Portable Nano Hydro Generator for the DC House Project

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Abstract

This Senior Project entails the design and testing processes of the Portable Nano Hydro Generator for the continuing DC House Project. No natural resources should go unused, especially in developing countries where they are found in abundance. Small streams in particular have potential to further Professor Taufik's DC House Project that will provide electricity to 1.6 billion people in the world without access to electricity upon completion. The goal of this project is to create a small portable generator that utilizes the discharge from small streams and convert it into useable electricity that could charge a car battery as an example.

Chapter 1: Introduction

In 1600, a man by the name of William Gilbert discovered that by rubbing amber together with jet would cause an attraction with surrounding metal particles, which he called "electrica," what is known today as electricity [1]. Electricity is a very dependable source, that mankind relies on for day-to-day functions. Without the use and production of electricity, people would not be as technologically advanced as they are today. Although it is rare for a person to go throughout the day without using electricity to do their daily functions, there are people all around the world that do not have easy or affordable access to its bountiful worth. Those that are in developing countries deal with the struggles of having to do their daily functions without it. Satisfying such a demand requires a small yet substantial amount of electricity going towards a wider population. Renewable energy may be the solution to answer this demand, and the international community is beginning to realize this as well. According to Figure 1-1, renewable energy made up a marginal chunk of global energy in 2010.

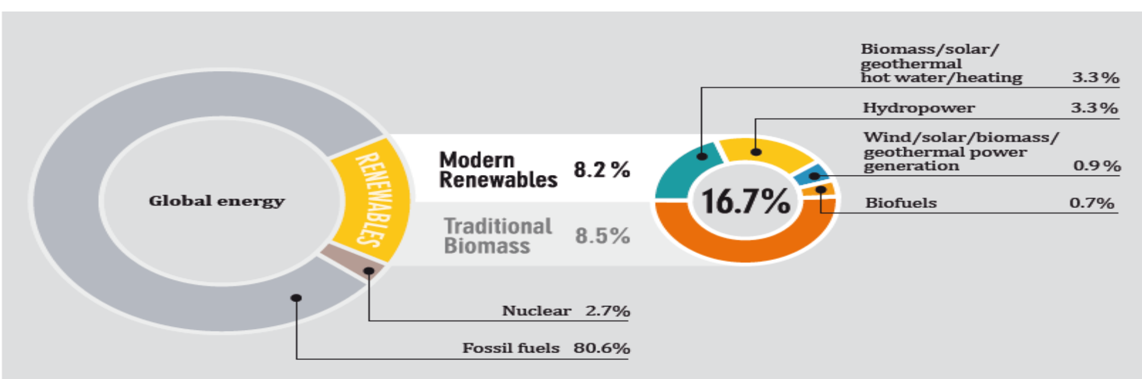


FIGURE 1-1: RENEWABLE ENERGY SHARE OF GLOBAL FINAL ENERGY CONSUMPTION IN 2010 [2]

Renewable energy seems to be the best solution to helping developing countries. Right now many developing countries are using only fossil fuels to generate energy. Using such fuels is a struggle for them, and it is only getting worse. Developing countries should try to move from fossil fuels to renewable energy as America has been doing. For years, America has been trying to transition from fossil fuels to renewable energy, with the pros heavily outweighing the cons, and other countries have been following suit according to Figure 1-2. The benefits from using renewable energy are simply that it is more efficient, it is a sustainable form of resource and it is safe for the environment. Over time, humanity has discovered and explored several new ways to efficiently utilize renewable energy types such as solar, wind, hydro, and vibration as well as others that are being discovered.

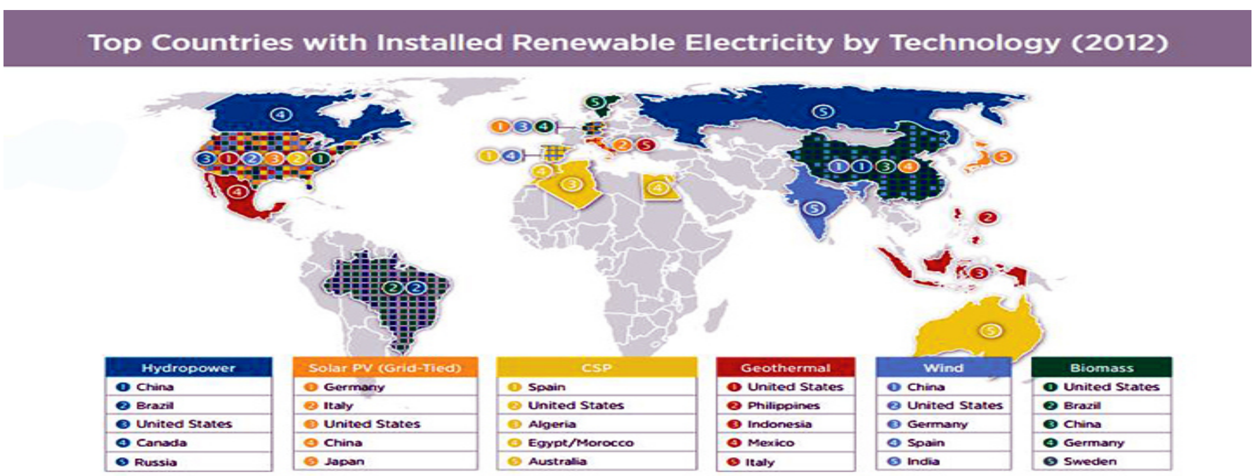


FIGURE 1-2: COUNTRIES WITH RENEWABLE ENERGY [3]

Hydropower, hydro-electricity, and hydropower generation are a few names given to renewable sources that utilize water flow as a means to produce electricity. The concept of using water flow as a means to power machinery has existed for centuries, from the era of Rome's great empire, to modern day hydropower, has lent a hand and has enabled civilization to function in the form of aqueducts, artificial canals, and water wheels. Even today, hydropower has produced the most energy when compared to other forms of renewable resources as Figure 1-3 shows. Today's most common form of hydropower relies on dams along with giant generators and turbines. Additionally, small-scale versions of these dams provide power to less than the average city's population. The scaling could even go down to personal home use and possibly further. Hydropower is seen as probably the best form of renewable energy as it converts about 90% of its energy to electrical energy. The difficulty in hydropower is the ability to harness this energy because the zones for development of dams are limited. However there is an abundance of smaller source of water. Knowing that there are many sources of water, a way to use that water could be through a hydro generator. Developing a small-scale hydro generator that utilizes kinetic energy from water motion and converts it to electrical energy would be the solution.

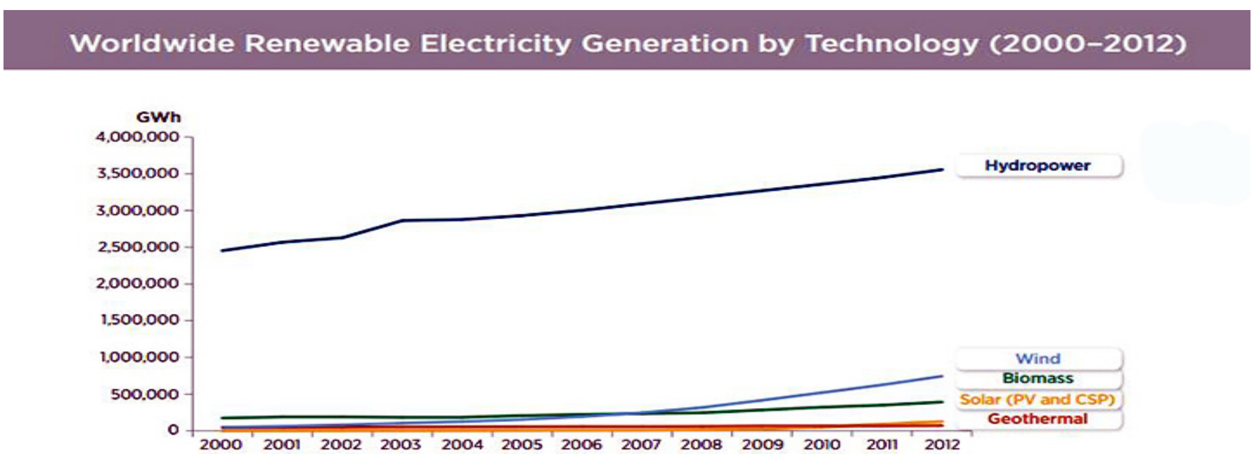


FIGURE 1-3: HYDROPOWER IN COMPARISON TO OTHER RENEWABLE ENERGY [4]

Chapter 2: Background

2-1. DC House

The DC House is a house (displayed in Figure 2-1) that will provide electricity to those who are not connected to the electrical grid such as those who live in rural communities or islands. The project started in September 2010 with the goal of providing electricity through renewable sources of energy such as swing sets, merry-go-rounds, and solar power. The idea of the DC House is to provide power without needing to go through the many intermediate steps required to provide electricity, thus making the process more efficient and less costly for the consumer.

FIGURE 2-1: DC HOUSE IN SPRING 2013 [5]

2-2. Portable Nano Hydro Generator

In common practice, hydropower plants require heavy machinery and building material. It requires housing for the generator and transformer as well as a reservoir to store the water needed to provide electricity. The reservoir, housed behind a dam, provides the intake for the turbine. A control gate inside of the dam controls how much water passes through the gate. Water that makes it past the gate, known as penstock, turns the turbine in a chamber under a powerhouse, where all the electrical components are stored. The turbine then turns the generator. Electricity created from the generator goes through a transformer to create useable electricity that is fed out of the powerhouse and into nearby Power Lines. Any excess water is removed from the system and is known as Outflow. Figure 2-2 illustrates the above process. For this project, the goal is to design something similar to a hydropower plant on a smaller scale, providing power to a 12 Volt lead-acid car battery as opposed to power lines.

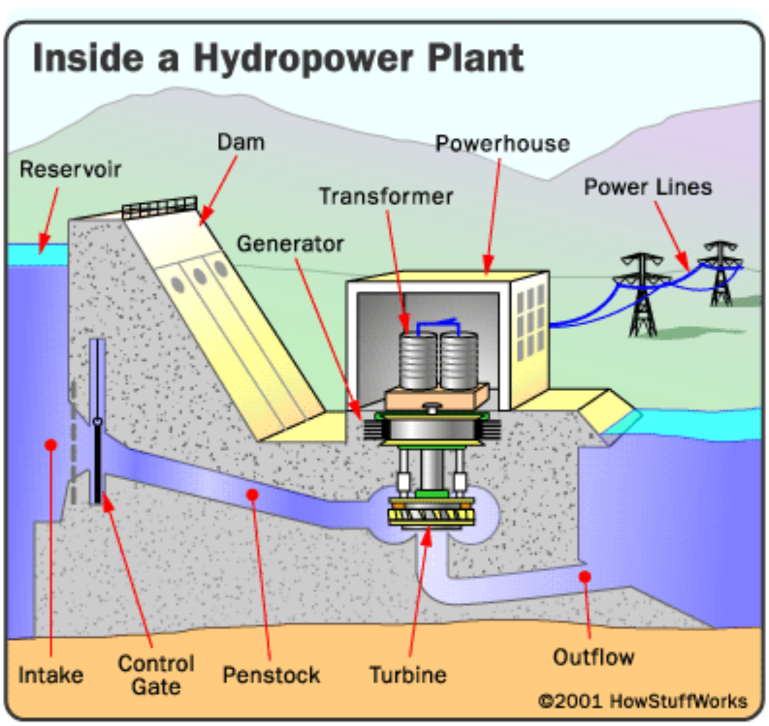


Figure 2-2: Diagram Depicting how Hydropower Plants Generate Electricity [6]

Prior to development on this iteration of the Portable Nano Hydro Generator project, another team worked on this same project in the Fall Quarter, 2013. Looking at the report, the previous team made some advancement when working on their project. They were able to figure out how to charge a Lead-acid battery and choose a charge controller and converter to help implement the plans for charging the battery [7]. All of their preparation and component choices were to properly charge a 12 Volt battery, which in turn will help with completing their project. The main problem the prior group had was insufficient knowledge of what was needed to complete their project. One issue they said they had was choosing too many converters. In order to compensate for the output voltage, whether a high output voltage or a low output voltage, they got two boost converters in order to output the necessary output voltage needed to charge the car battery. They later discovered that if they got a fly back converter first they would be able to boost or buck any output voltage they received all based on the transformer windings. This would result in not having to buy multiple converters for their project. In regards to the transformers, they felt they needed to buy the transformers on their own as opposed to making their own that worked specifically for their design plans. One of the last issues they had to deal with was the overall final design of the Portable Nano Hydro Generator. They were working separately from a team tasked with helping them choose the turbine and flotation device in order to help choose the proper motor and have the complete product.

In order to solve the problems that the previous group had, it is important to review what they did and plan accordingly. Learning from what the other group did and from initial designs for the project, the decision was made to use either a small boost converter or a fly back converter to account for whatever output voltage would come out of the generator. If the generator produces a voltage less than the required amount to charge a 12 Volt battery, then the boost or fly back will boost the voltage, and if greater than what is needed, the fly back converter will step down the voltage while the boost converter should be able to adjust and account for higher input voltages without changing the output voltage. This group also has some experience in selecting and designing transformers so that one may be effectively and cheaply designed for whatever desired output voltage. One other difference is that the project is solely comprised of one team of Electrical Engineers instead of two teams working on the same project. Careful calculations were made to select the proper generator that will charge the battery. As for the turbine, it was decided that creating a miniature Pelton water wheel as depicted in Figure 2-3 from spare parts would be the best approach, something that the previous group did not have the luxury of doing when designing their project. The wheel will connect to the generator and convert water motion to electrical energy.

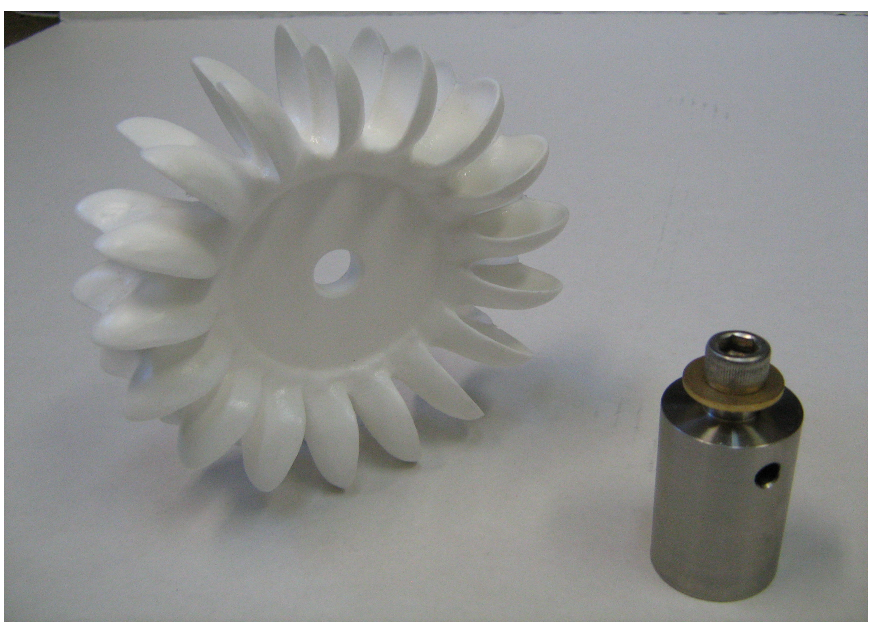


FIGURE 2-3: A PELTON WATER WHEEL USED IN A DIY MICRO HYDRO GENERATOR [8]

References and design ideas will include several examples of what people have done to make water wheels for hydro generators [8]. In starting the project anew, a new float will be constructed to fit the new wheel design. By the end of this project, this group will have made sure that all shortcomings of the previous group are resolved.

Chapter 3: Requirements and Specifications

3-1. Beneficiary Needs Assessment

The beneficiaries need an affordable and easy source of power, and the Portable Nano Hydro Generator provides the solution for that. They need a generator that can give them power for necessities such as lighting. This project targets beneficiaries in developing countries for those less fortunate to live without electrical power. Table 3-1 catalogs the marketing requirements and engineering specifications that will be kept in mind during the design and testing phases of the project.

Table 3-1: Engineering Specifications And Marketing Requirements for Nano Hydro Generator

Marketing Requirements	Engineering Specifications	Justification
1,3,4	The generator connects to a portable rig.	Mobility allows the beneficiaries to move the generator and load with ease from the DC House to the stream. [9]
5,7,9	The non-electronic components used should be robust, replaceable and easily found.	The device should give beneficiaries peace of mind with regards to replacing non-functioning parts. Materials should be commonplace yet durable and affordable to emphasize sustainability.
3,4	The device requires only one person to setup and operate with ease.	It should not have complicated or unnecessary controls or inputs. [10]

5,8	The generator floats on water and made with waterproof material.	Since the device needs stream water to function, it also needs materials and a design that allows it to run properly in water without damaging the system. This also allows the device to function with fluctuations in water level.
2	The device needs to provide voltage of ~14.6V and have a peak power of 20 W. [11]	The device needs to have enough power so that those of developing countries can use it, for lighting in their homes.
7,9	The device should not cost more than $200.00 in order to make it affordable for everyone.	Given the device's function, the cost needs to be low compared to similar devices.
1,6	The device should weigh at most 20 lbs.	The user should have little to no difficulty in carrying the product to and from the DC House.
2,5,8	The device needs to be able to function in the range of water velocity from 1.3 to 5 ft/s.	The device needs to withstand the discharge and pressure of a small river stream, irrigation canal, or creek.
1,3,4,6	The dimensions for the device should not be any larger than 3 ft x 3 ft x 2 ft .	The device size should fit easily inside the DC House for storage.
8	The device should implement an electrical shock preventive design	Using the generator in water likely increases the likeliness of electrical shock.

Marketing Requirements

1. **Portable**
2. **Generates a useful amount of electricity**
3. **User Friendly**
4. **Operable by a Single Person**
5. **Durable**
6. **Light Weight**
7. **Affordable**
8. **Safe to use**
9. **Sustainable**

3-2. Requirements and Specifications:

The marketing requirements were determined from the beneficiaries' needs, which in turn determined the engineering specifications. In order for the generator to meet the needs, the device needs mobility. The DC House project, a relief house, incorporates the Portable Nano Hydro Generator, and portability plays a part in it. The device needs to be easily repairable and/or replaced, which means that the components used will need to be commonly found. The generator must generate a useful amount of electricity to fulfill its purpose. The electricity generated will depend on the velocity of the water. The device should have a user-friendly design for the generators because the beneficiaries have limited resources for setup and use of the generator. The generator should need no more than a single person to operate it. Since the generator should not break during or while not in operation, it requires durability as a sustainable specification. The generator should not weigh very much, as some of the beneficiaries include children. The product should not cost much, as the beneficiaries have limited monetary resources. The generator should emphasize safety. The product should be waterproof due to the nature of the project. The product should be able to handle obstructions and debris caught in the moving water that could damage components. The device should withstand minor weather changes and should not be operated under extreme conditions.

3-3. Building Preparations

Before building the Portable Nano Hydro Generator, research must be conducted in order to determine what parts to use. Though it is important to select electrical components that are the most capable and optimal for the task at hand, design considerations of the mechanical portions must not be neglected either. It's also important to note what material for the turbine and the float will be the most durable yet sustainable. Water resistance of sustainable materials for the turbine must also be taken into account. Once the proper research has been done, the next step would be purchasing the material and components and making the device in parts for individual testing.

Chapter 4: Design

4-1. Basic Components

When designing the Portable Nano-Hydro Power Generator, the block diagram shown below in Figure 4-1 was kept as a constant. This system block diagram minimizes power losses and component count and promotes greater efficiency while staying consistent with DC Power's linear nature.

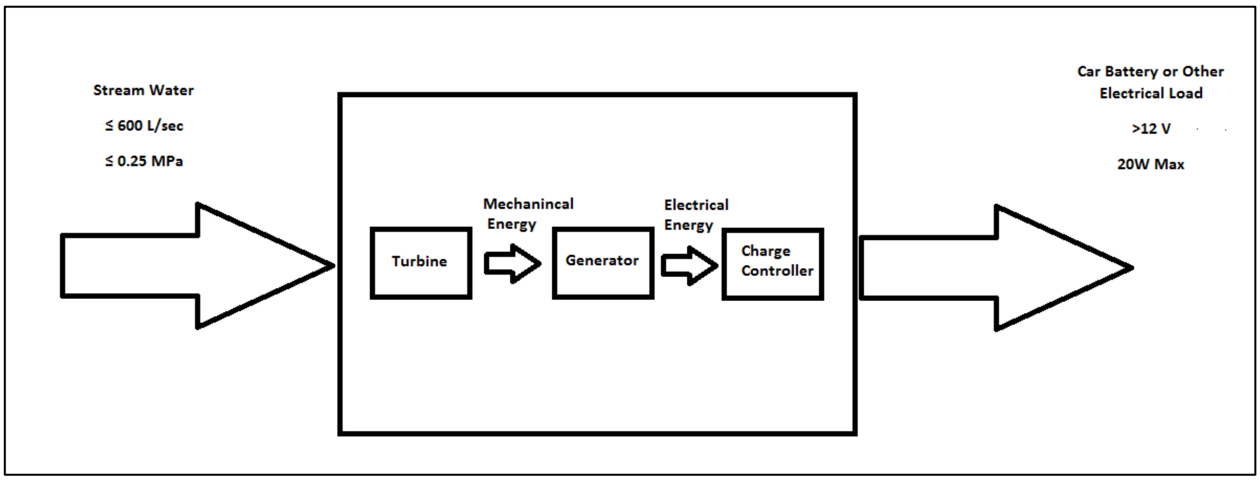


FIGURE 4-1: PROPOSED BLOCK DIAGRAM OF PORTABLE NANO-HYDRO POWER GENERATOR

4-2. Generator Calculations and Selection

The torque calculations in Table 4-1 were used to link the actual water stream flow data [12] with the appropriate torque. This torque would be looked for when choosing a generator. The red text indicates the minimum flow rate encountered in this irrigation canal that was used in selecting the generator.

Table 4-1: Torque Calculations

Water Velocity m/s	Water Velocity ft/s	Cross-Area Assumption Based on center depth m^2	Flow Rate m^3/s	Flow Rate kg/s	Torque N-m	Torque lb-ft
0.26	0.853018	0.5776	0.150176	150.176	2.975286912	2.194459007
0.2	0.656168	0.4761	0.09522	95.22	1.4511528	1.070297086
0.18	0.590551	0.7056	0.127008	127.008	1.742041728	1.284849078
0.16	0.524934	0.4096	0.065536	65.536	0.799014912	0.589323154
0.16	0.524934	0.2116	0.033856	33.856	0.412772352	0.304445262
0.17	0.557743	0.09	0.0153	15.3	0.1981962	0.146182015
0.24	0.787402	0.9216	0.221184	221.184	4.045012992	2.983448474
0.13	0.426509	0.2025	0.026325	26.325	0.26077545	0.192338101
0.22	0.721785	1.44	0.3168	316.8	5.3108352	3.917071023

0.16	0.524934	0.2116	0.033856	33.856	0.412772352	0.304445262
0.15	0.492126	0.64	0.096	96	1.09728	0.809312195
0.19	0.62336	0.3364	0.063916	63.916	0.925375848	0.682524155
0.46	1.509186	0.5184	0.238464	238.464	8.358640128	6.165016577
0.24	0.787402	0.1764	0.042336	42.336	0.774240768	0.571050686
0.18	0.590551	0.3844	0.069192	69.192	0.949037472	0.693336057
0.19	0.62336	0.1936	0.036784	36.784	0.532558752	0.392795176
0.32	1.049869	0.3364	0.107648	107.648	2.624888832	1.936018646
0.27	0.885827	0.3025	0.081675	81.675	1.68038145	1.239385753
0.32	1.049869	0.4096	0.131072	131.072	3.196059648	2.357277873
0.2	0.656168	0.5476	0.10952	109.52	1.6690848	1.231053772
Equations and Conversion Factors used:						
Water Velocity: From Iraq Canal Data [1]						
Cross-Area Assumption = (Center Depth)^2; Center Depth obtained from Iraq Canal Data						
Flow Rate [m^3/s] = Cross-Area Assumption [m^2] * Water Velocity [m/s]						
Flow Rate [kg/s] = flow rate [m^3] * 1000						
Torque [kgm^2/s^2] = 0.5*water velocity [m/s]*flow rate [kg/s]*wheel radius [m]						
0.3048 m = 1 ft						
1 N-m = 0.7376 lb-ft						

Calculating the RPM also helped in determining the expected water flow rates that that the device will operate under. The red text indicates what we would expect at a power of three watts, which should be sufficient to charge a battery.

Table 4-2: RPM Calculations

Power W	Ang. Vel. Rad/s at Desired Water Velocity	Ang. Vel. RPM at Desired Water Velocity
1	13.55725724	129.462181
2	27.11451449	258.924362
3	40.67177173	388.3865431
4	54.22902897	517.8487241
5	67.78628622	647.3109051
6	81.34354346	776.7730861
7	94.9008007	906.2352672
8	108.4580579	1035.697448
9	122.0153152	1165.159629
10	135.5725724	1294.62181
11	149.1298297	1424.083991
12	162.6870869	1553.546172
13	176.2443442	1683.008353
14	189.8016014	1812.470534
15	203.3588587	1941.932715
16	216.9161159	2071.394896
17	230.4733731	2200.857077
18	244.0306304	2330.319258
19	257.5878876	2459.781439

Equations and Conversion Factors used:
$P = n\tau$
1 Rad/s = 9.54929 RPM

Since the design was being built from scratch (aside from the 12 V lead-acid battery), research was required in determining the generator that would best suit the environment that the project would ideally be used. Based on several recorded data points from an Iraqi Canal and after getting approval for the smallest water velocity obtained by the canal, the ideal maximum torque for the generator was calculated, Table 4-1. Knowing that as well as the requirement of supplying three watts to the car battery, the angular velocity in RPM was found, as shown in Table 4-2. With those specifications in mind, the Pittman Model 9434 DC Gear Motor (DC motors and generators are the same) was purchased and ordered. The specifications from the calculations were close to those of the Gear Motor, and at maximum torque for the desired water velocity, the motor would produce close to 5 amps as seen in Figure 4-2, charging the 20 Amp-hour car battery in four hours. The only downside to this particular generator was the relatively short length of the shaft which means that the turbine cannot go out as far along the shaft.

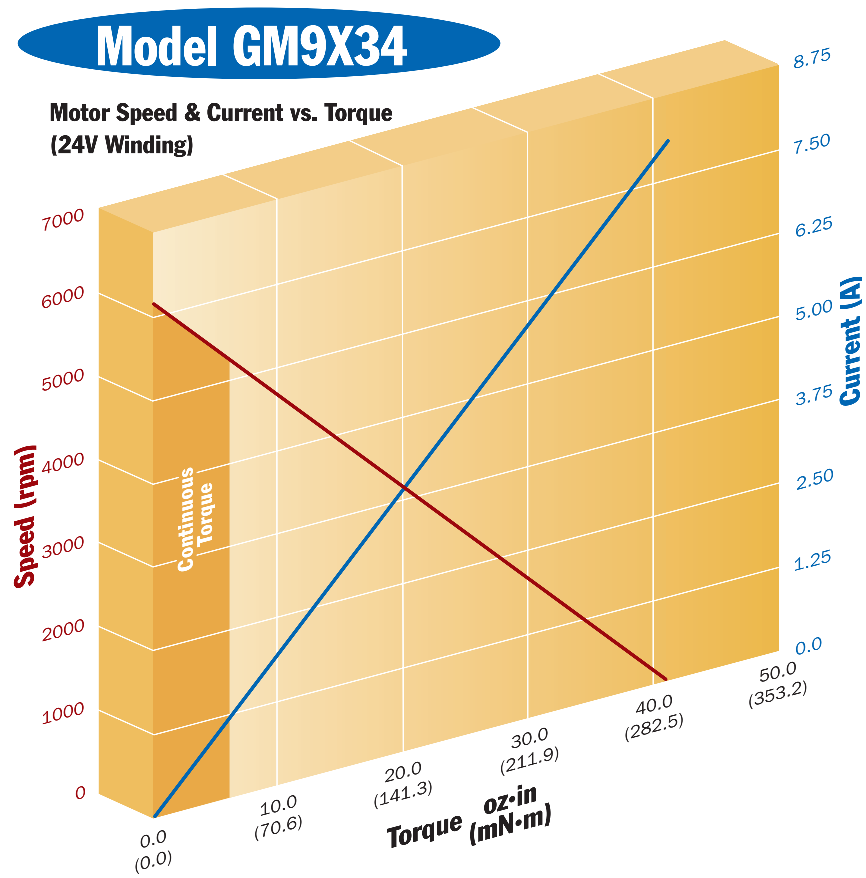


FIGURE 4-2: PITTMAN MOTOR DATASHEET TORQUE-SPEED AND TORQUE-CURRENT CHARACTERISTICS [13]

4-3. First Turbine

Before doing the calculations for the generator, the wheel design needed to be selected first. The wheel is the most important part of the design choice because no matter how efficient the electrical components may be, the entire system is only as efficient as its first component. The Pelton wheel was selected because in terms of calculations, it made finding the torque simpler since by design, half of the wheel is influenced by torque (thus the 0.5 in the torque calculations). Originally, the wheel was to be made using aluminum cans in order to promote sustainability and easy replacement, but due to the difficulty of welding aluminum to itself, a five-gallon bucket was used instead. The casing of the bucket was the material used for the fins while the lid of the bucket formed the base of the wheel. Using several wood screws to hold the cut out bucket parts onto the outer part of the lid, the end product and current design of the turbine can be viewed in Figure 4-3. The direction of the fins was adjusted to better suit the rotation of the generator shaft for positive voltage. Two holes were made in the bucket lid in conjunction with two shaft collars and cotter pin to secure the shaft of the generator with the turbine. The fins were made such that the radius of the wheel would fit the radius used in the calculation (0.5 ft). The problem with the current design is that the fins are not uniform. Some of them are off-center or uneven in length or width, leading to non-uniform cross-sectional areas between the water and any given fin. Others are curved at a certain angle, thus the force of oncoming water against the water wheel would be lessened unless the water was coming at a favorable angle. The wheel was also not fully secured on the shaft of the generator, even with the shaft collars. The wheel would move around between the collars from time to time, another possible source of inefficiency. It is also possible that the material of the wheel is resisting the force of the water pushing against it. The wheel was also unintentionally designed as a Turgo-Pelton hybrid instead of a full Pelton wheel. However, after talking to Water Turbine Professor Jumonville of the Mechanical Engineering department, neither the Turgo nor the Pelton wheels are ideal for the case. Despite these shortcomings, the first turbine did produce results that would show the plausibility of this project.

FIGURE 4-3: PELTON WATER WHEEL DESIGN

4-4. Float

Initial design considerations for the float that would house the turbine and generator consisted of a five-gallon bucket with a hole at the bottom to allow for water to pass through and push the turbine along. However, the final and current design for the float can be seen in Figure 4-4. The reasoning behind this particular choice was the stability that the float offered since the floating parts consisted of two segments of PCV tubing equal in length, width, and weight. The steel bars used for support for the generator and turbine are placed evenly and are equidistant across the tubes from one another. The bars also help in fastening the float to four on-shore stakes via rope so that the oncoming current does not carry the float away. Each bar is close to the same length as the one opposite of it. The bars are held together via U-Strut spring nuts and 90 degree brackets. The steel bar that is standing up has a pipe clamp that would hold onto the generator, though the generator needed additional housing, which will be discussed at a later point. The clamp would be adjustable so that the wheel would be able to get enough coverage in the water. However, the float is so light that the first turbine had little to no contact with the water during initial tests, leading to a design change that will also be discussed later. It was also designed for head-on water, so the first turbine would not be ideal for the float either.

FIGURE 4-4: PORTABLE NANO HYDRO GENERATOR FLOAT

4-5. First Boost Converter

Charging the 12 V lead-acid battery provided by this project's predecessors requires a minimum voltage of 13.5 volts and a maximum of 14.5 volts. When determining the characteristics of the Pittman DC Motor, it became evident that the output voltage would be nowhere near either of those values. Given that at the ideal RPM the generator would produce 3 volts, a boost converter was selected to step up a minimum of 2.5 volts to an output between 3 and 25 volts. The boost converter in Figure 4-5 was set to an output of 14.25 volts to give some leeway in charging the battery. A flyback converter was also ordered and was rated at a minimum input of 3 volts to step up to a maximum of 35 volts. However, 3 volts seemed less likely than 2.5 volts, and though 2.5 volts was less than ideal in comparison to 3 volts in terms of charge time, the 2.5 V boost converter would at least ensure that the battery would still charge if the output voltage fell short of three volts. In future tests with this board, a diode will need to be implemented to ensure that current coming out from the battery as it charges up does not go back into the board and potentially break it.

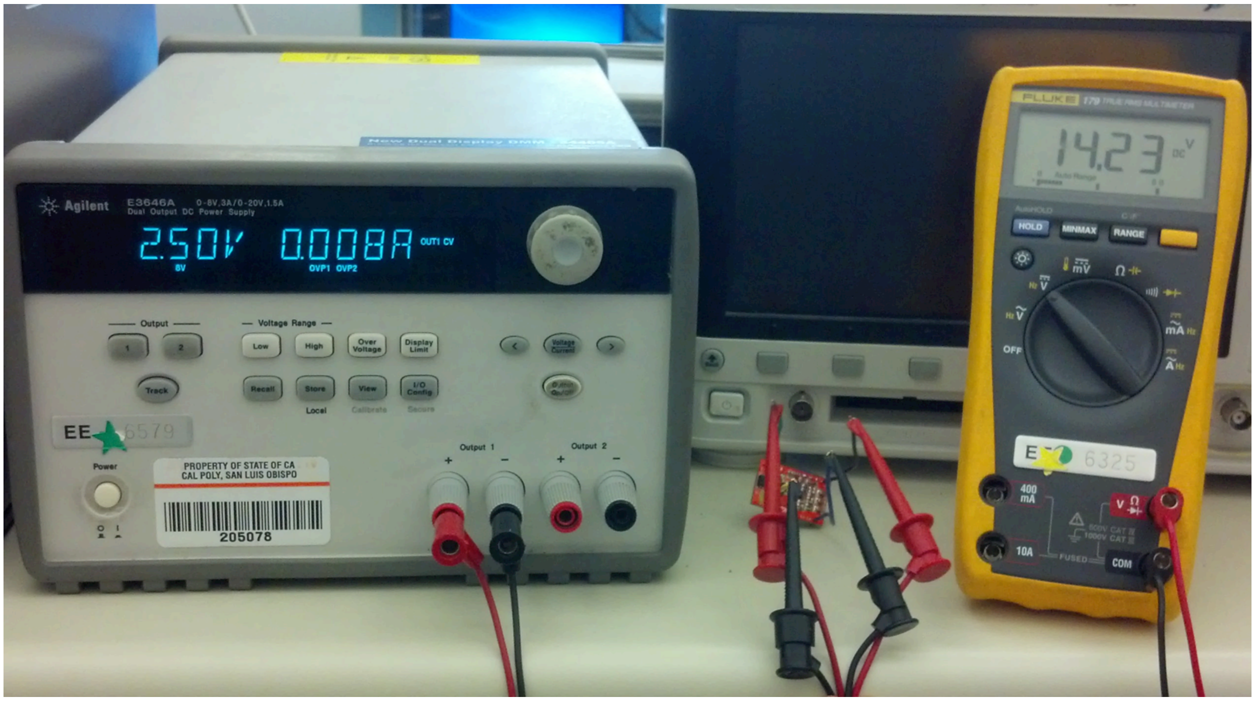


FIGURE 4-5: FIRST DC-DC BOOST CONVERTER

4-6. Second Turbine

As revealed during the first test at the San Luis Obispo Creek, the first turbine (though ultimately more efficient than the next one), when paired up with the current float design, did not come in full contact with the water and was therefore unable to turn much. After receiving feedback from peers and friends alike, the decision was made to make a second turbine, one with longer, flatter fins so that the oncoming water would come into more contact with the fins. The design was very much the same in that it used another five-gallon bucket for fin material and the lid of the same bucket as the wheel itself. This time, the fins were designed to be much longer than those of the wheel before it. The wheel did retain the problem of non-uniformity in the positioning and angle of the fins, and the radius of the wheel as well as the cross-sectional area had changed, requiring a change in calculations for the maximum torque at the desired water velocity. Those calculations however would end up proving to be fruitless as the equation used to calculate the torque no longer applied; as it appears in Figure 4-6, the wheel was no longer a Pelton wheel and did not follow the same torque equation as the first turbine (though in reality, the torque equation for the first wheel was never correct due to it being a Turgo-Pelton hybrid). It also had turned out that the fins were put on backwards, meaning that all voltage produced came out to be negative, though that was minor at worst so long as the leads were switched around when connecting to the boost converter or battery. In the end, the second turbine proved to be inferior to the original in terms of data gathered, though it did spark a change in the first wheel. It also would suit the current float design more than the first wheel unless the float was weighed down enough so that enough water would come in contact with the fins of the first wheel without getting the generator wet.

FIGURE 4-6: SECOND WATER WHEEL DESIGN

4-7. Generator Casing

Also revealed during the first test was the fact that the pipe clamp alone was not suitable for securing the generator. Bits of PVC piping were used to help fasten the generator during the first test, but even then, it was not fully secure. To compensate this while at the same time providing some electrical protection for the wires, a case was made for the generator out of PVC pipe. In Figure 4-7, the generator is fastened to the PVC pipe with the wires coming out of the other end of the pipe. The pipe clamp then fully secures the generator via the PVC pipe. This casing also made gripping the generator much easier in tests where bringing the float along was more trouble than it was worth.

Figure 4-7: DC Motor Casing

4-8. First Turbine Edit

Noticing that water was getting caught up in the cupped areas of the fins and wanting to expose more of the first turbine's fins to the oncoming water, the decisions were made to cut open the fins during the second test at the Hydraulics Lab so that it appears as it does in Figure 4-8. The output voltage increased slightly as a result of this change, though the wheel did wobble. However, this change also made it more evident that the wheel was not truly a Pelton wheel and that it performs best when the water is hitting the fins at an optimal angle.

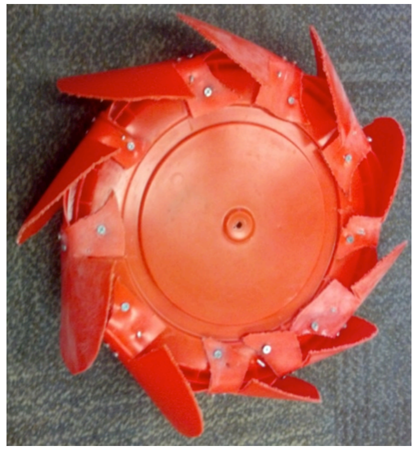


FIGURE 4-8: FIRST WATER WHEEL WITH OPEN FINS

4-9. Second Boost Converter

Though it was possible to charge the 12 V lead-acid battery given the results of the third test, it was not feasible to do so with the intended use of the float and two turbines. After doing testing at the Los Osos Creek, a second boost converter was ordered, one that would take between 0.02 volts and 0.4 volts and step it up to one of four set voltages of up to 5 volts via switches. The goal also changed from charging a 12 V 20 Amp-hour lead-acid battery to charging a 3 V 600 milliamp-hour lithium-ion battery. Charging the new battery required a minimum of 3.6 volts, and the new board allowed for an output of 4.1 volts. The new boost converter as seen in Figure 4-9 however needs to be calibrated with an adjustable voltage source, three ammeters, and three resistive loads, something that cannot be done without any of the previous equipment and would be near impossible if attempted prior to testing the board out in the field [14]. It also cannot handle more than 0.4 volts without putting the board at risk, so the water velocity cannot be too forceful if the Li-ion battery is to be charged without burning out the board.

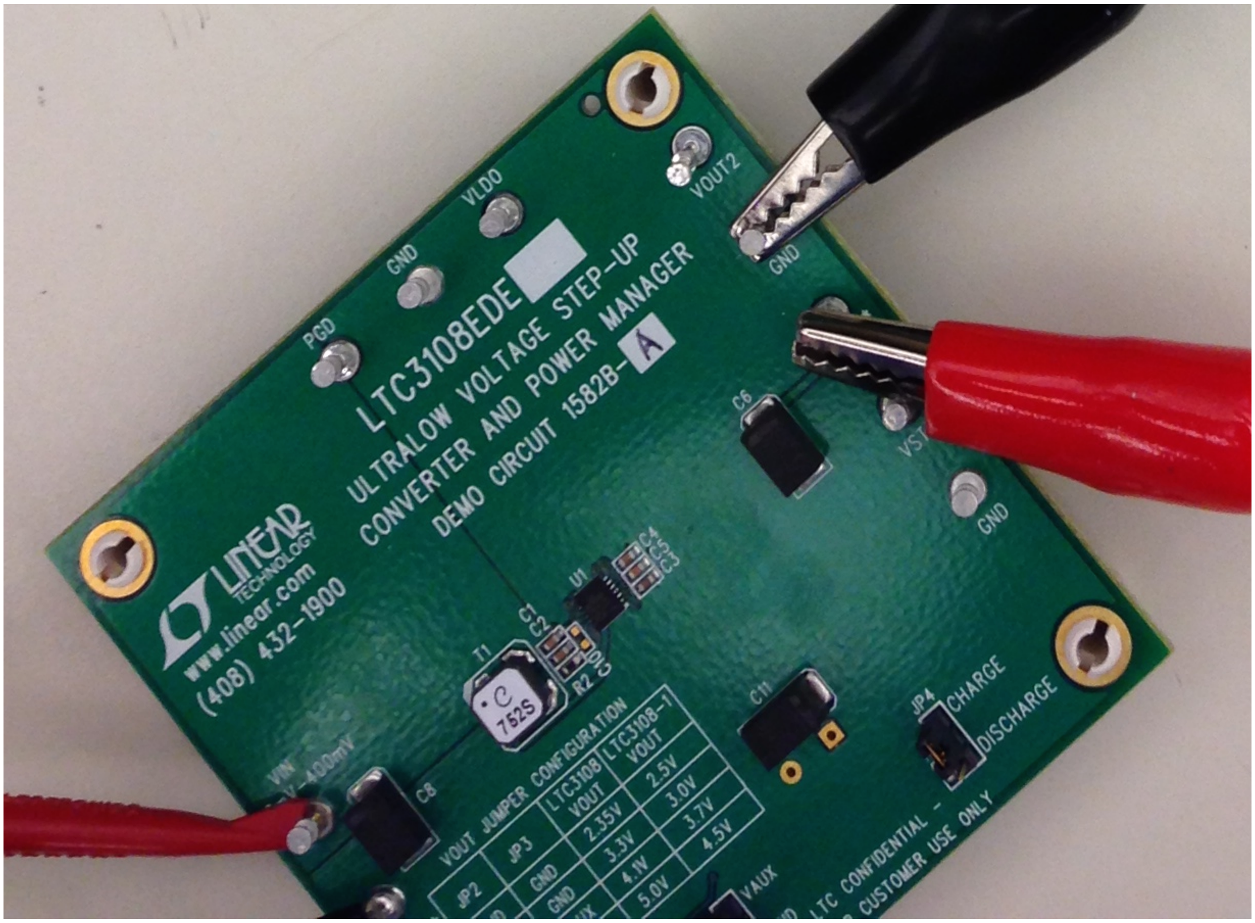


FIGURE 4-9: SECOND BOOST CONVERTER [15]

4-10. Final Product

The final product combines the float, the orange turbine with its fins open, the generator and turbine assembly mounted to the float, the demo board connected to the generator, and the battery connected to the board as it is in Figure 4-10. The demo board and battery will be kept onshore while the float, turbine, and generator will be placed in the middle of the moving water with stakes and rope holding the float still. Waterproof wires from the generator will connect to the board, supplying it with the voltage and current required to charge the battery.

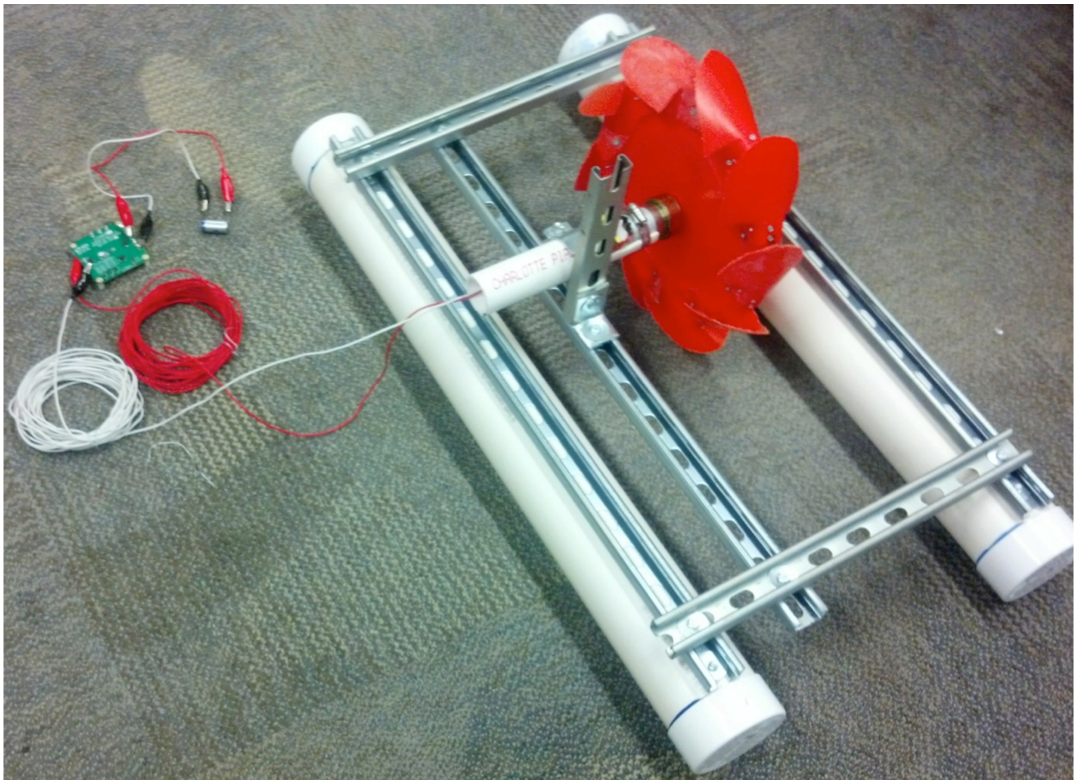


FIGURE 4-10: COMPLETE NANO HYDRO GENERATOR

Chapter 5: Testing

5-1. Motor Characterization

Characterizing the motor as a generator involved using an 18V cordless drill to spin the shaft of the motor with a voltmeter reading the voltage output. The RPM was measured with a tachometer. By placing small strips of tape on the nose of the drill and using the tachometer we determined the RPM of the motor was determined by placing four small strips of tape on the drill nose and using the tachometer to measure the rotation speed. The drill used could only be tested at two different points: at the lowest speed possible, 764 RPM with a voltage of 3.4 V, and at full speed of the drill, 2069 RPM with a voltage of 9.9 volts. Those RPMs were recorded with the tachometer reading four strips, after which the values were divided by four, resulting in 191 RPM for low speed and 517.25 RPM for high speed. The data was used to plot of the two points of RPM versus voltage, shown in the figure 5-1. The plot's trendline provided an equation that could help in estimating the output voltage at any given RPM. All of the data gather during characterizing the motor are also shown below in Table 5-1 and Figures 5-1, 5-2, and 5-3.

Table 5-1: Motor Characterization Data

Voltage (V)	RPM * 4	RPM	Power (W)	Amps (A)	Rad/s	Torque (N-m)	
9.9	2069	517.25	33.112	3.345	54.166	0.6113	18 V Cordless Drill
3.4	764	191	3.905	1.149	20.002	0.1953	
1.9	400	100	1.220	0.642	10.472	0.1165	Values of Interest
2.97	605	151.25	2.980	1.003	15.8399	0.1882	

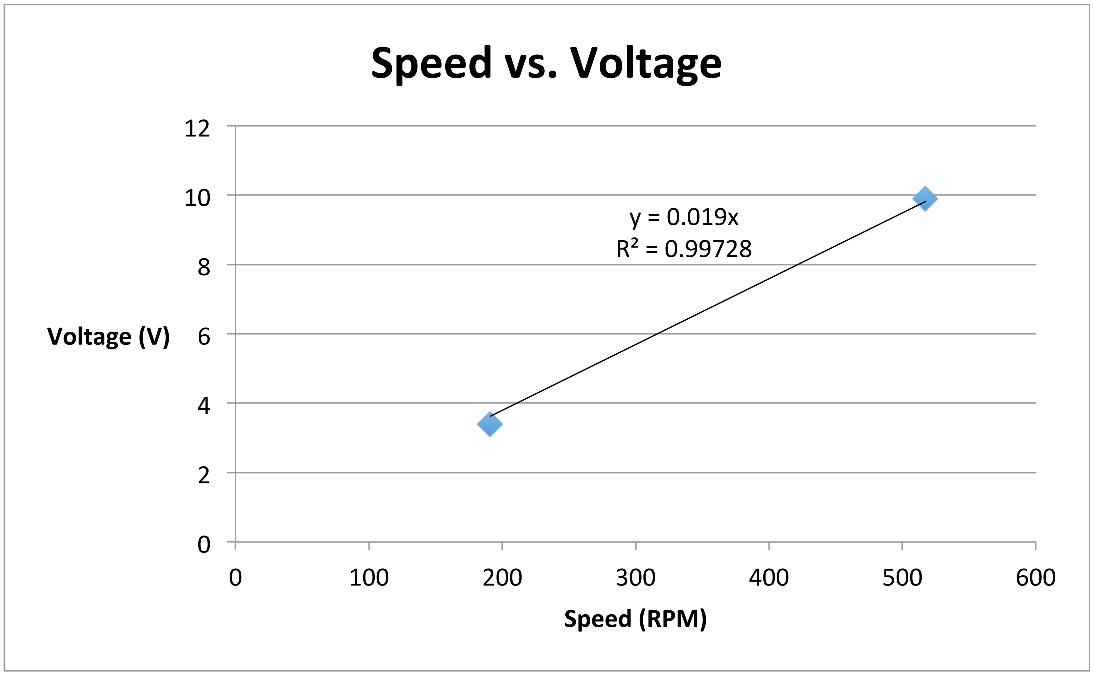


Figure 5-1: Motor Characterization plot Speed vs. Voltage

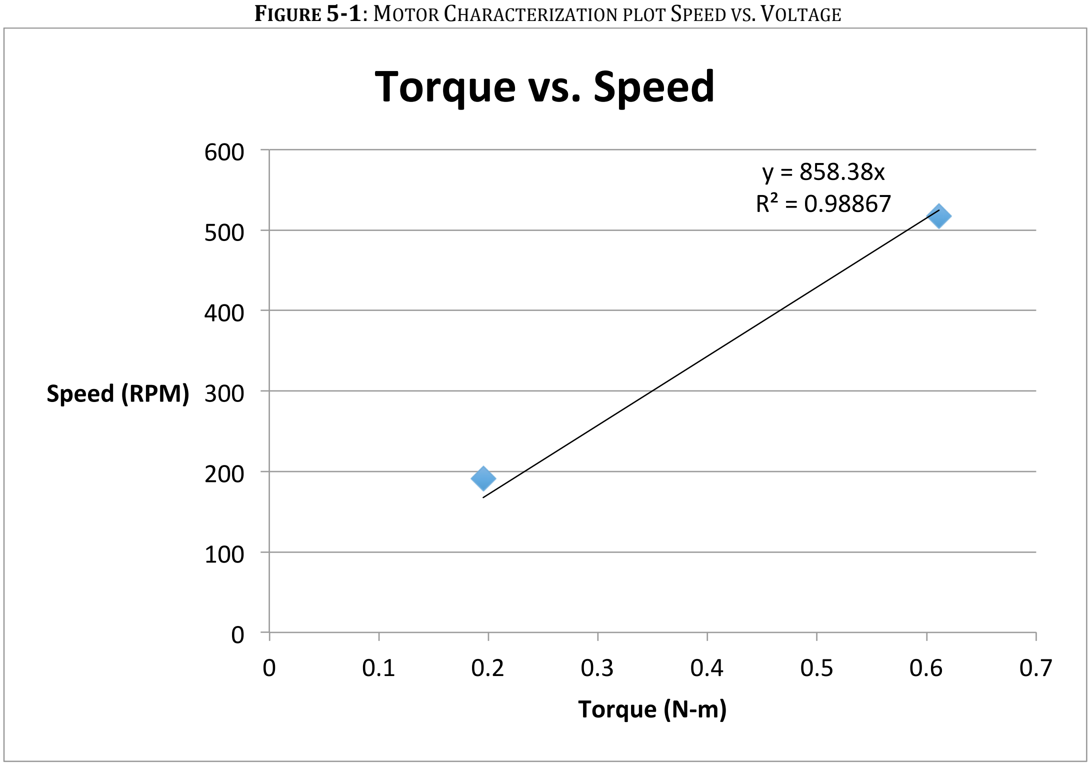


Figure 5-2: Motor Characterization plot Torque vs. Speed

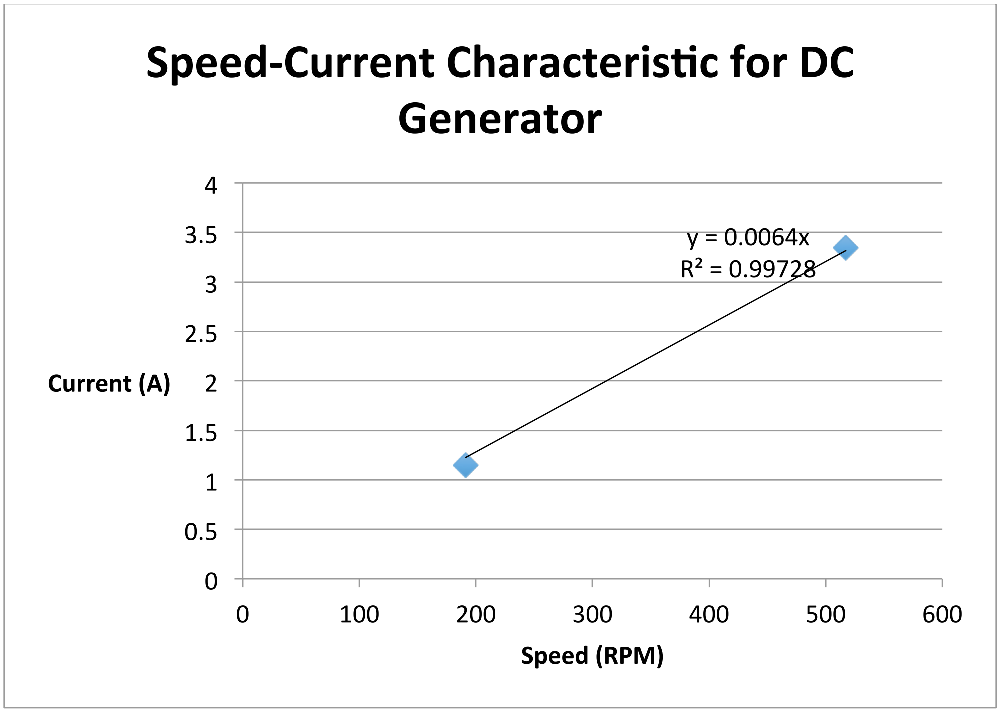
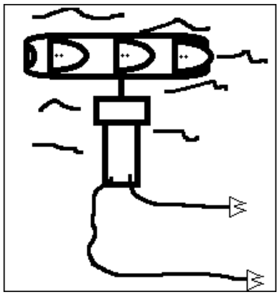
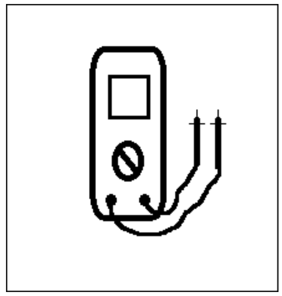


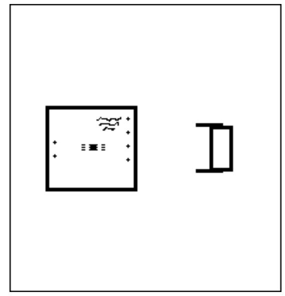
FIGURE 5-3: MOTOR CHARACTERIZATION PLOT SPEED VS. CURRENT

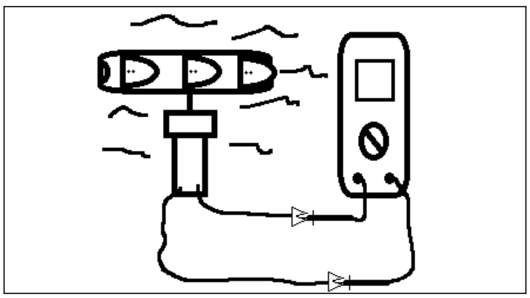
5-2. Test Procedure and Testing Sites

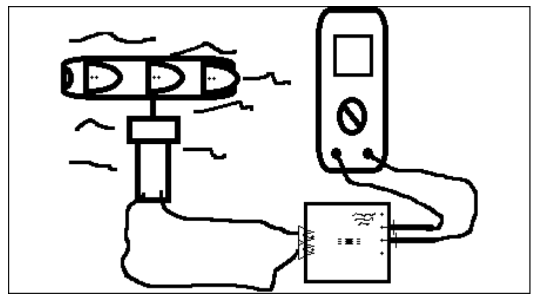
The testing procedure consisted of placing the waterwheel into the water where it would produce the most optimal voltage. The wheel was tilted at different angles to get a rough estimate of where it performed best. The procedure: placing the water wheel in the water enough to get it spinning on the motor shaft. A voltmeter/multimeter was used to take the voltage of the motor. The motor was then connected to the LTC 3108 Demo board's input, where a voltage measurement was taken at the output. After the measurements were taken to ensure performance of the wheel, a Li-Ion battery was connected to the output, where the current and voltage was measured to confirm that the battery was actually charging. Figure 5-4 shows the procedure layout.

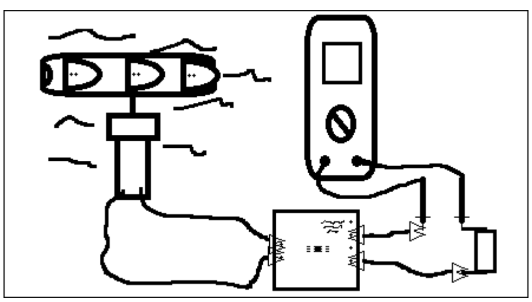

Motor and Waterwheel


Voltmeter/Multimeter


LTC 3108 Demo Board and Li-Ion 3v Battery


Generator Voltage Test


Generator and Board Voltage Test


Generator, Board, and Battery Current Test

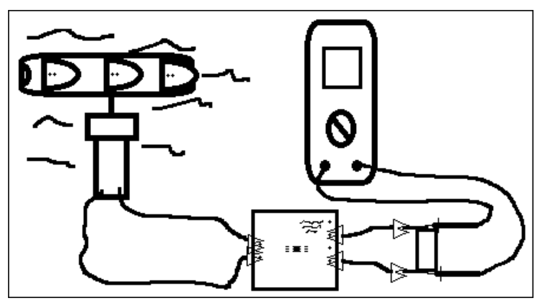

Generator, Board, and Battery Voltage Test

FIGURE 5-4: PROCEDURE LAYOUT

5-3. SLO Creek at Cuesta Canyon

The first testing site for the Portable Nano Hydro Generator was in the SLO Creek at Cuesta Canyon Park. This was done in poor testing conditions as it was raining, and the electrical components needed to remain as dry as possible. Figure 5-5 shows the motor and turbine assembly attached to the float.

FIGURE 5-5: ORANGE TURBINE TESTING WITH FLOAT IN SLO CREEK

5-4. Hydraulics Lab Orange Tub

The Hydraulics lab was the second testing site. Under the supervision of the supervisor of the civil engineering lab technician, Xi Shen, an orange tub that has water flowing through was provided for testing purposes. By placing the turbine in the tub, the water would push the fins of each turbine, and the voltmeter would determine how much voltage it could output. Some issues in using this tub occurred when the turbine was placed in the water, and the turbine would not rotate. Due to the design of the turbines, specifically the fins, the water went around each fin rather than being caught in them. The testing procedure had changed to make better use of the environment and turbine as the tub had a section where the water poured down from the tub, and the downward motion of the water due to gravity seemed as though it would be powerful enough to turn the turbines, which it did so, but still not as consistent or as fast as desired. The turbines were tilted at an angle where the turbine actually caught the water better and rotated more consistently.

Making these adjustments, it was observed that the voltage produced by the turbine were above 1 volt, which wasn't even feasible at the previous testing site. On average the voltage from the orange turbine (seen in Figure 5-7) was 1.5 volts, and average voltage from the white turbine (Figure 5-7) was 0.551 volts. The decision was then made to slightly change the design of the orange turbine by cutting the fins to make them have more surface area to catch the water better, and improve the transfer of energy from the motion of water to the turbine and from there to the motor Figure 5-8. By doing this, the output voltage slightly increased to an average of 1.546 volts. Xi Shen provided a flow meter to measure the flow rate of the water flowing through the tub, which was 4.6 ft/s. It seemed as though the orange turbine performed better than the white turbine, and the turbines rotated better when water was hitting it at an angle. The orange turbine was also improved by cutting little slits in it. Even though the setting for the turbine and motor was not ideal, the test provided enough information to get a better idea of what changes the turbine required and whether the concept could be done or not.

FIGURE 5-6: ORANGE TURBINE IN HYDRAULICS TUB

FIGURE 5-7: WHITE TURBINE IN HYDRAULICS TUB

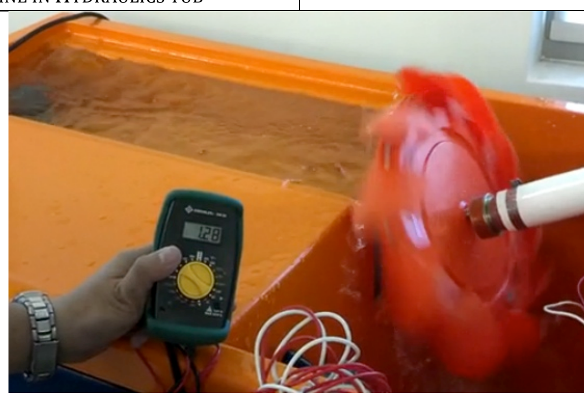


FIGURE 5-8: ORANGE TURBINE WITH CUT FINS IN HYDRAULICS TUB

5-5. Fluids Lab

The third testing site took place in the Fluids Lab under the supervision of Fluids Professor and Mechanical Engineer Dr. Westphal. After receiving permission to use the facility, he helped in setting up the tests. One turbine attached to the generator would clamp down against a rail. The voltmeter and leads would be set at a table away from the testing area to avoid getting wet. Once the generator and turbine were secured, Dr. Westphal would turn on the pump motor, and one of three mounted hoses would spray water at a singular point on the wheel, causing it to turn. The Fluids Lab was also the testing site of the previous Portable Nano Hydro Generator Mechanical Engineering team, where they also tested and stored their cage turbine. The water sprayed was at a high velocity and pressure, leading to water splashing off of the turbines and everywhere, even more so when the hose was angled for optimum speed, as the tests in the Hydraulics Lab suggested that the turbines were found to rotate faster when the water is pushing the fins at an angle. On average, the orange turbine (seen in Figure 5-9) produced 3.32 volts without a load, enough to provide power to the 2.5 V boost converter, and enough current to charge the 12 V Lead-Acid Battery in under 20 hours. The white turbine (Figure 5-10) produced a significantly lesser average voltage of 1.89 volts, almost 50% less than what the orange turbine outputted. After testing was done, to find the velocity of the water from the hose, Dr. Westphal pointed the hose up and shot water out of it. He had estimated the height of the arching water to be 3 feet. Knowing that the water would have no velocity at the peak, the negative upwards acceleration due to gravity, and the distance from the hose to the height of the arc, kinematic equations were employed to find an initial and constant water velocity of 13.894 ft/s. The testing that took place here, though messy, proved that with the orange turbine's somewhat flawed design, it was possible to achieve the goal of charging a 12 V car battery, though not in the way that it was intended to be charged and certainly not how it would be charged in a more natural and rural environment.

FIGURE 5-9: ORANGE TURBINE TESTING AT THE FLUIDS LAB

FIGURE 5-10: WHITE TURBINE TESTING AT THE FLUIDS LAB

5-6. REC Whirlpool

The fourth testing site the Whirlpool located at Cal Poly's Rec center. The whirlpool is a circular shaped pool that has its water rotating in a constant motion, which was ideal for testing the project. One member would remain in the pool to hold the turbine, which is connected to the motor, and place it in the water. The other member had the output of the motor connected to a voltmeter and recorded the results for each test, one set for the orange turbine, and one set for the white turbine, with photos and recorded videos of the tests as proof. To also make the best of the designs, the turbines were tilted, as during the Hydraulics lab testing, the turbine were found to rotate faster when the water is pushing the fins at an angle. From the recorded data, the average voltage for the orange turbine (seen in Figure 5-11) was 0.375 V, and the average voltage for the white turbine (Figure 5-12) was 0.545 V. The tests show that for an open pool with such a wide volume like this pool, the white turbine performed better than the orange turbine. The flow rate of the pool was determined by placing a can in the whirlpool and timing how long it took for it to go 3 ft. By taking the average time for it to go 3 ft in the pool, the flow rate of the pool was 1.040 ft/s.

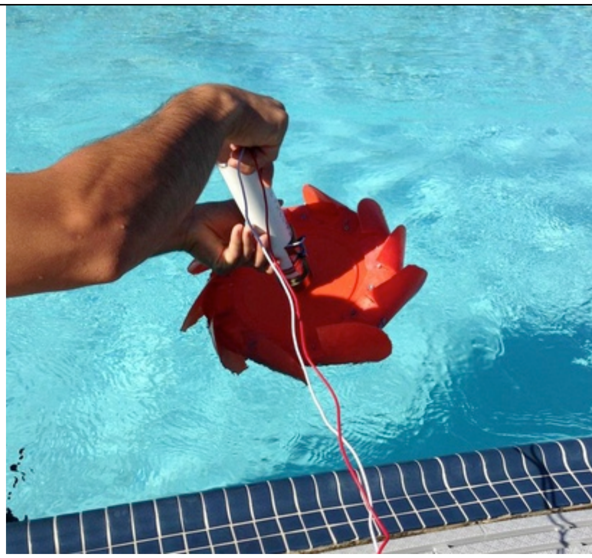


FIGURE 5-11: ORANGE TURBINE TESTING IN WHIRLPOOL

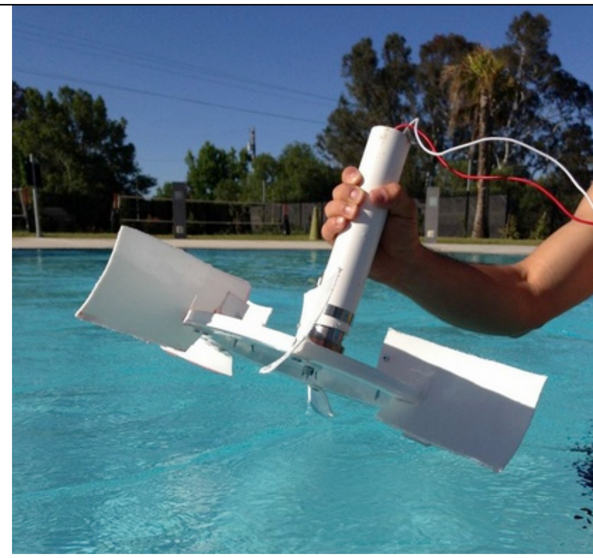


FIGURE 5-12: WHITE TURBINE TESTING IN WHIRLPOOL

5-7. Los Osos Creek at LOVR and Higuera St.

The 5th and final testing site was again at the Los Osos Creek under the crossing at Los Osos Valley Road and Higuera. The site is a natural creek, and a continuation of the very first testing site, yet the water flows through a treatment plant, which could be the reason for a better flow rate further down the stream where the turbine was tested. This site produced the best water flow of all the sites in a natural setting in which this project was designed for. Since the demo board is able to take an input of 0.02 V and step it up to 4.1 V, this site is ideal to demonstrate that the project accomplished its goal of charging a battery. With an average flow rate of 2.168 ft/s, the orange water wheel (seen in Figure 5-13) was able to convert to 0.641 V. This voltage was much greater than the maximum taken by the demo board, 0.4 V, so the wheel was placed in a section in the creek where the generator would not provide above the maximum voltage for the board. The white wheel (Figure 5-14) would have also been suitable since its maximum output was at 0.485 V.

FIGURE 5-13: ORANGE TURBINE TESTING AT LOS OSOS CREEK

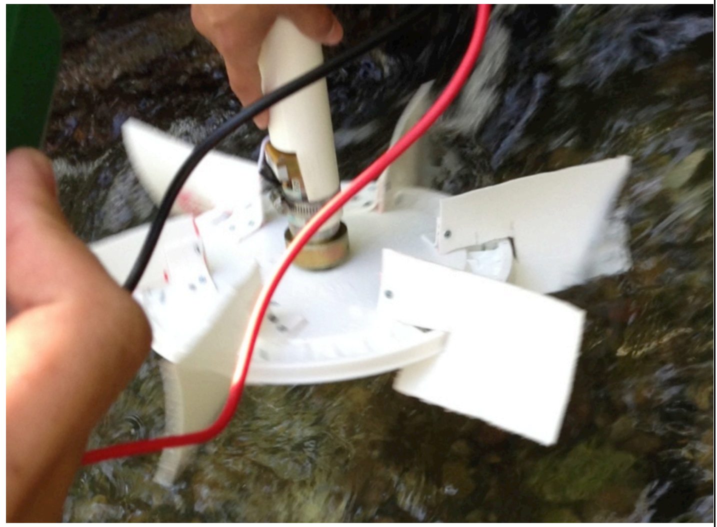


FIGURE 5-14: WHITE TURBINE TESTING AT LOS OSOS CREEK

5-8. Combined Testing Results

The results are tabulated from each testing site. Though not all sites were ideal, it can be seen the differences in how fast the water flows, and how the water is directed, as with the fluids lab. Though some testing resulted in much higher voltages and flow rates, they were not actually ideal for the design (indicated by *). The maximum of all of the sites are indicated in bold in Table 5-2.

Table 5-2: Combined Testing Results from All Test Sites

Combined Testing Results	Flow Rate (ft/s)	Orange Wheel with fins cut/open (AVG Voltage)	White Wheel (Voltage)
1 SLO Creek at Cuesta Canyon	0.871	NA	NA
2 Hydraulics Lab Orange Tub	4.6*	1.546*	0.551*
3 Fluids Lab	13.89*	3.32*	1.89*
4 REC Whirlpool	1.04	0.376	**0.546**
5 Los Osos Creek at LOVR and Higuera	**2.168**	**0.641**	0.485

From the results, it is theoretically possible to charge the 20 Amp-hour 12 V Lead-Acid Battery in about 17 hours and 53 seconds (an average output voltage of 3.32 volts means that the generator shaft is rotating at about 174 RPM, which corresponds to 1.12 amps) via the 2.5 V boost converter, assuming current isn't lost. However, using a hose to spray water at a single point on a water wheel in order to provide power to a battery is not how the project was designed for use. For that, the Los Osos Creek would be a more suitable environment for using the Portable Nano Hydro Generator in conjunction with the 0.4 V maximum boost converter in charging up a 3 V 600 milliamp-hour Li-Ion Battery in about 4 and a half hours (an output voltage 0.4 volts means that the generator shaft is rotating at about 4.45 RPM, which corresponds to 135 milliamps). The Orange wheel could also be used in the whirlpool and on average would be able to charge the 3 V Li-ion battery in about 4 hours and 45 minutes. Though it will not be a 12 V Lead-Acid car battery at the load as was the original goal, being able to charge the Li-Ion Battery should prove that, though flawed, the current design can charge a battery via boost converter.

Chapter 6: Conclusion

The Portable Nano-Hydro Generator was a year-long project designed for the purpose of delivering power using water as the source of energy. By placing the project in a stream of water, the vision was that enough power would be supplied to charge a 12V lead-acid battery, which in turn would give power to lighting in the DC house. The project involved making a design that could float in a small stream of water and provide a steady voltage that could charge a 12 V battery. By making most of the project out of everyday materials, the cost to build the product can be reduced. This was accomplished by making the float out of PVC piping and the turbine out of commercially available buckets. The generator was chosen through careful calculations and the boost was chosen following the characterization of the generator.

A few changes from the original design had to be performed after more testing were conducted. During testing, the group found that the turbine was not ideal for its intended purpose. It couldn't rotate the shaft at the necessary RPM to produce the required output voltage. The output needed to be a specific voltage of 2.5 V that the boost required as a minimum input voltage to function properly, but the initial turbine design could not produce enough voltage. A different turbine would be needed to obtain the voltage the boost required and was designed in order to get the desired voltage out of the motor. However, the turbine also failed in getting the 2.5 V required for the boost converter. After more testing and careful consideration the plan to charge a 12 V battery had to be modified to enabling the system to charge smaller size battery. Therefore a 3 V Li-Ion battery became the new goal in conjunction with a boost converter that required a minimum input of 0.05 V to produce a maximum output voltage of 5 V.

The project was finalized after changing the boost converter and using an ideal test site, Los Osos Creek. The Los Osos Creek was the best place to test as it was a natural stream under the conditions that the Portable Nano Hydro Generator was created for. After placing the turbine in that creek, connecting it to the new boost converter, and reading the output, the generator produced a constant output voltage of 4.08 V. The 3 V Li-Ion battery required about 4 V for it to properly charge, and the output voltage of the board met that need. To prove the concept, the battery was connected to the system in order to see if the voltage and current was enough to charge the battery. By taking down the voltage across the battery prior to initial testing, it was witnessed that the battery went from 3.51V to 3.53V after being connected to the board for a couple of minutes. As is, the system can provide the necessary voltage required for the battery but still lacks the current for the most efficient form of charging the battery. These are things that will hopefully be fixed next year for any groups building off the current design.

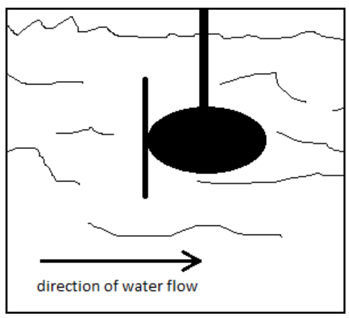
The results of a year's worth of work on the project prove that this concept can be done. There are some necessary adjustments the project, in order for the project to be ideal for the DC House, but for now it shows much promise. There are a few improvements that are mentioned in detail in the section below. These improvements, such as changing the turbine and having a boost converter with a wider input and output voltage range, will greatly make the project at the level required for a functioning DC House. Hopefully future groups will be able to build upon the progress made, improve upon the system's current incarnation, and surpass this group's expectations. It is safe to say that the Portable Nano-Hydro Generator is a system that can be done, and has the potential for use in a DC House.

6-1. Senior Project Improvements:

6-1a. Design

- DC Thruster motor as generator, similar to windmill, can use a 12v boat bilge pump,
  - See instructables: http://www.instructables.com/id/How-to-build-a-thruster-for-a-homemade-submersible/
- The design of the hydrokinetic energy capture could be reworked to incorporate a design more like a windmill, where the rotor/fan is submerged in the water as in Figure 6-1.

FIGURE 6-1: WINDMILL TYPE DESIGN



6-1b. Electronics

- Use an improved Battery Charge Controller like the MCP73861
- In order to fully charge a lithium ion battery, a charge controller must be utilized. See Lithium-Ion battery charging:

  http://batteryuniversity.com/learn/article/charging_lithium_ion_batteries

  http://www.microchip.com/wwwproducts/Devices.aspx?dDocName=en020210

  "*The MCP73861 provides a complete, fully-functional, stand-alone charge management solution for single-cell Li-Ion and Li-Polymer applications.*"

- Consider implementing a better boost converter to take advantage of higher voltages within range of 0.5v -0.8v.
- Overcharge protection needs to be taken into account and may be included in battery charge controller circuit. If the battery has fully charged, the generator needs to send the energy somewhere, or consider freewheeling (disconnecting the wheel from shaft).
- Implement an LCD to display current, voltage, and possibly length of charge or time remaining. It will also be useful to add an LED-charging indicator, which gives the user access to information about the state of the charge of the battery; let the user know what is going on.

6-1c. Turbine/Wheel

- Changing the water wheel design by asking help from mechanical engineering students or mechanical engineer Professor Jumonville in Spring, since he holds a turbine design contest and can help with designing the ideal water wheel for project. A better design of the water wheel can be implemented toimprove efficiency.

6-1d. Float

- Consider less hardware; use PVC for float and hotweld glue. Using PVC for the float instead of steel U-strut and hardware provides a way to easily manufacture the float. PVC can be used over steel and bolts, as it is easy to cut to length and only requires glue to put together. PVC also has many different connectors to accompany many designs.

- Back straps to carry float easier, currently float has to be carried by hand. Carrying the float with hands free allows for more comfort and less hassle.

6-1e. Other

- Research availability of materials in designated regions for Taufik's DC House to address the issue of availability of the materials used in Indonesia. The materials used in this design may not be easily or even impossible to find. Knowing the area where the DC House project will be implemented will allow the designers to prepare for alternative solutions to the project.
- Mechanical engineering lab would be an ideal place to look into, as they have many tools and equipment that the electrical engineer students are not normally accustomed to. By getting in contact with the professors and looking into the labs such as the hydraulics or fluid lab, student can utilize tools that could help in completing their project. The labs and their tools helped with testing and gathering data for analysis.

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Appendices

Appendix A. Gantt Chart

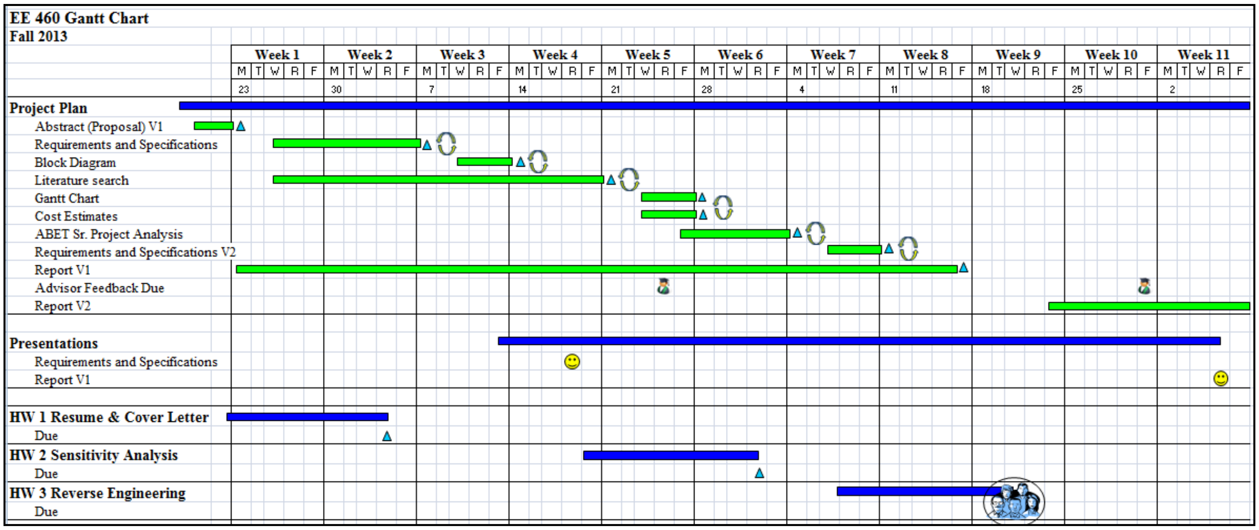

FIGURE A-1: GANTT CHART FOR FALL 2013 EE460

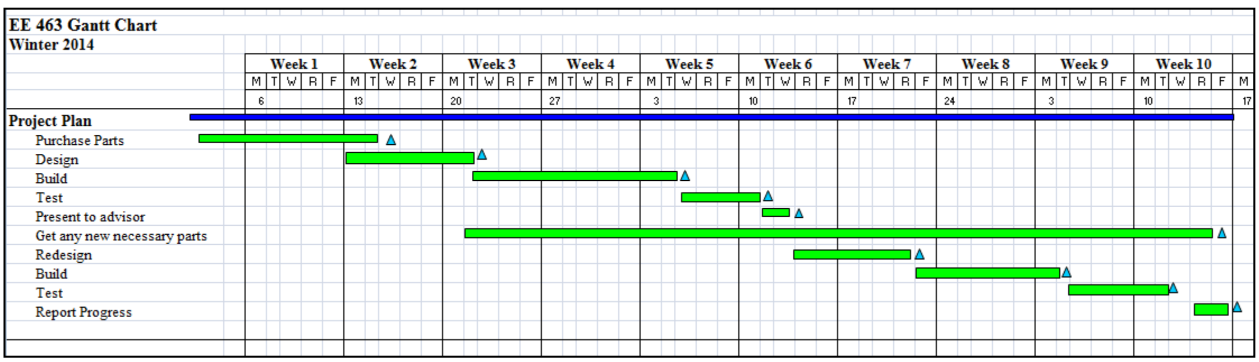

FIGURE A-2: GANTT CHART WINTER 2014 EE461/463

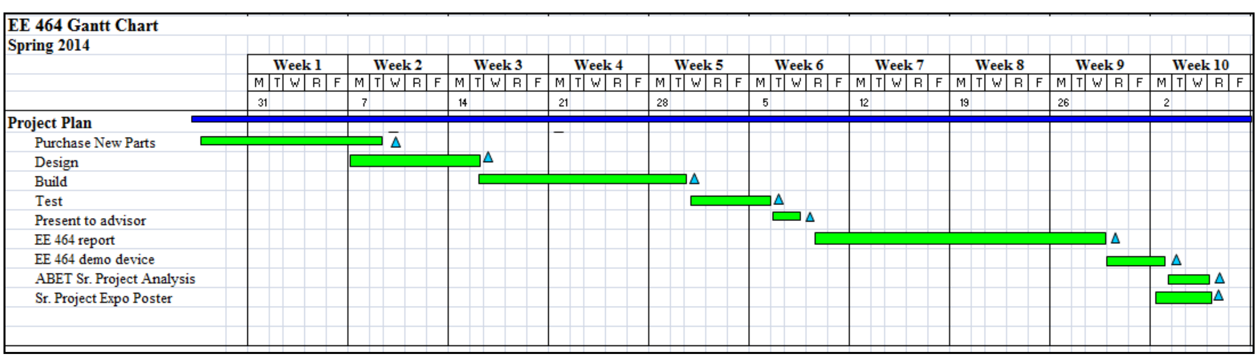

FIGURE A-3: GANTT CHART SPRING 2014 EE462/464

Appendix B. Senior Project ABET Analysis

B-1. Summary of Functional Requirements

The project produces energy by using small streams of water. The project utilizes water streams and uses the water stream as mechanical energy to generate usable energy. The design will help people unable to afford power in their homes for such things as lighting by allowing them to generate their own electrical power at an affordable cost.

B-2. Primary Constraints

Lack of mechanical understanding for turbine design; the design for converting the kinetic energy of the water into rotational energy to provide power on the shaft of the generator is a design, which requires the use of the theory of fluid dynamics. A Mechanical Engineering student would better understand this knowledge. Minimum access to adequate testing sites; testing the device requires access to a stream, river, creek, or irrigation canal. Near Cal Poly, the sites are not quite as accessible. The project was tested on campus facilities, but the conditions of the test were negligible to the proposed function. Transportation and Time; the team needed to be present to do field testing, but scheduling made such meetings very limited. This caused difficulty with when it came to working on and testing the project as a group. The testing required at least two members when working with on campus facilities, but required the whole team when going to the off campus creek in San Luis Obispo. The issue with transportation also was difficult because only one of the three members had a vehicle to go to the site.

B-3. Economic

Table B-1: Estimated Cost

Housing and intake screen	\$5 + \$2	\$7	5 gallon bucket and mesh screen/netting for debris. *Home Depot*
Turbine/Generator	\$200	\$200	Quick search on Google for

			Generators
Boost Converter	$3-$6	$4.50	TI Boost Converters. Average cost is used for total.
Charge Indicator	$15	$15	Quick search for Voltmeter on Google
Jumper Cables	$20	$20	Quick search on Google for Jumper Cables
Hardware	$30-$40	$35	Estimate of miscellaneous parts. Average used for total.
Other	$50-$100	$75	Estimate for miscellaneous parts not accounted for in first design. Average used for total.
Total Cost for Parts:		**$360.50**	

Table B-2: Bill of Materials

Device	Description of Part	Quantity	Cost of Part
Barge/Float	3' PVC Pipe 4" Diameter	2	5.52
	PVC Cap 4" Diameter	4	11.56
	PVC Glue		4.39
	10' U-Strut Steel		15.57
	U-Strut Spring Nut	8	31.76
	1/4" Bolts	8	8.57
	90 Degree Bracket	2	2.68
	Self Tap Hex Screw	12	5.48
	Washers	8	9.44
	Universal Pipe Clamp	1	2.85
	Paracord Rope	1	2.97
	Tent Stakes	4	2.2
	1/4" Nuts		1.5
Motor+ Assembly	PITTMAN GM9434		75
	Shaft Collar	2	7.38
	Cotter Pins		1.44
	9" PVC Pipe 1-1/2" Diameter		0.85
	SS Hose Clamp	4	10.36
Water Wheel	5-Gallon Bucket Lid	2	2.56
	Wood Screws, Phillips		3.79
	5-Gallon Bucket		2.78
Converter and Connections	LTC3108EDE Demo Board		150
	18 AWG Wire Spool	2	29.98
	Aligator Clip	6	8.97
	Heat Shrink		3.59
		TOTAL	**$401.19**

There weren't any additional equipment costs aside from what was bought. Originally, the project was anticipated to take about 33 hours based on the Gantt Charts in Appendix A, but the actual amount of time spent in development and testing was half that at about 16 hours.

B-4. If Manufactured on a Commercial Basis

The project was estimated to sell about 250 units per year if manufactured on a commercial basis. The project cost was estimated to be about $400.00 for designing and manufacturing, and the purchase price for the device was estimated to be at most $100.00 for the target market with relatively little to no profit, as the target market should not have to pay much for the product. The cost for users to operate should cost no more than what they paid for the device. Since the generator should use streams of water to generate energy, it should not cost anything to use that water. Operation and maintenance costs should remain low since any one person could use it.

B-5. Environmental

The project directly uses the ecosystem pertaining to rivers, streams, canals, and creeks. The project uses water but does not consume it so that the project does not have an impact on the water quality. The materials used in this project include metals like copper and iron, plastic like polyvinylchloride (PVC), clay and ceramics, resin coatings, along with wood and other materials not yet accounted for. The materials may not harm the environment, but the processes in which they may or may not raise some concern. The project could bring harm to the local ecosystem by possibly causing species to avoid the area, due to the noise that device makes or the sight of it. The project should look like a foreign object when introduced to the ecosystem and natural habitat. The species it would have the most impact on include coyotes and other predators that depend on fish as their main food source. The fish may act in avoidance of the project and the surrounding area. The project may affect fish, ducks, crawdads, tadpoles, frogs and other fresh water animals. Their predators such wild dogs, bears, birds, and coyotes may suffer the impacts in turn. This project does have an impact on the environment in that requires further research when placed on market. On the other side, natural debris from fallen plant life could also affect the device's performance should some debris get caught in the turbine.

B-6. Manufacturability

Manufacturing the generator presents a challenge if the given resources' sustainability does not last long. Unavailable yet crucial materials may affect the manufacturability and the design. Conducting research on the availability and life span of specific materials would provide the best strategy in avoiding delay or cancellation in manufacturing the device. The second best strategy involves making a simplistic design that manufacturers could easily reproduce by means of a number of different materials.

B-7. Sustainability

The sustainability of this project depends on the materials used, as well as its performance. The sustainability of the project was made a priority, but the implementation of it may not make it possible. The idea provides renewable energy so that it can theoretically produce clean electricity rather than harmful. The durability of the project should also contribute to its sustainable use. The introduction of this project should counter the dependence on nonrenewable energy sources. A better turbine would most certainly upgrade the design, as a more efficient way of converting of energy would allow faster charging of a battery, if not a bigger capacity battery. Finding a better motor to be used as a generator would also upgrade the device, with the motor used now has a short shaft and requires a relatively high torque needed to get it moving. Coming up with a design for the turbine would be difficult, especially with the low flow rates that are required and typically measured in streams, creeks, rivers, irrigation canals etc. Designing a much more efficient turbine solely for this purpose would be the biggest challenge.

B-8. Ethical

Ethically, the project is designed to last several years without needing to be replaced or repaired more than once in its lifespan. Even though it is designed to be cheap, it is not made with poor materials so as to avoid cost and not leave the consumer with a faulty product. The project is built with reliable materials to ensure the consumer is spending their money on solely buying the product and not spending money to repair and replace the product countless times. It also is safe to use. Test engineers should properly set up and inspect the project to make sure it does not have any chance of harming the user. Any project that incorporates both water and electricity could present a safety hazard for the user, something that was accounted for when designing the project. No areas that can cause any electrical water issues for the user remain exposed. The group ensured that it is properly designed with the users' safety in mind. The final product should not be sold under the table by people who might abuse their power and try to sell it for additional profits. It must be sold with the intent to help those less fortunate, and not abuse the fact that they are in need of the product. These issues pertain to the IEEE code of Ethics, particularly statement numbers 1, 2, 3, 6, 7, and 8.

B-9. Health and Safety

The project must ensure safety when using. The barriers that might prevent this include the use of water and electricity. The design of the project incorporates safe operation and setup in order to prevent harm to the user. The device cannot cause harm in the process of manufacturing.

B-10. Social and Political

The social and political issues that could occur with regards to the product focus on the stakeholders who would produce independent sources of energy. Some countries may not allow or like the idea of people generating their own power without them using what the country provides. Most people remain in poverty because of the lack of help/care the country provides its people. People using the generator to get around that may actually get in trouble for doing so. The clear stakeholders of this product are the people who buy and use the product. The project generates power for those who can't afford to get power any other way. It makes it cheap and easy to have power for people and their families. It works equally as long as the majority of the households in a specific country have one. One problem involves the affordability of the device amongst several households in the case that some may not afford the price, possibly leading to further problems amongst the stakeholders, as some have power and others do not. This may depend on the community since some don't mind sharing possessions. Such a problem in other households though could lead to envy and jealousy among their neighbors if they have the generator and their neighbor does not.

B-11. Development

In the process of this project, the team has learned how to use LTSpice for sensitivity analysis, how to estimate part costs, how to create and manage a Gantt chart with design, build, and test iterations. The team knows how to test the flow rate of fluids, placement analysis, and how to transfer kinetic energy via fluids into electrical power, all of which were found in various textbooks and resources. The team has also demonstrated their resourcefulness in finding and creating components as well as adaptability to changes in requirements.