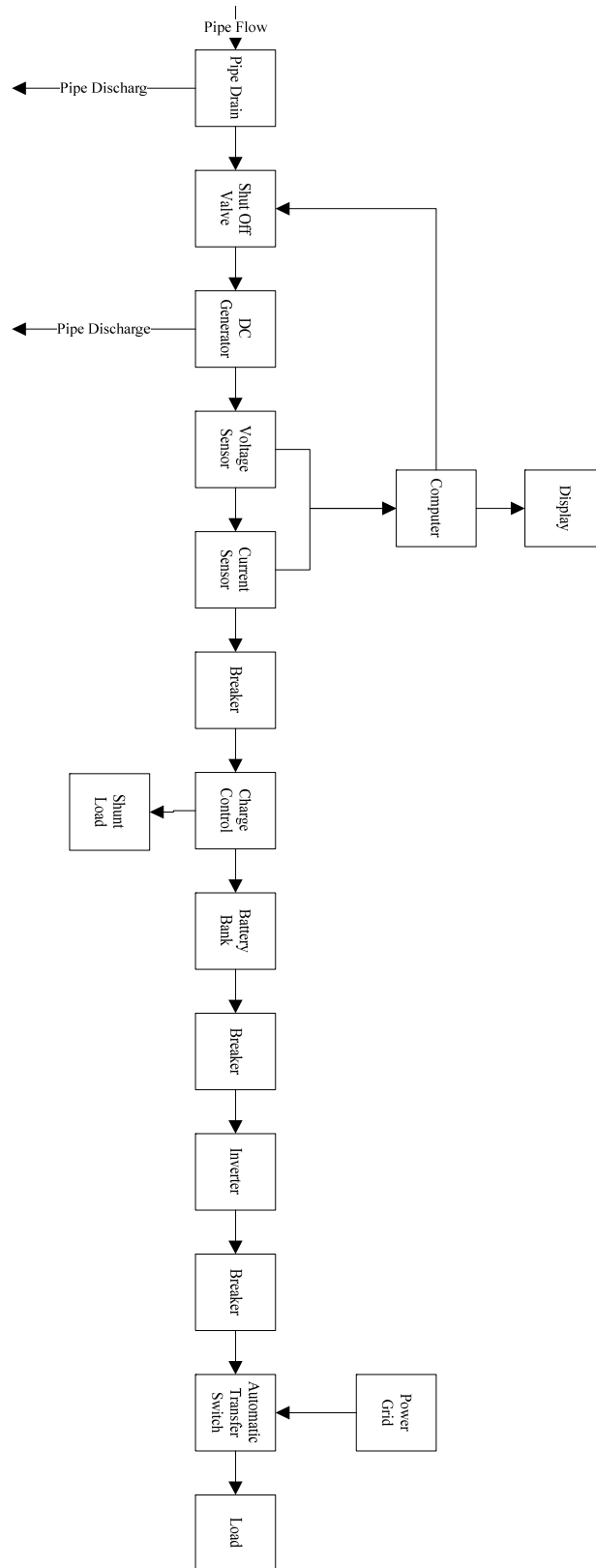


Figure 1: Block Diagram of Off Grid System

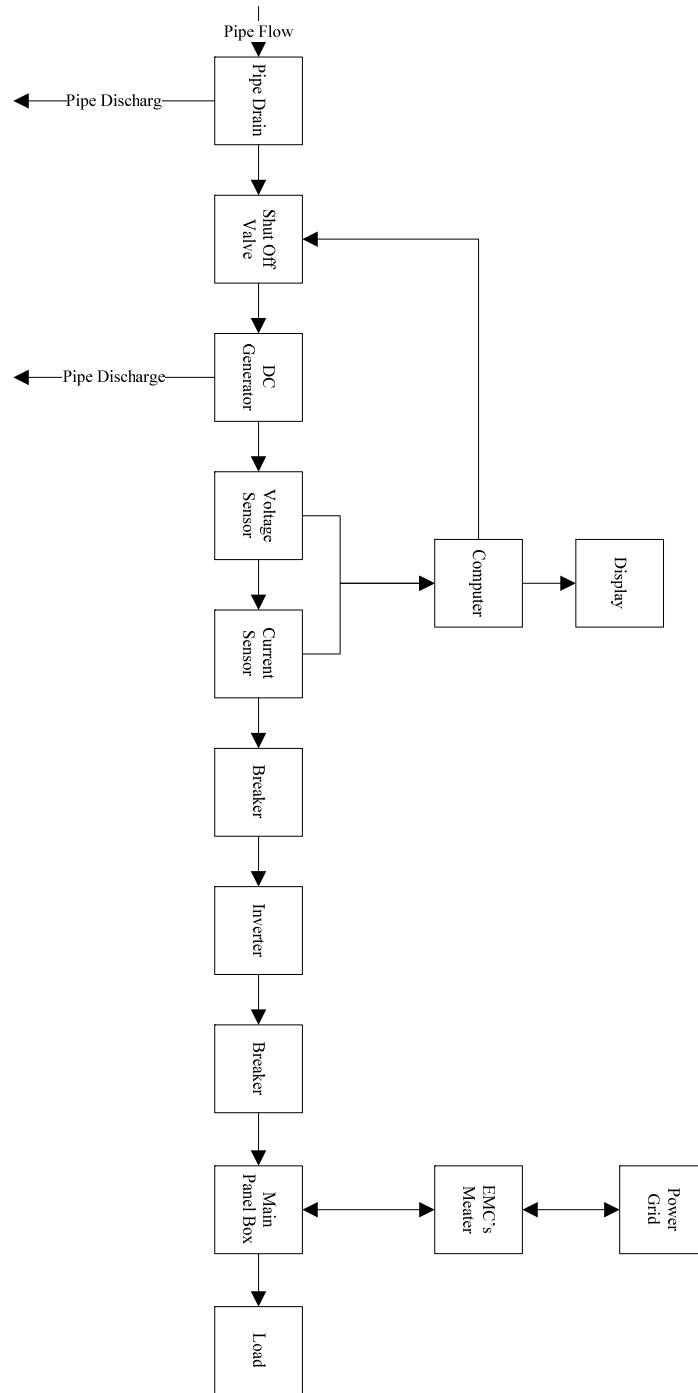


Figure 2: Block Diagram of Grid Connected System



3.2 Generator

For this design it is possible to use either a DC or AC generator that can convert the hydraulic power into energy. The DC generator is ideal for charging batteries that will then be converted to AC, while the AC generators are more suited to connect directly to the load. For this reason, the DC generator is more suited for this location. The reason for this is because the location is considered a low flow low head site. This means that the instantaneous power produced by a generator is not very high. By using a DC generator, it is easier to store the energy in batteries and then power a load.

Using the data acquired at the site, it was determined to design the system using the LV Hydro 48V generator from Solar-Catalog. This generator was chosen because it will work at minimum and maximum flow for the site. It has a maximum power output of 1.2kW and works on a flow of 5 to 400 GPM. The turbine can be fitted with up to four nozzle inputs. The nozzles have sizes ranging from 1/8” to 1” diameter. [8] The flow through the turbine is determined by the number of nozzles and the size of each nozzle. From the table “Nozzle Flow Chart Flow Rate in U.S. Gallons per Minute” [8], it was determined to use four nozzles with a size of 1”. With this type of nozzle, the maximum amount of flow through the turbine will be approximately 428 GPM. In order to get more flow another generator would need to be added. This was also a factor in choosing the type of the generator. The advantage of using four nozzles is that it allows the flow to be controlled using valves. This will allow for the changing in seasonal flow. Given the generator and its output, it is now possible to size a charge controller. To find the maximum flow of the system, it is required that data be taken during the high season. For this reason max power estimations cannot be made.

3.3 Off Grid System

3.3-1 Charge Controller

From the generator the power is sent to the charge controller, which ensures that the battery bank is properly charged to extend the life of the batteries. This is done by regulating the voltage that is sent to the battery bank. Also, since the power coming from the generator will be continuous there must be a diversion load to prevent overcharging



of the batteries. This diversion load is usually a water or air heater that is turned on to use the excess power that is being generated.

The Flexcharge NCHC-48-35C/D charge controller was chosen for several reasons. The controller has very small internal resistance and results in more efficient charging of the batteries. This controller also comes with a built in diversion contact that negates the need for a second controller for the diversion of the load, which is both convenient and cost effective. The product comes with a five year warranty as well. [9]

3.3-2 Diversion Load

For the diversion load the Ohmite DC 300 watt heating load was chosen. A quantity of four of these will be needed to ensure a large enough load. These were chosen due to cost and simplicity. If the customer has another DC load that would suffice as a diversion load and has a more practical use; it can be implemented. [13]

3.3-3 Battery System

When choosing batteries for this project research shows three main types of batteries for this application: lead acid (Wet Cell), gel cell, and absorbed glass mat (AGM). [16] In order to decide which battery is best suited for this application; criteria must be developed to judge them by. The purpose of these batteries is to supply the surge power needed to operate appliances. These batteries could be called on to discharge a high percentage of their stored energy and must be ready to recharge again to complete another cycle. There is a general type of battery called a “Deep Cycle” battery that is designed just for this task. The first criterion is that the battery is considered “Deep Cycle.” It is understood that these batteries will be housed at the powerhouse at the proposed site. The powerhouse is poorly insulated and is not heated directly from any source. “Battery capacity (how many amp-hours it can hold) is reduced as temperature goes down, and increased as temperature goes up.” [20] Because of this capacity loss in cold temperatures, the second criterion is set to be performance in cold weather. For some batteries the electrolytic fluid contained in them will evaporate overtime and must have the electrolytic fluid refilled. Because this upkeep is time consuming and can be



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hazardous if not done properly maintenance needs are set as the third criterion. When recharging a battery from a deep discharge certain battery types have very extensive limitations to how they are charged and at what rate. Since some batteries need to charge slowly, this is used this as our fourth criterion. Table 1 shows the analysis of the proposed battery types.

Table 1: Battery Study

	Criteria			
	Deep Cycle	Resistance to Cold	Maintenance Needs	Charging Rates
Flooded Cell	Moderate	Moderate	Poor	Moderate
Gel Cell	Very Well	Well	Very Well	Poor
AGM Cell	Very Well	Very Well	Very Well	Well

From table 1 Absorbed Glass Mat deep cycle batteries were chosen to perform best for this application. These batteries are designed to perform repeatedly in deep cycles, have the best performance in cold weather [16], have little to no maintenance needs, have less stringent charging regulations, and battery life “remains excellent in most AGM batteries if the batteries are not discharged more than 60% between recharge.”[17]

The proposed generator operates at 48 volts DC. To make the battery bank compatible with this generator a minimum bank of four 12 volt batteries is required. There are two proposed battery bank systems: one containing four 12 volt batteries and one containing eight 12 volt batteries. The main difference between these two proposed systems is the depth of discharge each battery will experience thus improving overall battery life.

An analysis of brand quality, battery pricing, and shipping cost led to the specific Deka batteries proposed. These batteries provide 12 volts and 55 amp-hours for 20 hours. This covers any surge that this power system might incur from appliances such as a microwave or a hair dryer.

3.3-4 Inverter

The inverter is a very important element of the system. It will convert the DC power from the generator and batteries to AC power used in the electrical system. After



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comparing several inverters, the Outback FX3048T appears to be the best suited for this application. The 3000 VA inverter is capable of handling any load spikes that can be anticipated and has safeguards against low battery voltage. This inverter is also sealed to prevent damage from the environment and appears to be a very robust system that comes with a two year warranty. With accessories the inverter can house some of the necessary breakers that are vital to protecting the system. [14]

3.3-5 Transfer Switch

In the event of a system failure or high demand that is above the hydro system's capability, the proposed design has a backup. Utilizing an automatic transfer switch, the system will detect the loss of power and automatically switch over to grid power. While the load is being powered by the grid the hydro generator will recharge the batteries for future use. Once the batteries are charged, the transfer switch will automatically switch back to the hydro system and discontinue use of grid power. Please note that during these changeovers there will be a very short, possibly unnoticed, power interruption.

The Guardian 100 amp automatic transfer switch was chosen because it is capable of handling the load and was the most cost effective solution. [15] Although this proposed system uses the national electric grid as backup when the generated power ceases to be sufficient for the load, this transfer system will not allow the hydro power produced to supply the grid. It is not recommended with this system to attempt to supply the grid due to increased regulations and low average excess power produced.

3.4 Grid Tie System

The grid tie system shares many of the same components of the off grid system. With this system, the generator and the inverter from the off grid system are going to be proposed. Since there is going to be a grid tie, there is no need to have a battery bank or a shunt diversion load for the excess generated power. There are some stipulations that need to be met by Enota Mountain Retreat before the installation of this system. **Enota will be responsible for any permits or any other regulations that need to be handled prior to the installation date. Also, Enota needs to get into contact will Blue Ridge**



Mountain EMC to take care of the power box metering that will allow Enota to supply the grid.

3.5 Educational Display

The client of this project has made it extremely clear that educating the public about alternative energy sources is very important. The proposed way to educate the public is with a display screen showing the instantaneous power generated in watts, the power generated in the past 24 hours, week, month, and year in kilowatt-hours. Any additional information the client requests will be displayed. The information shown in the display will come from current and voltage sensors connected to a computer that will calculate generated power which then outputs to the display. For each kilowatt-hour shown, a money saved column will also be displayed based on a kilowatt-hour rate provided by the client. By showing the public a monetary value that the system has saved they can best equate this to their personal power expenses.

4.0 Project Management

This project is to consist of two semesters of work. During the first semester the project formulation, proposal, conceptual design, and a system simulation are to be implemented. By the end of the first semester, a full computer simulation is to be constructed. This simulation will simulate various generation, load, and switching situations. During the second semester, the physical system is to be constructed. Tests are to be formed to test for faults in the system. These tests will be developed and applied at Tennessee Tech to ensure the equipment is functional. Upon construction at the Enota site, tests will also be applied to ensure reliability. Also during the second semester, an educational system will be designed.

September 2008

- 2nd Team Formulation
- 8th/17th Research of Background Information
- 19th Kick Off-Date (Measurements)
- 22nd Begin Calculations and Design



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October 2008

- 4th Site Visit and Measurements
- 6th/17th Recalculation and Implement into Design
- 24th Proposal
- 31st 1.2 kilowatt System Modeled

November 2008

- 3rd Begin Software Model of System
- 6th Begin Design of Education Software
- 21st Battery Study
- 26th Full Computer Simulation of System

December 2008

- 1st/5th Present Model System and Progress
- Christmas Break
- Begin Part Ordering

January 2009

- 26th Begin Testing Hardware
- 30th Start Implementing Educational Software

February 2009

- 13th Developed Hardware Test for Whole System
- 27th Test the Implemented Educational Software

March 2009

- Install and Test System

April 2009

- 20th /24th Final Report and Presentation

5.0 Team Dynamics

The chart below shows the designated responsibilities of each team member. This will show how we plan to interact and work together to achieve our goal. Through this we plan to design and build a hydroelectric generation system for Enota Mountain Retreat.

Utilizing each member’s specific qualifications, the tasks were divided to ensure product quality.

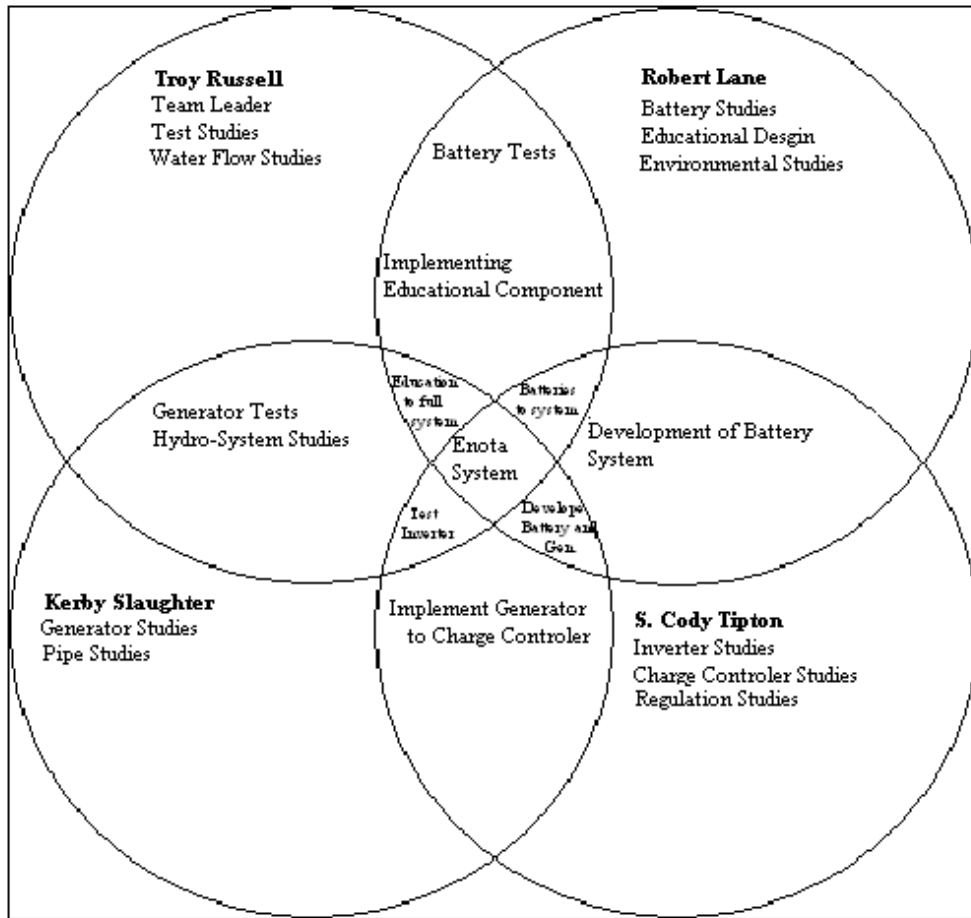


Figure 2: Team Interaction

6.0 Parts and Cost Estimation

In this proposal there are two available options. The only difference between the options is the size of the battery bank. The first option is to use four batteries, which will be capable of storing 2.64 kW-hours. The second option increases the number of batteries to eight; this configuration will increase the capacity of the batteries to 5.28 kW-hours. The larger battery bank allows the generator to store more energy; thus, decreasing the dependence on the electric grid. The price of the project including the variance caused by the battery bank option is shown in tables 2 and 3.



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Table 2: Cost Estimation

Type	Part	Size	Qty	Unit cost	Total	
Piping	Tee	4"	1	\$3.67	\$3.67	
	Pipe	4"	1	\$8.91	\$8.91	
	Elbow	4"	5	\$3.17	\$15.85	
	Bushing	4"/2"	4	\$5.76	\$23.04	
	Bushing	2"/1"	4	\$1.76	\$7.04	
	Valve	2"	3	\$12.77	\$38.31	
	Pipe	2"	1	\$6.14	\$6.14	
	Generator	ES&D Stream Engine	1000W	1	\$2,000.00	\$2,000.00
	Diversion Load	Ohmite DC 300	300W	4	\$32.50	\$130.00
Breaker	Flexware 250 Enclosure		1	\$74.29	\$74.29	
	Homeline	100A	1	\$21.97	\$21.97	
	OBDC-175	175A-DC	1	\$102.80	\$102.80	
	OBDC-30	30A-DC	1	\$21.23	\$21.23	
	Square D	60A-AC	1	\$7.74	\$7.74	
	Inverter	GTFX3048T	3000VA	1	\$1,766.22	\$1,766.22
Charge Controller	NCHC-48-35	48V 35A	1	\$293.00	\$293.00	
Batteries	Deka	55A-h @ 20h	4	\$155.97	\$623.88	
	Deka	55A-h @ 20h	8	\$155.97	\$1,247.76	
Transfer Switch	Guardian	100 A	1	\$299.00	\$299.00	
Computer	Asus Eee PC 2G Surf		1	\$253.75	\$253.75	
Display	17" Display		1	\$109.99	\$109.99	
Sensors	Phidget Interface Kit	C-200-P1018	1	\$76.00	\$76.00	
	Phidget Voltage Sensor	S-50-P1117	2	\$19.25	\$38.50	
	Phidget Current Sensor	S-50-P1122	1	\$29.45	\$29.45	

Table 3: Total Project Cost

Design	Grand Total
4 Batteries	\$5,950.78
8 Batteries	\$6,574.66
On Grid	\$4,604.90

The payoff for this project assuming \$0.115 per kW hour to purchase electricity from the grid, averaging 1.2 kW by considering only low stream flow, and a total installed cost of \$7,000 is approximately 6 years. A permit is required to remove more than 70 gal/min



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flows from the stream [19], and it is our belief that taking more than 50% of the stream could have detrimental effects on the ecosystem.

7.0 Conclusion

From academic research completed in the formation of this proposal, this design is believed to be the most cost effective and efficient hydroelectric system for this location. Using the low flow and head parameters measured, this proposed system can produce a minimum output power of 400 W. From the proposed educational display it is possible to inform the public who visit Enota Mountain Retreat of an efficient cost effective alternate green power source.



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ENOTA HYDROELECTRIC POWER GENERATION

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