Micro Hydropower System

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Abstract

The micro hydropower project strives to meet the needs of a specific village in northern Thailand in partnership with Engineers Without Borders. Specifically, the electrical side of the system must be designed to convert the mechanical power of a flowing river that is turning a turbine into sustainable and dependable power. Currently available hydropower systems will be considered, analyzed, and tailored to suit the specific needs of the community in need. The system to be designed will be flexible enough to demonstrate proof-of-concept with the limited maximum generable power in lab while having the ability to be easily scaled for the village demands. After testing, the system will be analyzed for suitability to be used by Engineers Without Borders in Thailand, with any recommended changes included in the report.

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Acknowledgements

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Sincerely,

Chris & Ian

Introduction

This project originated from a visit to Thailand by Cal Poly's Engineers Without Borders (EWB) student chapter. Engineers Without Borders (EWB) is an international non-profit organization whose mission is to improve the quality of life of disadvantaged communities worldwide through education and implementation of sustainable engineering projects, while promoting new dimensions of experience for engineers, engineering students, and similarly motivated non-engineers (EWB mission statement). The micro hydropower project strives to meet the needs of one specific village in northern Thailand in partnership with Engineers Without Borders. Access to a dependable source of energy is a basic need that all should have access to and developing hydropower is one solution that fits well with the community in mind. Utilizing currently available systems, this senior project team is designing a micro hydropower system that will meet the demand of this community while realizing the importance of ease of construction, availability of parts in the partnering country, and durability of the system. At the completion of this senior project, the team will report its results to the Cal Poly Mechanical Engineering department, Electrical Engineering department, and the Cal Poly Engineers Without Borders chapter, with the mindset that this system will be implemented, if seen as suitable by both EWB and the partnering community.

Background

The decision to propose the micro hydropower project was developed while traveling with the Thailand team of Engineers Without Borders, Cal Poly on an assessment trip to meet with hill tribe communities in northern Thailand. It was on this assessment trip that the need for a dependable form of electricity was noted in several partnering communities and hydroelectric power was specifically preferred as the most feasible choice.

After completing these monitoring trips, an assessment trip was made in June, 2012 to decide upon other needs within Huai Nam Khun and within other communities throughout northern Thailand. It was on one of these assessment trips that the need for a form of dependable power generation was determined as a primary need. Access to electricity has become increasingly important throughout the world and this need is no different in these rural villages. Two villages in particular, called Jasae and Ban Sip Lahn, described hydropower as the most suitable form to meet the energy needs of their specific communities. Both villages were thought to be inaccessible to the Thai power grid and currently they only have limited access to solar power, implemented by separate development organizations. To give the travel team a better perspective, one villager described how the entire village currently has the power capacity to allow for 30 minutes of television, a capacity well below the village's current demand.

With this information available, the design of a hydroelectric system was proposed for approval as a senior project to the mechanical and electrical engineering departments at California Polytechnic State University. Following approval, the senior project team was organized into three mechanical engineering students (Adam Eberwein, Adam Hendry, and Ravi Sahai) and two electrical engineering students (Ian Verstuyft and Chris Neally). This senior project team spent the fall quarter of 2012 researching hydro system design, fundraising for building materials, and developing an extensive assessment packet for the EWB team to complete upon a future assessment trip to the communities in mind.

From December 7, 2012 to December 30, 2012, the Thailand team of EWB Cal Poly conducted an assessment trip, and determined that the Mai Chan Thai community would be the optimal location for a hydroelectric system. During the trip, the assessment team took detailed measurements of the flow rate of the river, the elevation change between the settling tank and turbine location, and GPS coordinates of the surrounding area. The community currently has a non functioning hydroelectric system with a

small dam, settling tank, piping, and a pump that has been converted into a turbine. The community also has an inverter, battery, and transmission lines that deliver electricity to the village. The settling tank and pipe have been clogged with sand, and the turbine was struck by lightning. The community is seeking a new turbine system to replace the current one, and the existing dam, settling tank, and transmission lines may be reused.

Concept Selection

The micro-hydropower system will consist of a settling tank, penstock, power house, power transmission lines, and return piping (see Figure 2). Water will be piped from the river into the settling tank, the purpose of which is to accumulate water to better control the flow of water into the penstock and to filter out sediment and debris that could clog the penstock and damage the turbine. Filtration procedures must also be assessed, such as settling tanks or screens, to eliminate the possibility of sediment in the flow and pipe blockages. The penstock is the piping that will transport the water to the power house. The elevation change from the settling tank to the power house will provide the necessary pressure head required to power the turbine. The power house will contain the turbine and generator. Water from the penstock will be sent through high-pressure nozzles to create water jets that will impact the buckets of the turbine wheel and spin the generator shaft to produce power. To produce a steady current, accounting for changes in the rotational speed of the shaft, a DC generator will be used. The power from the generator will be inverted into 3-phase AC power, stepped up with a transformer for transport to the village and individual houses, at which point it will be stepped back down again to 220-V, 50 Hz, for normal household power consumption. Finally, the water used at the power house will be piped back to the river. A depiction of this system can be seen below in Figure 1 [4].

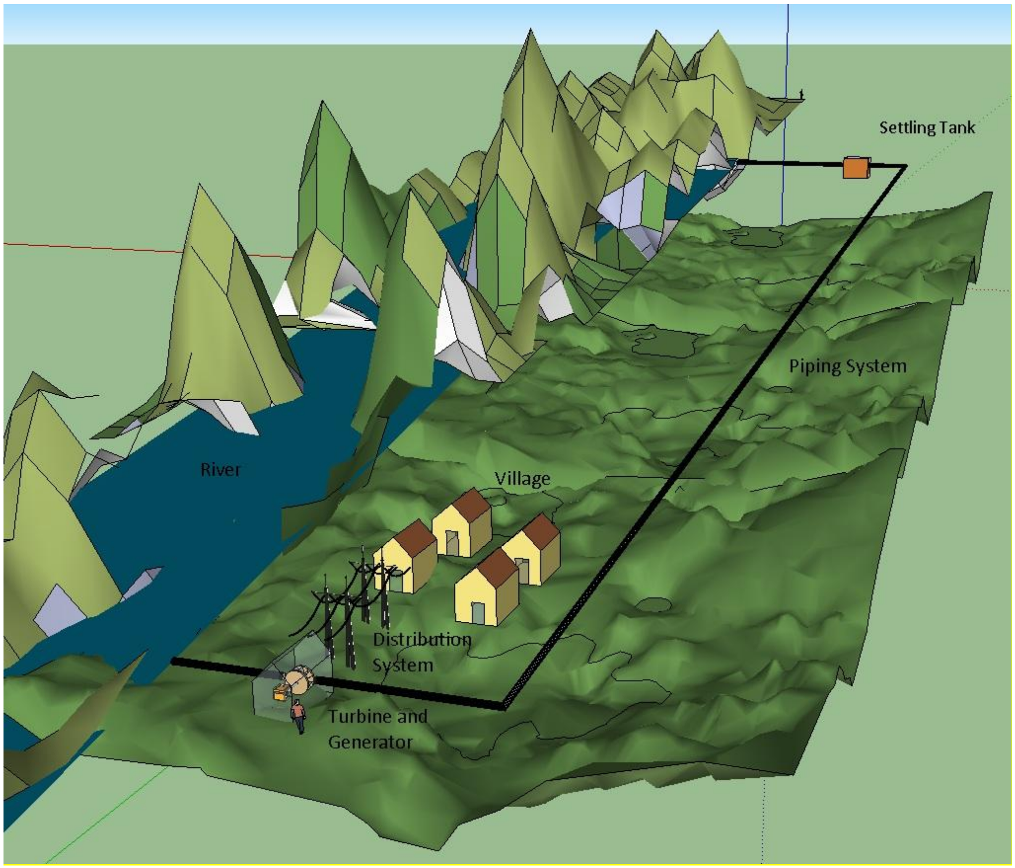

Figure 1: Micro Hydropower System in Mae Chan Thai

Requirements

The objective of the micro hydropower project is not to design a brand new form of power generation and implement that technology in the field. The micro turbine is a relatively well-established technology and is utilized throughout the developing world. Therefore, there is little need to deviate from a system that is already successful in the field. Instead, this senior project team is focusing on the design specifications necessary for a successful implementation at the specific site of Mae Chan Thai. This process includes a number of steps. First, the senior project team must arrive at a consensus on the energy demand for this community. The estimated village load demand is shown below in Table 1. The prototype should be designed with both the current energy demand in mind, as well as the increase in demand over the entire life of the system.

Depending on the demand, the model to be built at Cal Poly is not required to meet these necessary loads. Instead, the model is intended to provide proof of concept, and serve as learning tool for the EWB team that will be installing the system in Mae Chan Thai. The senior project team will also complete an installation and maintenance guide to describe the components of the system and how the system should be assembled to maximize its lifetime.

The focus of this design will not necessarily be on optimizing efficiency. Instead, the focus will be ease of construction, availability of parts in the partnering country, and durability of the system. After these initial goals are met, if improvements to efficiency can be made then they will be considered.

Finally, the system has to be fully autonomous with close to 100% reliability so the villagers do not have to make many complicated adjustments to the system during operation. The electrical long term goal for the Thailand system is for it to run for years under changing load conditions without any electrical problems developing, as long as the system is properly maintained. The team is required to keep safety a priority for the system; most importantly, the batteries must be safeguarded from overcharging, and the system protected against runaway. The engineers want to design a system that utilizes as much of the power as possible, so that very little is wasted.

Equipment	Power per unit (W)	Quantity	Total Power (W)
Fluorescent light bulb	13	102	1326
Television	111	2	222
Refrigerator	540	1	540
		Total	**2088**

Table 1:Estimated village load demand

Design

The power system design of the micro hydropower project is called an AC-DC-AC link power system. The AC-DC-AC link was chosen for a number of reasons including cost, reliability, and efficiency. The decision for the type of power system revolves around the type of generator in the system.

A DC generator does not require the rectifier, therefore in theory it should give us better power efficiency. The problem with a DC generator lies in its cost and size. DC generators are a couple times bigger and more expensive than AC generators. DC generators are more known for their use in higher power systems, usually in the megawatt power region like a dam power plant. Canyon Hydro estimated a $1500-$2500 quote for a 1.2kW DC generator matched at the village river's flow rate and head [1].

An Induction generator could use this AC-DC-AC link system and would be cheaper than the AC synchronous generator [7]. Except induction generators are inherently inefficient from a lagging power factor. The efficiency can be compensated with shunt capacitors to provide the leading reactive power that can correct the poor power factor. The induction generator was not chosen because the turbine's output power to the generator was theoretical. There would not have been enough time or money to compensate our system if the turbine's output power was not as expected for the induction generator [5] [6].

For a further look into other alternatives that were explored, see Appendix B.

An AC synchronous generator is the generator that is integrated into this micro hydropower AC-DC-AC link system. A main advantage of the synchronous generator with the rectifier is that the turbine can vary in speed (within ~100 RPM of the optimal turbine RPM) because we do not need a certain output frequency using a DC link. This RPM flexibility is extremely important because there is not enough time to make major adjustments to the system if the turbine's RPM does not meet theoretical calculations. The generator is also fairly inexpensive, approximately $200. A possible problem can occur if the turbine does not reach a minimum of 600 RPM to produce over 14V to charge the batteries.

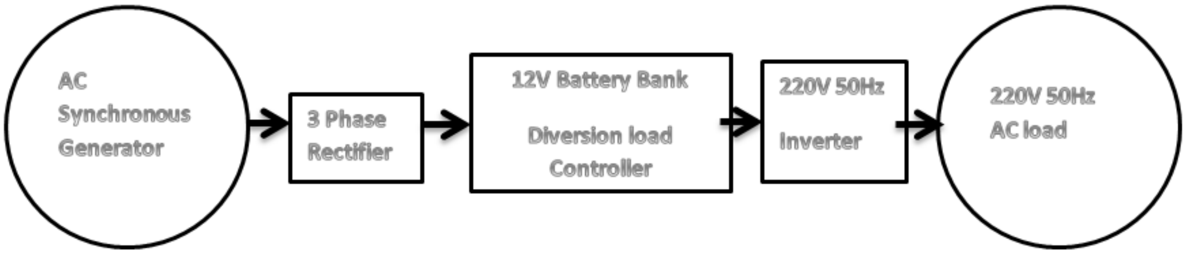

Figure 2: AC-DC-AC Power Generation Design

The diversion load controller is a Schneider Xantrex C60. The Xantrex has two separate connections with common grounds; one connection is on the battery bank while the other is on the diversion load. The Xantrex is rated for 60A continuous and 85A peak, this means that the Xantrex cannot divert more than 720W at 12V or 900W at 15V to the diversion load. The power flows through the battery connection on to the Xantrex then into the diversion load. To prevent a surge current from burning the Xantrex, an 80A fuse is installed on the battery connection. There are multiple 80A fuses in the design to provide the system with over current protection. The AWG #6 is rated for 75A, so these fuses will provide protection for the wires heating and melting their insulation while above rated current.

Figure 3 shows a diagram of how the Xantrex controller changes states to divert power to the diversion load and prevent over charging of the battery bank. The Xantrex has two voltage settings, the first is the bulk voltage setting which determines what point the controller starts its transition timer to float mode. The second is the float voltage setting which determines what point the controller starts its transition timer back to bulk mode. The settings have potentiometers for the ability to change the voltage setting, but we have our system optimized for a Bulk setting of 14.9V and Float setting of 14.5V. The controller starts in Bulk mode and diverts current to the diversion load when above 14.9V to keep the system at 14.9V and when the controller sits at the 14.9V Bulk setting for an hour it transitions to Float mode. In Float mode the controller diverts current to the diversion load till the system hits the Float setting of 14.5V and diverts less if the system voltage is less than 14.5V in attempt to keep the system at 14.5V. Figure 6 in the test plans section shows a black box diagram of the full micro hydroelectric power system design in the fluids lab [8].

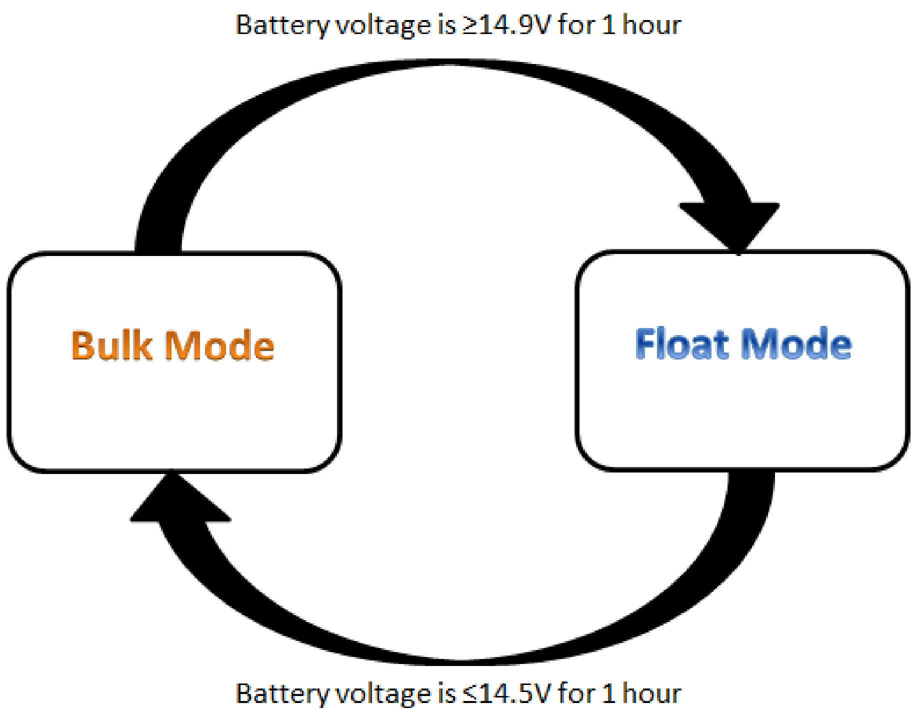

Figure 3: Xantrex Diversion Load Controller's Mode Transition Diagram

Overall, this design provides the team with the greatest sense of flexibility to purchase and move forward before the system is completed. They can test the system as they go to verify the results with the expected value. This system design will fulfill the design requirements because it is autonomous, safe in that it protects against runaway, and should be reliable. Most significantly, the system will make the most of the power generated by storing it in batteries and then any excess power can then be put to use on the diversion load as water or space heaters [3].

Test Plans

The primary tests for the electrical design are to check the system hardware for full functionality. Testing the generator begins by coupling a 3 Phase Induction Motor in the power lab(EE building 20 room 102) to the AC synchronous generator and rectifier to check the DC output at different RPMs. There were very few specifications given from MotEnergy on the AC synchronous generator. "The output is 1000 watts at 12 VAC at 1000 rpm, and up to 3000 watts at 36 VAC and 3000 rpm. The generator is a 3-phase, Y-connected winding. To convert to DC power, simply connect a 3-phase Full Wave Bridge Rectifier (not supplied)." The test results in lab proved very different from the numbers given by MotEnergy, which are shown in the Integration and Test Results page. Figure 4 below shows the test system in the power lab.

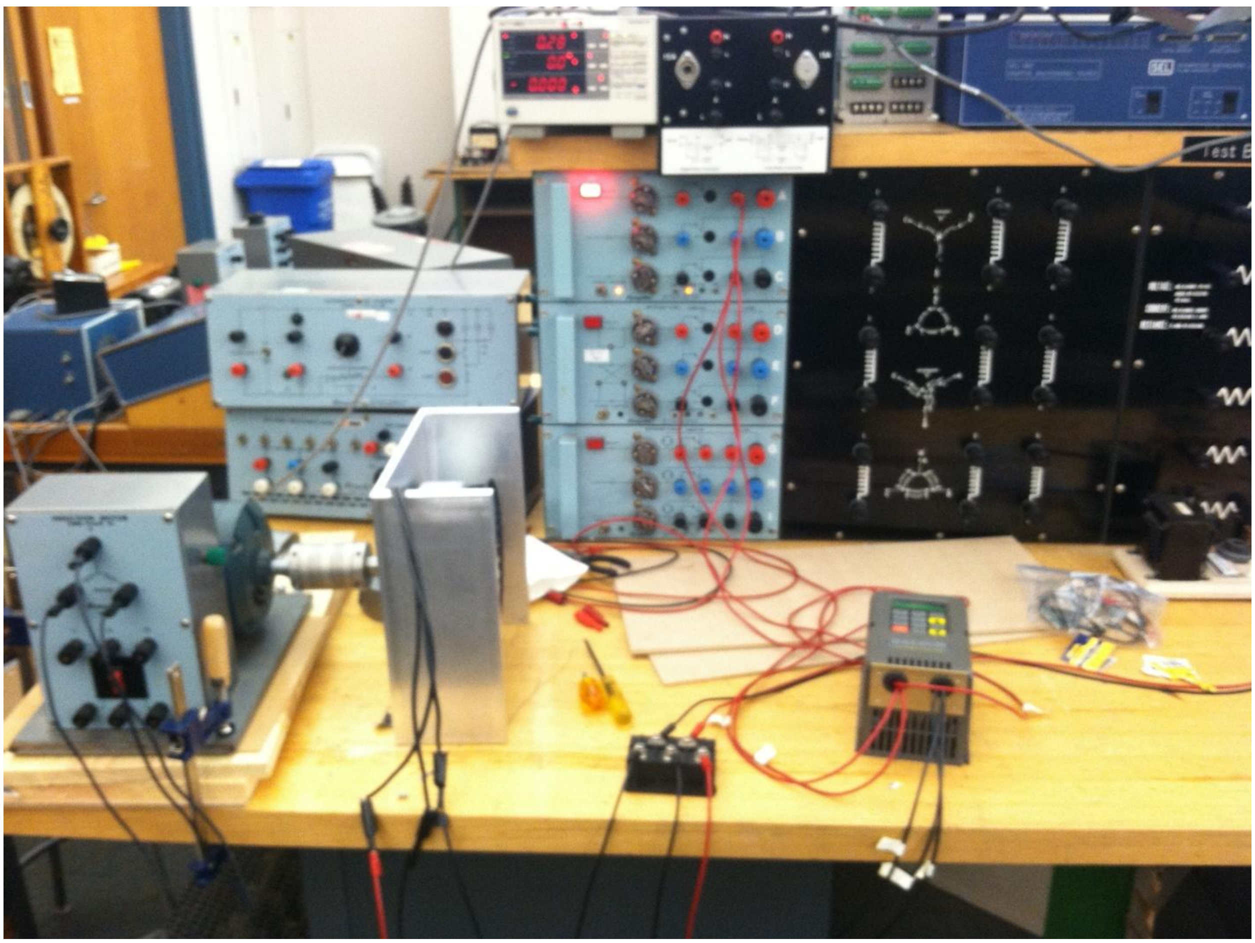

Figure 4: Three Phase 208V VFD to 1/3HP induction motor, which is coupled to the AC generator with a three phase rectifier

The variable frequency drive (VFD) used AC 3 phase 208V from the back wall in lab. The VFD allowed for speed (RPM) control of the induction motor by varying the frequency of the AC 3 phase 208V input. The test results section shows data for RPM vs. voltage, power, and RLC loads.

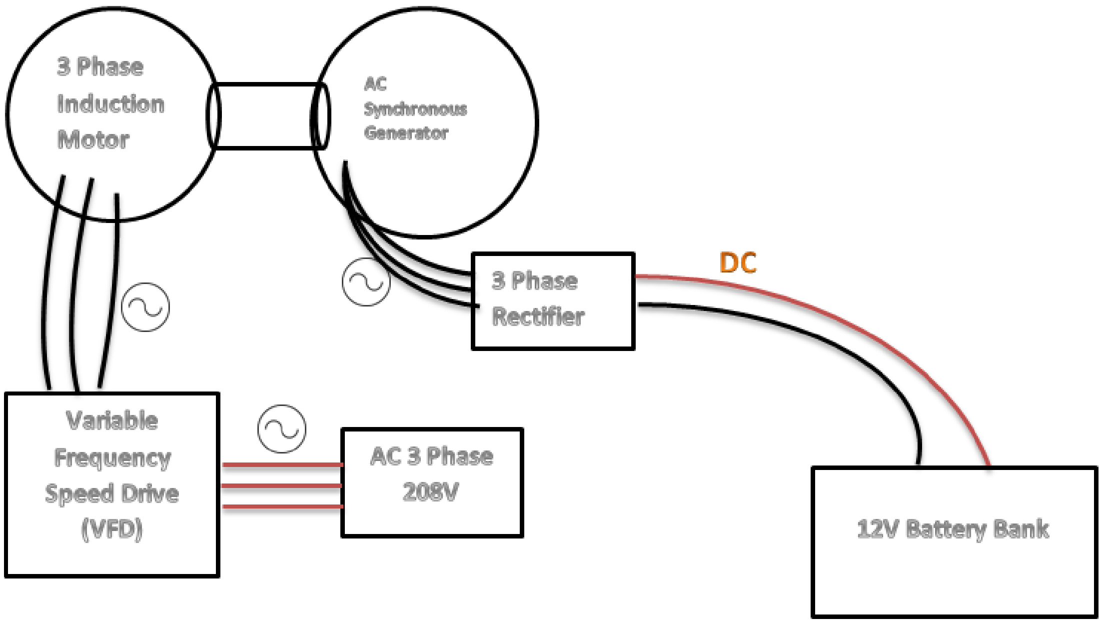

Figure 5: Preliminary test setup in the power lab with the generator, rectifier, and 12V batteries

Tests continue in the Fluids Lab (Building 192 room 102), where the full micro hydroelectric system is setup. Figure 6 below shows the system in its entirety, excluding the water pump and piping to the pelton wheel turbine. Multiple tests are performed with this set up using the Hampden AC load on the output of the inverter. The graphs in Figure 8 shows a unique test utilizing only a connection from the rectifier to the diversion load with all other system parts disconnected. This test is to see the full power capabilities of the turbine and generator.

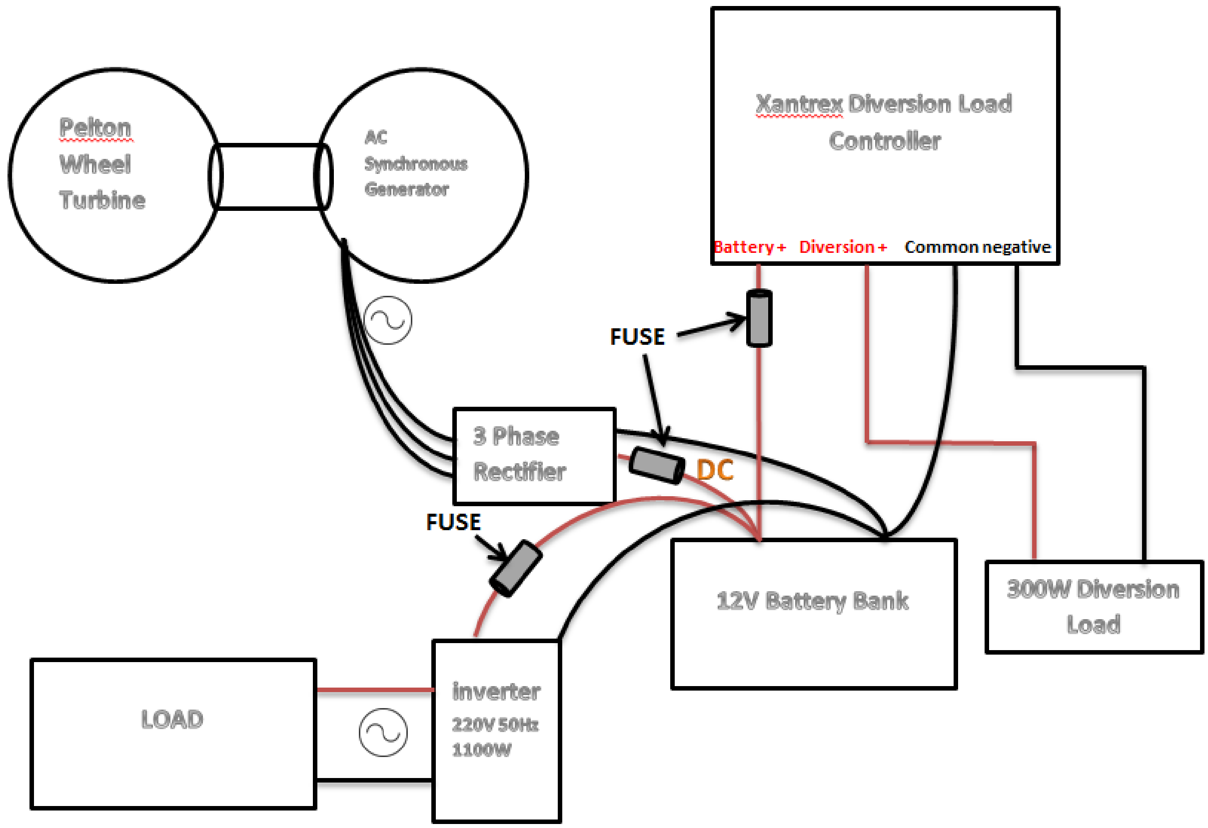

Figure 6: Micro hydropower final project setup in the fluids lab

Development and Construction

To model the system in Mae Chan Thai, the Senior Project team is constructing its Final Design in the Fluids Lab at Cal Poly. The mechanical system will consist of a pump to simulate the flow rate and head of the river, piping and fittings to transport the water and simulate the losses in the system, and a Pelton wheel turbine and turbine housing to convert fluid energy to mechanical power. The electrical side of the system will include a generator to convert mechanical power in electrical power, a rectifier to convert AC to DC, a charge controller to regulate the flow of current, batteries to store energy, an inverter to convert DC back to AC, and a transformer to step down voltage for testing purposes. The system at Cal Poly is intended to model the Mae Chan Thai system as closely as possible, and serve as a teaching model for the EWB hydropower team, giving them the opportunity to become familiar with a working system and all of its components before they implement it. A diagram of the system as planned is shown below in Figure 7.

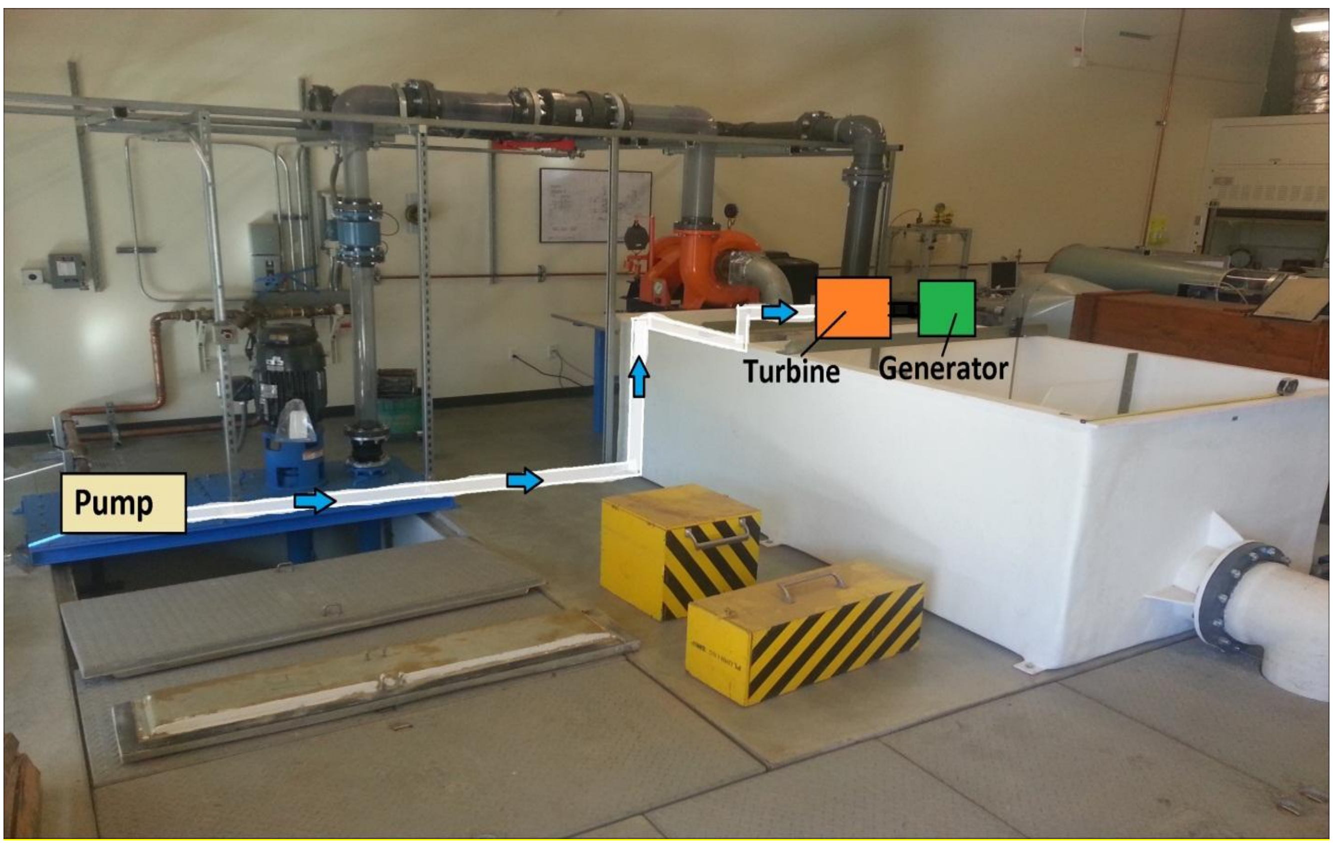

Figure 7: System design layout in the fluids lab

While the mechanical engineers focused on building the housing and piping system for the fluids lab setup, the electrical engineers concentrated on researching and developing first the best system to handle the needs of the village and next finding each component of the design that would most closely match ideal specifications and be the most cost-effective. The electrical engineers decided to utilize the power systems laboratory located in building 20 room 102 on the Cal Poly San Luis Obispo campus. They were able to use a lab bench in the room as a staging area for the electrical components as they would arrive. After researching and designing the specifications for the components, they would order them and test each part individually in the lab. They would then integrate the component into the entire electrical system to verify that it runs as expected. After they had the entire electrical portion of the project set up and checked in the lab, they moved it to the fluids lab to integrate into the entire system.

Integration and Test Results

As described above, the first step for the electrical side was to order all the parts and test them in the power systems laboratory in building 20. The picture in Figure 5 was the test setup for these tests. The first test was to test the generator to rectifier output for an open circuit with respect to change in speed, which was controlled by the VFD. The results of the test are shown below in Table 2 and Figure 8. The relationship was verified as a linear one, which was expected from the product guide of the generator.

RPM	Volts
200	4.59
287	7.16
344	8.85
431	11.37
488	13.07
546	14.77
603	16.45
661	18.17
718	19.87
776	21.55
833	23.25
891	24.95
948	26.64
1006	28.34
1063	30.03
1121	31.73
1207	34.27
1293	36.81
1379	39.35
1466	41.89
1552	44.39
1600	46.03

Table 2: Relationship between RPM and open-circuit rectified voltage output

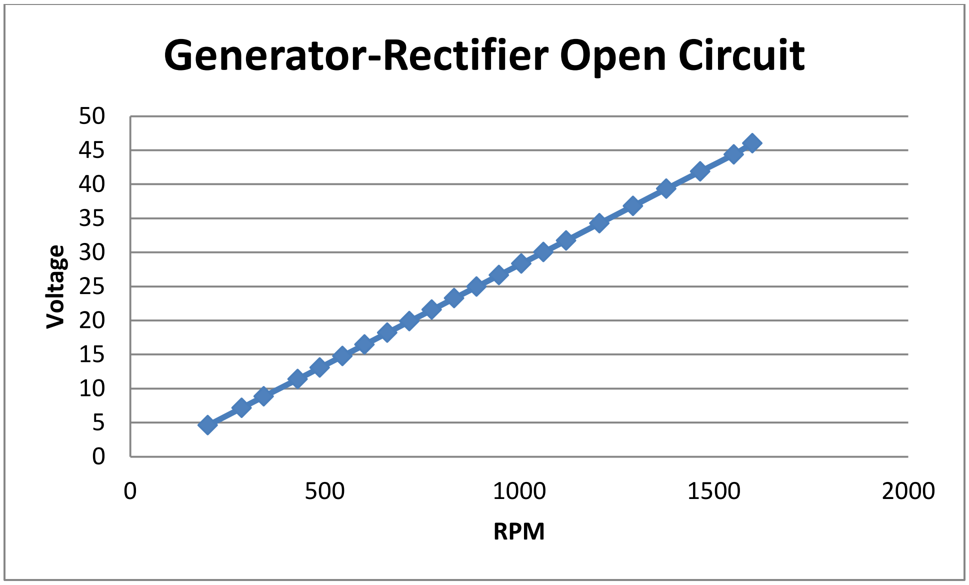

Figure 8: Relationship between RPM and open-circuit rectified voltage

The next test was to compare the behavior of a 24V system and a 12V system. First, the four batteries were ordered based on specifications shown in Appendix A. Once arrived, the tests were formulated that involved two different configurations. The first configuration was for a 24V system and used two batteries wired in series. This test was quickly stopped though because the RPM required to charge a 24V system was above what the team could achieve in the lab. The results for the24V system test are shown below in Table 3. The next test was for the 12V system, which was configured using two batteries in parallel. The speed of the motor started at 517 RPM for 12.67V and was ramped up to 1006RPM, which required almost all of the power that the 1/3HP induction motor could produce. Thus, the VFD shut itself off at this point. The results of the 12V system test are shown below in Table 4 and Figure 8. It is notable that the tests were run on the batteries while their open circuit voltage was 12.65V.

RPM	Volts	Amps	Power
919	25.63	0.46	11.5
977	25.97	1.75	45
1034	26.67	3.31	87.3
1121	28.35	4.5	127

Table 3: Output of generator loaded by two 12V batteries wired in series to form a 24V system

RPM	Volts	Amps	Power
517	12.67	1.51	19.1
488	12.67	0.43	5.43
546	12.91	2.44	31.4
603	13.19	4.7	62
661	13.57	6.72	90.8
718	13.9	8.69	119
776	14.04	10.45	146.7
833	14.29	11.9	170
891	14.54	13.18	192
948	14.76	14.24	209.8
977	14.82	14.86	217
1006	SHUTDOWN		

Table 4: Output of generator loaded by two 12V batteries wired in parallel to form a 12V system

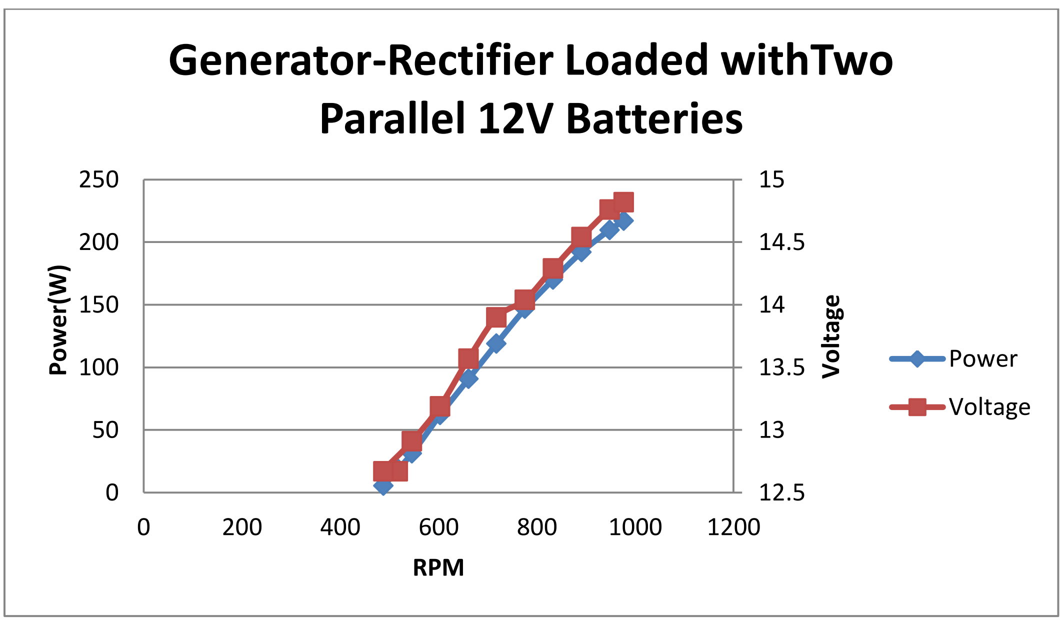

Figure 9: Relationship of voltage and power with respect to changing speed for the two battery 12V system in Table 3

Now that testing was finished for purely the electrical portion and the turbine was setup in the fluids lab, the team shifted focus of their testing to the full system. It was clear from the tests that a 12V system was the best to go, so they configured the system with four batteries in parallel. Before connecting the batteries, they tested the turbine connected to the generator to the rectifier and used the diversion load resistors, which each have resistance of around .7Ω to see their effect on the speed and power output from the generator. The results are shown below in Figure 10 & 11.

Figure 10 below shows at what RPM the system receives maximum power out of the turbine. The maximum power the turbine can generate into the system is 232 watts at 641 RPM. Figure 11 shows that at that maximum power the resistance is 0.73 Ω or one dummy load resistor.

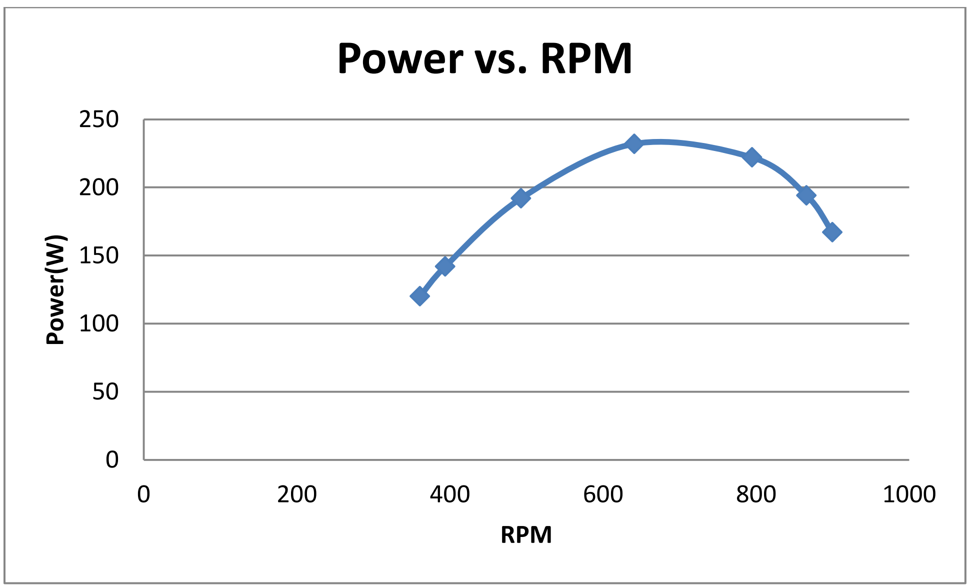

Figure 10: Turbine powered by water from pump mechanically connected to generator and varying resistor configurations

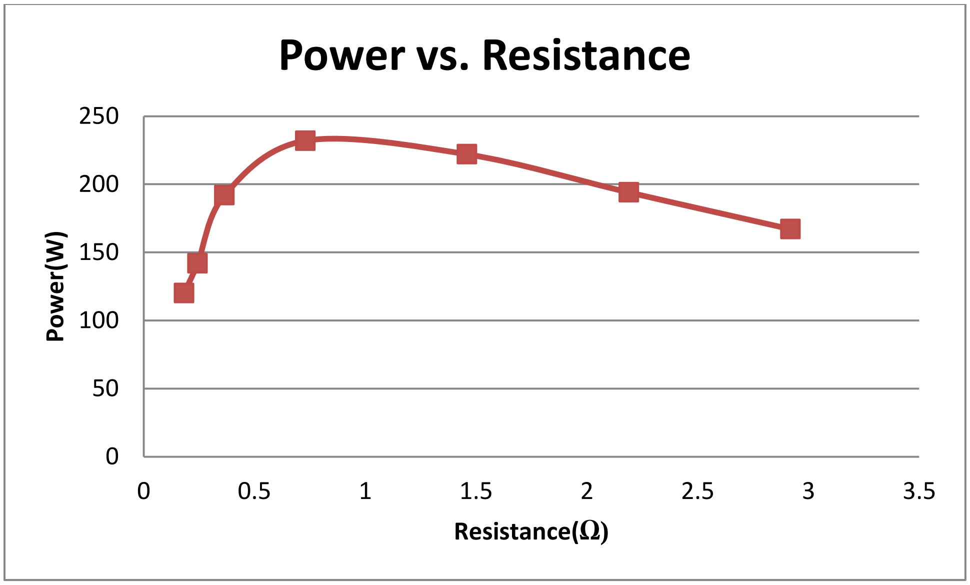

Figure 11: **Turbine powered by water from pump mechanically connected to generator and varying resistor configurations (Same test as above)**

The team next connected the system all together, as shown in Figure 6. The load demand on the inverter was varied using a Hampden RLC AC Load. The test was used to see how much the batteries and diversion controller would compensate for the load change. At an approximate 400W load change, the speed of the generator would slow by 50RPM. Speed of the generator is directly related to voltage, shown in Figures 8 & 9, so when the generator is loaded the voltage drops with the speed. The steep drop in the figure 8 at 86W load demand is because the system is no longer diverting power to a dummy load and is balancing the full power generated with the load demand. The full results can be seen below in Figure 12. The team then measured how load changes affect both the power delivered and the power generated. They varied the load power demand by varying the Hampden AC Load on the inverter. Finally, to gain a full comprehensive understanding of the system, the team explored exactly where the power came from and went in the system. They did this again using the Hampden AC Load, and recorded how much power was generated, delivered, and diverted. It was noted that once the AC load becomes greater than the power produced by the generator, the additional power comes from the battery bank. These relationships can be seen in Figure 14 below.

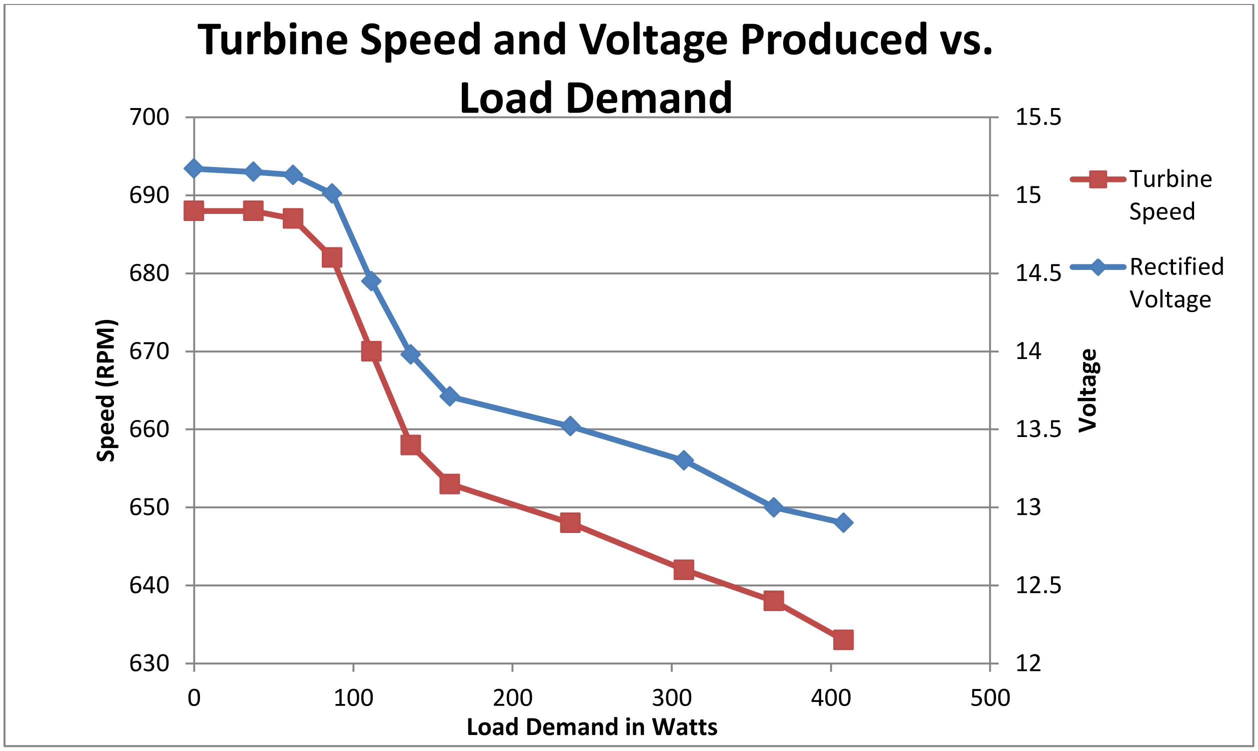

Figure 12: Effect of increasing the power drawn from the load on the speed of the turbine and voltage of the rectifier

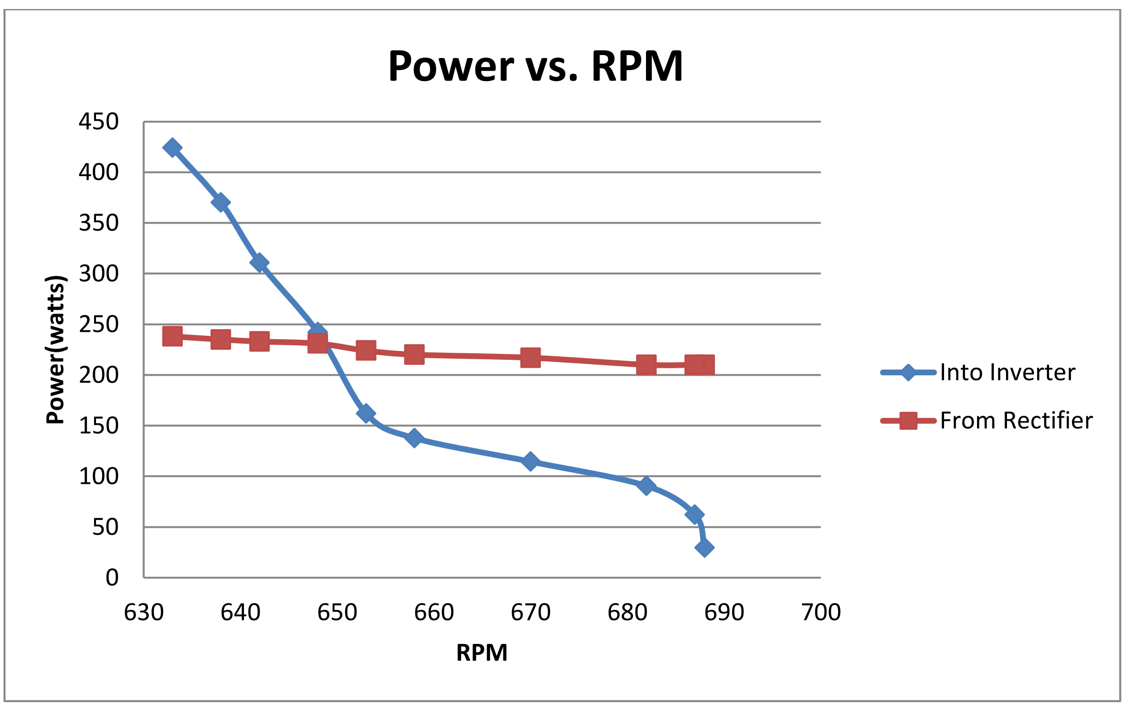

Figure 13: Observing how the power generated and power delivered changes as the RPM changes

Figure 14 below shows the Power on the Y-axis generated, diverted to a dummy load, and drawn from the batteries. The X-axis shows the power demanded by the AC load. Under low load demand (0-100 W) the system starts by diverting the excess power generated to the dummy load. Then under a medium load demand (100-200 W) the system diverts no extra power because it is supplying the needed demand to the AC load and charging the batteries with its needed current. Finally under a high load demand (>230W) the system is supplying all generated power to the AC load and any extra power needs through the batteries discharging. This final stage is where the turbine is fully loaded and will drop to a speed of ~630 RPM. The relationship between the numbers is as follows: when the load demand is 408W (the last point in the figure), 238W comes from the generator directly while the remaining 170W is provided by the batteries. Because all of the produced power is being used, 0W is diverted.

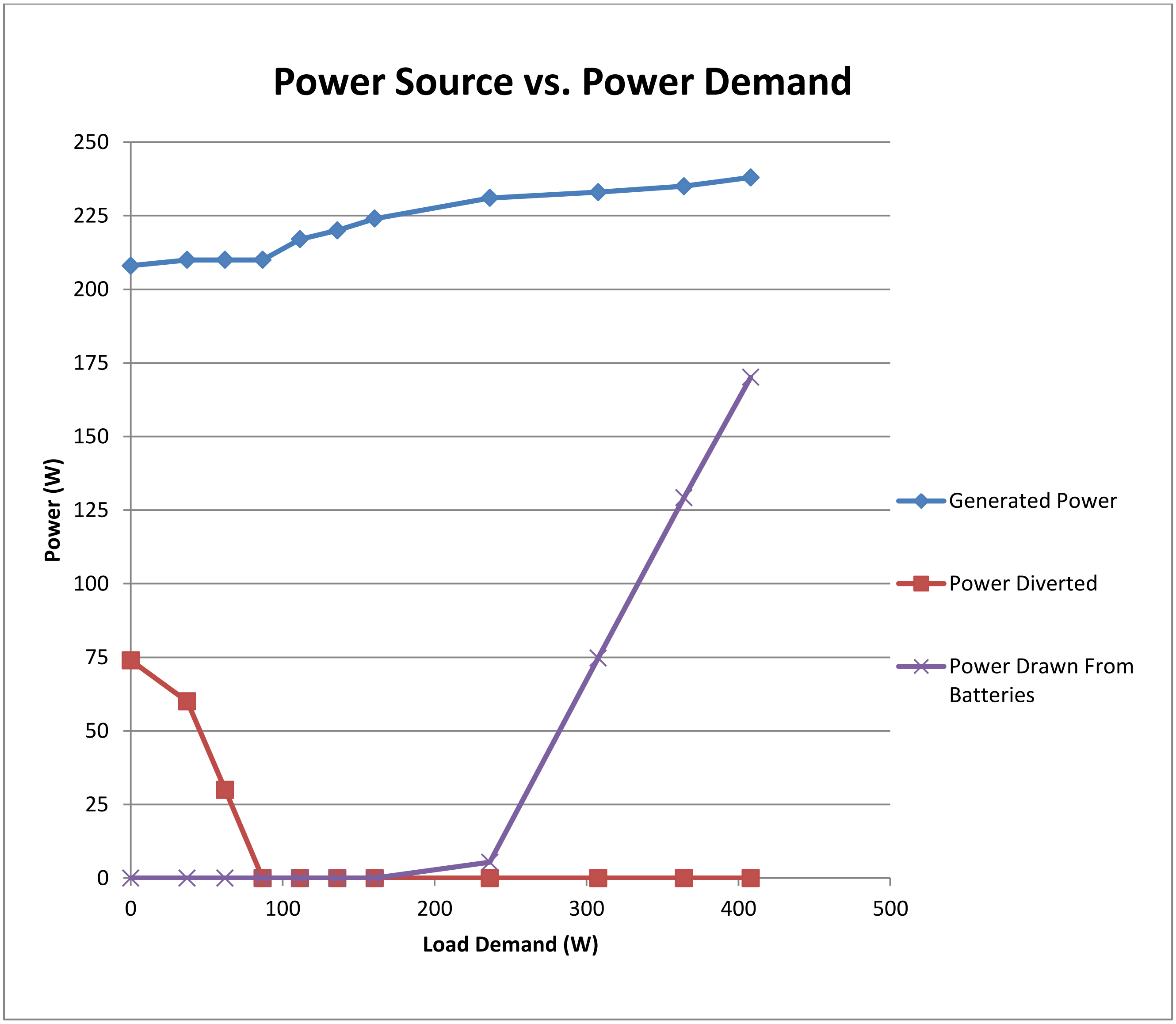

Figure 14: Results of the test that explored each facet of the system to determine how power is used

The team attempted to do load tests with inductive and capacitive loads, but was unable to because the inverter also expects a resistive load so that it doesn't experience overcurrent. Also, they couldn't clearly observe the effect of speed droop from the reactive loads because the inverter needed to be connected to the batteries rather than purely the rectifier output, most likely because the output from the rectifier was not constant enough. Using 500Ω resistor and a reactive load of 18.4VAR, the power factor was at the test-high 0.864.

Conclusion

The micro hydropower design project was a success. Through it, the team was able to demonstrate proof of concept for a system that could realistically be put in place in Mae Chan Thai in Thailand. Although the output from the generator was much less power than originally calculated by the mechanical engineers, this loss ultimately only affects the time it takes to charge the batteries. With the flexible design of the electrical portion of the project, the batteries will store the energy produced in off-peak hours such as during the day and late at night and it can still power the village demands which are much higher than the direct generator output. As shown in Figure 14, the design can still be used to power loads that are much greater than what the turbine outputs. Thus, rather than being able to use the turbine to generate enough energy to directly power the village as originally hoped, most of the supply will now be drawn from the batteries. This has a few drawbacks though. See Appendix A to determine exactly how many watt-hours can be drawn from the battery bank at a time, as much more careful consideration must be given to ensure the batteries are not fully drained, which is harmful to battery life. Also, the idea that the batteries would almost always be fully charged and much power would be diverted by the controller is no longer true. This means that to possibility of using the extra power to provide hot water would be extremely tough to realize. However, it is clear that this system is still the most desirable for EWB to implement in terms of the electrical system. Charging the batteries and utilizing a diversion controller are proven ways to keep the system under relatively constant load and thus provide an extremely autonomous solution for the village. Because the battery bank capacity is flexible, more or less batteries may be added depending on the village needs throughout the years. The batteries only need to be replaced every three to four years, and so maintenance of the electrical system is not demanding. With proper housing, grounding, and fusing as will be described to the EWB team, the system will most importantly be safe. Thus, the electrical system design for the micro hydropower project was a success and should be recommended to EWB to be put in place in Thailand.

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Appendices

Appendix A. Battery Power Calculations

Sizing the battery bank: Below is the train of thought utilized to correctly size the battery bank [2].

Assume the demand is 2,000 Wh/day (given 1 hour autonomous).

2,000 Wh/day x 1 day = 2,000 Wh

25%DepthofDischarge: 2,000/.25 = 8,000 Wh

8,000Wh / 24V = 333Ah

Thus, the battery bank is desired to have 333Ah capacity.

Reduce to 1,000Wh for scaled lab version, battery bank should have 167Ah cap.

Could be achieved several ways: 1) two 12V batteries in series at 167Ah

2) two 24V batteries in parallel with ≈80Ah

3) two 12V, 80Ah batteries in series, in parallel with two more 12V, 80Ah batteries in series

The team decided to purchase four 12V batteries because this would provide the greatest flexibility in testing and allow for all shipping for batteries to be taken care of at the same time.+

Available power for 4 hour long Engineering Expo: Setup includes four 12V 90AH batteries in parallel with the generator producing a constant ~220W.

Using the batteries discharge specifications in Figure 15, each battery can fully discharge a constant 180W for 4 hours. We have four batteries so that makes 4*180W = 720W for 4 hours.

The batteries should not discharge below 30% capacity to avoid damage to their chemical properties. Discharging below 30% will greatly reduce their overall number of life cycles.

Therefore 70% of the battery will be used for 4hours, and our new power calculation 0.70*720W=504W for 4 hours.

Finally, add in the constant ~220W/hr the generator produces and we have a constant **<u>~724W for 4 hours at the expo.</u>**

UPG STAY POWERED® **Sealed Lead-Acid Battery**

UPG No. 45823

UB12900

Absorbant Glass Mat (AGM) technology for superior performance. Valve regulated, spill proof construction allows safe operation in any position. Approved for transport by air. D.O.T., I.A.T.A., F.A.A. and C.A.B. certified. U.L. recognized under file number MH 20567.

Maintenance-Free

Specification

Nominal Voltage	12 volts
Nominal Capacity	77° F (25° C)
20-hr. (4.50A)	90 Ah
10-hr. (8.37A)	83.7 Ah
5-hr. (15.30A)	76.5 Ah
1-hr. (54.00A)	54.0 Ah
Approximate Weight	59.52 lbs (27 kgs)
Internal Resistance (approx.)	7 mOHMS

Shelf Life (% of normal capacity at 77° F (25° C))

3 Months	6 Months	12 Months
91%	82%	64%

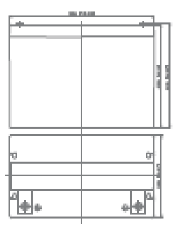
Temperature Dependancy of Capacity (20 hour rate)

104° F	77° F	32° F	5° F
102%	100%	85%	65%

Charge Method (Constant Voltage)

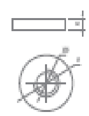
Cycle Use (Repeating Use)	
Initial Current	31.5 A or smaller
Control Voltage	14.5-14.9 V
Float Use	
Control Voltage	13.6-13.8 V

Physical Dimensions: in (mm)



L: 12.05in (306.1 mm)
W: 6.61in (168 mm)
H: 8.19in (208 mm)
TH: 8.35in (212 mm)
Tolerances are +/- 0.04 in. (+/- 1mm) and +/- 0.08 in. (+/- 2mm) for height dimensions. All data subject to change without notice.

Terminals



Dimension / Type	ø	H
I4	15	4

Constant Current Discharge Characteristics Unit:A (25°C, 77°F)

F.V/Time	5MIN	10MIN	15MIN	30MIN	1HR	2HR	3HR	4HR	5HR	8HR	10HR	20HR
9.60V	309.3	225.7	158.8	96.1	50.2	29.3	21.5	16.7	13.8	9.7	8.8	4.7
10.20V	272.5	205.7	142.1	91.1	47.2	27.9	20.9	16.3	13.5	9.5	8.5	4.6
10.50V	262.5	195.6	133.8	88.6	46.0	27.3	20.4	16.1	13.4	9.4	8.4	4.6
10.80V	252.5	185.6	125.4	86.1	44.3	26.6	19.9	15.8	13.0	9.2	8.4	4.5
11.10V	242.4	175.6	117.0	83.6	42.6	25.9	19.2	15.3	12.7	8.9	7.9	4.3

Constant Power Discharge Characteristics Unit:W (25°C, 77°F)

F.V/Time	5MIN	10MIN	15MIN	30MIN	1HR	2HR	3HR	4HR	5HR	8HR	10HR	20HR
9.60V	3284.6	2480.4	1687.0	1020.8	581.0	338.6	249.1	194.0	159.7	112.9	102.0	54.9
10.20V	3025.5	2283.1	1577.5	1011.6	545.9	323.5	242.4	188.9	125.5	110.4	99.5	53.5
10.50V	2977.0	2218.7	1516.5	1004.9	528.4	316.0	236.6	185.6	154.7	109.5	97.8	52.8
10.80V	2938.5	2160.2	1459.7	1002.4	514.1	309.3	231.6	182.2	152.2	107.0	97.0	52.6
11.10V	2885.0	2089.2	1392.8	994.8	507.5	308.5	229.1	181.4	151.3	106.2	94.5	51.0

Email: sales@biaf.com ISO 9001 :2008 Website: www.biaf.com VR070110

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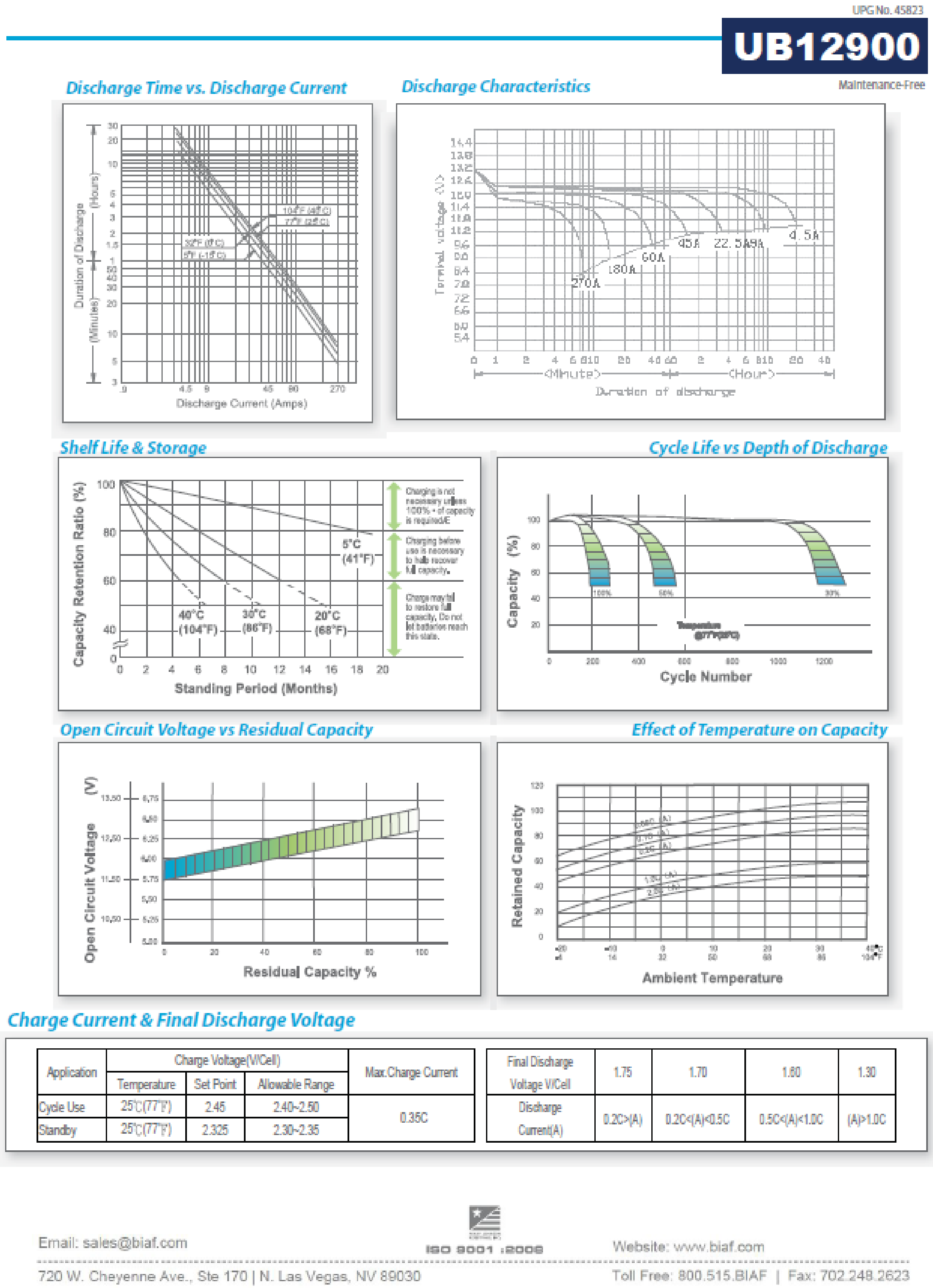
Figure 15: UB 12900 Battery Specifications



UPG No. 45823

UB12900

Maintenance-Free

Charge Current & Final Discharge Voltage

Application	Charge Voltage(V/Cell)			Max.Charge Current
	Temperature	Set Point	Allowable Range	
Cycle Use	25℃(77℉)	2.45	2.40~2.50	0.35C
Standby	25℃(77℉)	2.325	2.30~2.35	

Final Discharge Voltage V/Cell	1.75	1.70	1.60	1.30
Discharge Current(A)	0.2C>(A)	0.2C<(A)<0.5C	0.5C<(A)<1.0C	(A)>1.0C

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Figure 16: UB 12900 Battery Charge/Discharge Characteristics

Appendix B. Design Methodology

Analysis of the electrical system was utilized to determine the optimal system to put in place. The team of electrical engineers analyzed the needs of the village and researched the various types of generators. Originally, it was thought tha tthe best approach was to generate DC voltage and connect right up to the make-shift solar panel system the village already has, and that way the least impact could be made on the village. However, in addressing Dr. Shaban and Dr. Taufik, it was realized that for even a 4kW load, the best approach would be to use an AC generator, mostly because

DC generators are not widely used for high-power operations and would be massive both in size and cost for the system. Next to decide is what type of AC generator to use, with the choices consisting of sychronous or induction. Outlined in the table below is the summary of the benefits of using each machine, as found in Electric Machinery Fundamentals [7] and Babu and Mohanty [8].

Synchronous AC Generator	Induction AC generator
Higher Cost	Lower Cost
Higher Efficiency	Lower Efficiency
Frequency directly dependent on RPM	Lagging Power Factor (Needs compensation capacitance circuit)
Excitation from rectified output	Frequency less dependent on RPM
	Requires separate excitation

Table 5: Generator Comparison

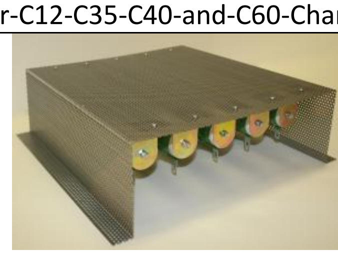
Now that it is determined that AC generation is best suited for the system, power distribution is designed. Initial concerns revolved around the system's ability to handle varying RPMs of the generator and as the wet and dry season affect the flow of the river. However, this was solved by implementing additional power electronic components, taking the AC generated and rectifying it to a constant DC voltage, and then inverting it back to the correct AC voltage with the 50Hz frequency needed and proper voltage step up to transmit 2km. Though this does add complication to the circuit design and more components which reduce reliability, the benefits far outweigh the cost.

The turbine is now free to vary in RPMs because the frequency of the output AC voltage does not matter as it is converted to DC regardless. Most promising, the entire system is now much for efficient and effective at utilizing its full potential, because the DC voltage portion of the circuit will also contain a controller to a charging battery bank.

Now, when less energy is required by the load than is produced, the battery will charge. If more energy is required by the load than the generator alone can produce, the battery will be utilized and output the additional power necessary.

Appendix C. Parts List and Cost

Power Bright 1100W Inverter 220V 50Hz	 $108 http://www.voltagetransformers.com/products/Power-Bright-12V-DC-to-AC-1100-Watt-Power-Inverter.html
150A 3 Phase Rectifier	 $35 http://www.amazon.com/Phase-Diode-Bridge-Rectifier-MDS150A/dp/B008F162KS
Permanent Magnet AC Synchronous Generator Motenergy's ME1016 PM Generator	 $149 www.motenergy.com
Motenergy's ME0903 Pelton Water Wheel	 $60 www.motenergy.com

12V UB12900 Battery(4)	 4 x $190 =$ 760 http://www.altestore.com/store/Deep-Cycle-Batteries/Batteries-Sealed-Agm/Universal-Ub12900-12V-90Ah-20Hr-Sealed-Agm-Batt/p2004/
Schneider Xantrex C60 Charge Controller	 $140 but Ian works for Schneider Electric and they gave us one for the project. http://www.schneider-electric.com/site/home/index.cfm/ae/
Xantrex Digital Display Faceplate	 $85 http://www.altestore.com/store/Charge-Controllers/Solar-Charge-Controllers/PWM-Type-Solar-Charge-Controllers/Xantrex-Solar-Charge-Controllers-PWM/Accessories-for-Xantrex-PWM-Charge-Cntrl/Xantrex-CM-Digital-Display-for-C12-C35-C40-and-C60-Charge-Controllers/p2082/
12V 1200W Diversion Load	 $102 http://www.windynation.com/products/accessories/dump-loads/12v-1500w-dump-and-diversion-load-system
1000W 2:1 AC Transformer	 $50 http://www.amazon.com/Goldsource-STU-1000-Voltage-Transformer-

	Converter/dp/B0022TVX2Q/ref=sr_1_4?ie=UTF8&qid=1369381304&sr=8-4&keywords=transformator+220v+to+110v
80A Fuses	10 x $2 = $20
AWG #6	$1.07/ft @ 60ft = $64.20 Home Depot

Appendix D. Analysis of Senior Project Design

Thailand Micro Hydropower Project Analysis

Functional Requirements: This project is designed to produce power utilizing the energy of the river. The power will be used to supply a village enough reliable power to run lights so children can do homework and some appliances.

Primary Constraints: Major constraints for our project is that we don't have solid verifiable information logistically yet. We estimations for flow rate and height of the river, but without solid definitions of each it is difficult to design the turbine system to output the necessary power. Another constraint is that, though we want to make this project as sustainable by the people of the villages as possible, it is difficult to tell what materials are readily available to them. Luckily, another team from Engineers Without Borders will be there in December 2012 to evaluate the situation and report back hard numbers for use in our teams calculations.

Economic: Currently in Thailand and especially in the villages this system will go into, coffee is a booming business. Therefore, we will be sure that our hydropower project does not hinder the growth of the coffee industry in the area and instead only serves to foster it. Because the system is highly sustainable and utilizes a renewable form of energy, we don't have to worry about a big environmental effect. Part of designing the system will focus on being sure that as much as possible, all water taken out of the river will be returned. The village currently uses it's own solar panel for power, so this system will not make them money or cost them money. If all the grants our team applied for are given, the team would build the turbine system and possibly purchase the generator here to test it. Then it would be shipped to Thailand and put together by a team with EWB, who would purchase the rest of the system and is a funded program. The hope is that at least the turbine will be completed by the end of winter quarter of testing. Most of the cost will be incurred here, so we will know if we need to apply for additional grants by this time. This entire project is going purely to benefit the people of these villages in Thailand. We as a team expect nothing back monetarily in hopes of raising the standard of living in the villages. It will not be manufactured on a commercial basis, though our hope is that the designed system we utilize could be picked up by future teams and placed in other areas of need.

Environmental: The main environmental impact of this system is on the river. This is where power is drawn and and used in the turbine system. The river also signifies the largest source of life for the villagers, in that it is their source of agriculture and business. For this reason, it is critical for our design to return as much water back to the river as possible and only redirect the minimal amount of water into our system to get the output desired and no more.This river not only provides food but also water and provides the necessary elements need for the continually growing coffee business. There will have to be a grate on the redirecting pipe from the river to be sure no fish are taken from the river. Other than that, the overall system is not extremely large, so no other species will be affected.

Manufacturability: A main issue in manufacturing a micro hydropower system is creating the housings for both the generator and turbine. Then making sure the coupled shaft to the turbine can operate in a safely and secure fashion.

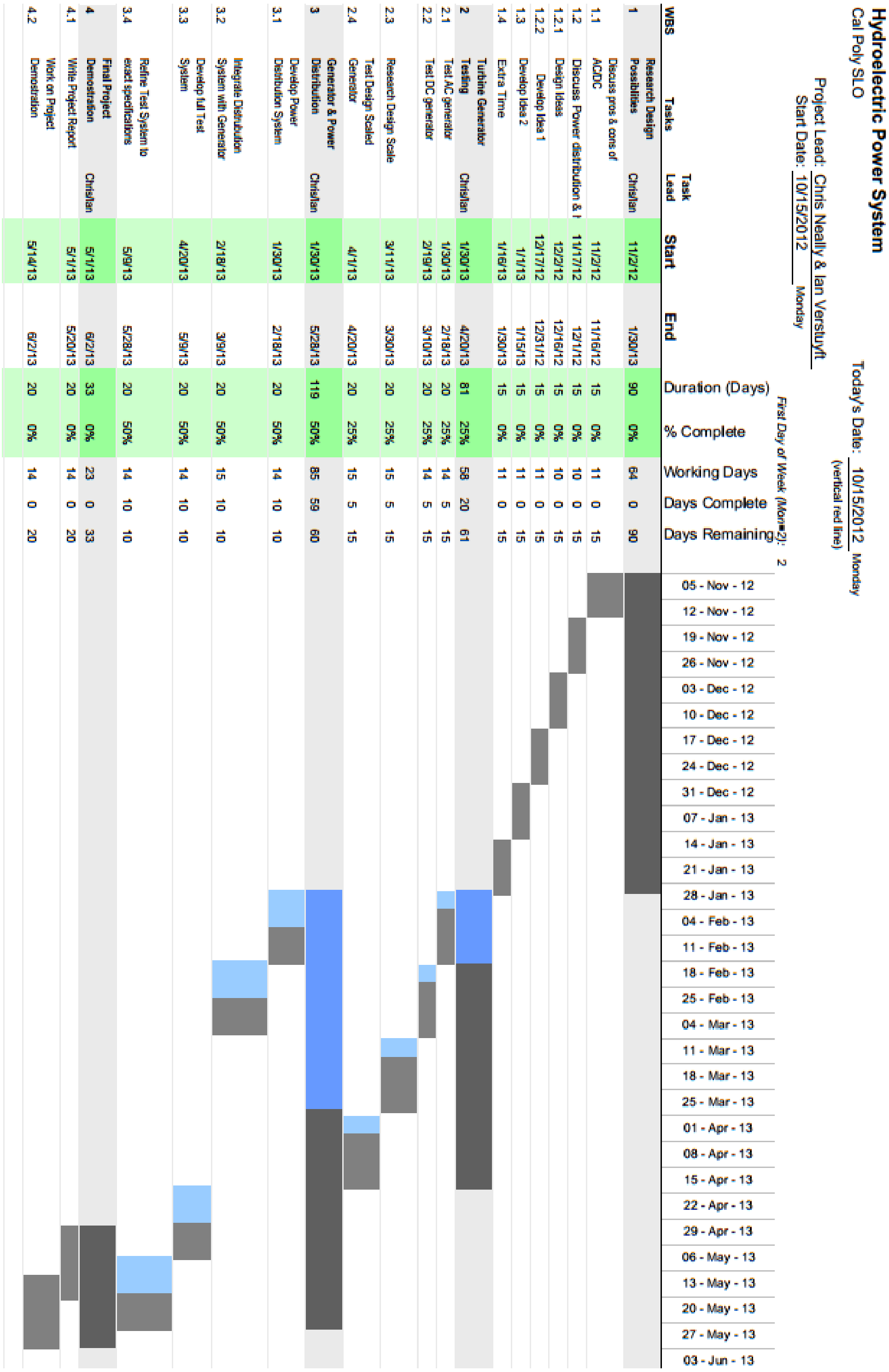
Sustainability: Maintaining the device may prove to be difficult based on just the instructions provided, so we will have to rely on somewhat constant EWB trips to Thailand to help with repairs. However, the document will provide basic instructions for quick fixes. Entire components would have to be replaced and the whole system redesigned if upgrades are needed, which would be a difficult task. But, an end goal is that with this village receiving free power, eventually the government will want to step in hook them up to the grid, providing vastly more power to the village.

Ethical, Health, and Safety: The villagers must be trained properly in order to ensure safety while using. Our design must provide many circuit breakers and other fail-safe devices to be sure that no one is harmed in using our project, even if they are using it incorrectly. Because it is high power, it is a relatively dangerous project and that much be taken into account in our design. However, this should provide the necessary power to the village so that the children can study and the people can be more productive with reliable power at night.

Social and Political: This project will benefit the villagers directly, providing them a chance to improve their quality of life. It will give hope to their children of receiving the full benefits of education. Reliable power to the village will give them an aspect of life that they currently do not have, and greatly improve their living situation. Socially, this will make the village more desirable to live in and ultimately increases its chance to thrive. The village also may make noise politically, as other villages realize their own need for reliable power. Indeed, the Thailand government may realize the usability of hydropower as a solution to most of their power needs, as the country is covered in steep mountains and many rivers. Because EWB is a nonprofit organization, we don't need to worry about monetary returns from the investment. Again, this entire project is done to benefit the villages in Thailand and not for the team members or EWB at all. Our hope is that the villagers' lives are vastly benefitted by our project and we can play a part in their own growth.

Development: During our testing in the power lab we learned how to use a Variable Frequency Drive(VFD) to run an induction motor at different speeds based on the input frequency. As we predicted, we found that loading the generator down causes the speed to drop dramatically. In the Fluids lab, the turbine runs at 687 RPM because that is where the system stays at the Bulk setting of 14.9V. We learned a lot about how the controller diverts excess power from the system to the diversion load. Now that we understand the controller, given the right circumstances we would even want to experiment with coding our own micro-controller to the same specifications as the Xantrex.

Appendix E. Scheduling & Time Estimates



WBS	Tasks	Task Lead	Start	End	Duration (Days)	% Complete	Working Days	Days Complete	Days Remaining
1	**Research Design Possiblities**	Chris/Ian	11/2/12	1/30/13	90	0%	64	0	90
1.1	Discuss pros & cons of AC/DC		11/2/12	11/16/12	15	0%	11	0	15
1.2	Discuss Power distribution & I		11/17/12	12/1/12	15	0%	10	0	15
1.2.1	Design Ideas		12/2/12	12/16/12	15	0%	10	0	15
1.2.2	Develop Idea 1		12/17/12	12/31/12	15	0%	11	0	15
1.3	Develop Idea 2		1/1/13	1/15/13	15	0%	11	0	15
1.4	Extra Time		1/16/13	1/30/13	15	0%	11	0	15
2	**Turbine Generator Testing**	Chris/Ian	1/30/13	4/20/13	81	25%	58	20	61
2.1	Test AC generator		1/30/13	2/18/13	20	25%	14	5	15
2.2	Test DC generator		2/19/13	3/10/13	20	25%	14	5	15
2.3	Research Design Scale		3/11/13	3/30/13	20	25%	15	5	15
2.4	Test Design Scaled Generator		4/1/13	4/20/13	20	25%	15	5	15
3	**Generator & Power Distribution**	Chris/Ian	1/30/13	5/28/13	119	50%	85	59	60
3.1	Develop Power Distribution System		1/30/13	2/18/13	20	50%	14	10	10
3.2	Integrate Distrubution System with Generator		2/18/13	3/9/13	20	50%	15	10	10
3.3	Develop full Test System		4/20/13	5/9/13	20	50%	14	10	10
3.4	Refine Test System to exact specifications		5/9/13	5/28/13	20	50%	14	10	10
4	**Final Project Demostration**	Chris/Ian	5/1/13	6/2/13	33	0%	23	0	33
4.1	Write Project Report		5/1/13	5/20/13	20	0%	14	0	20
4.2	Work on Project Demostration		5/14/13	6/2/13	20	0%	14	0	20

Figure 17: Gantt Chart