

Development of a Pico-Hydro Electric Generator with 3D-Printed Pelton Turbine

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Abstract. Most farmers in Bataan, Philippines are using diesel pump system to irrigate their crops. In this system, water is pumped out continuously during cropping period and one may think that the water is being squandered because the diesel pump operates for about eight to ten hours a day. Furthermore, with the high price of Diesel nowadays, the irrigation system seems to be a burden to most crop farmers. The proponents thought of applying the pico-hydroelectric generation technology to add value to the system. Specifically in this study, the proponents aimed to develop a pico-hydroelectric generator with 3D-printed Pelton turbine to be installed in diesel pump irrigation system, and be able to harness the energy from the flowing water and convert it into useful electric energy which can be used for lighting and for charging electronic gadgets.

Introduction

In Bataan Province, one of the prime livelihood is farming of palay or rice at any stage before husking. Bataan, being part of Central Luzon Region, is one of the biggest palay producers in the Philippines. According to Figure 1, the percent share of Central Luzon on Palay production is about 21% for the two quarters in 2018. In 2019, the percent share of Central Luzon on Palay production decreases to 16.53 %.

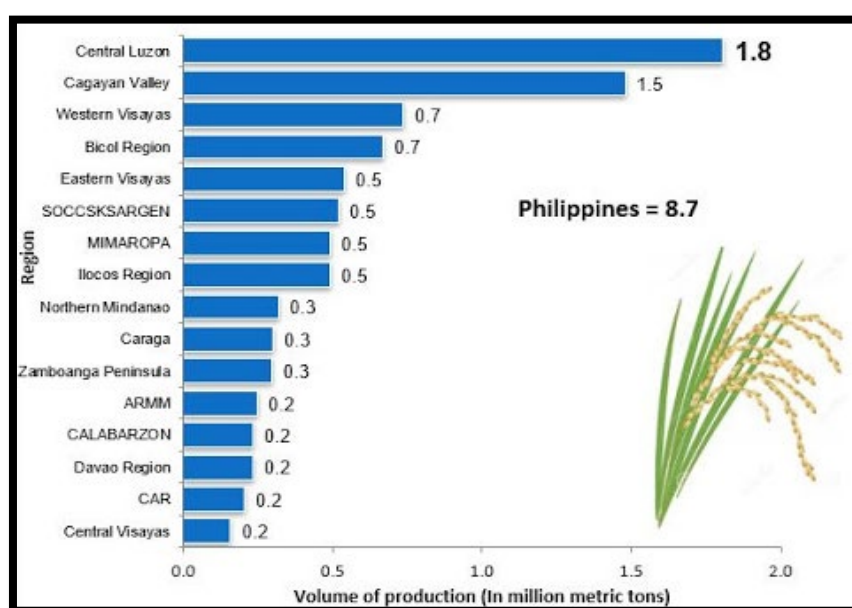


Fig. 1. Volume of Palay Production by Region, Philippines (January – June 2018)

It is surveyed that most farmers in Bataan were using diesel pump system to irrigate their crops. Figure 2 depicts a typical diesel pump irrigation system which farmers are using wherein water is drawn out from water bed using diesel-fed water pump. In this irrigation system, the water is basically free flowing throughout the cropping season.



Fig. 2. Typical Diesel Water Pump Irrigation System in Bataan

Based on assessment, pico-hydroelectric generators can be a potential source of electricity for this application. It is a proven electricity generation method with a maximum electric output of five kilowatts. These generators have proven to be useful in small, remote communities that require only a small amount of electricity. Pico-hydro setups typically are run-of-stream which means only small weirs or pipes to divert the flow through the turbine are needed and reservoir of water is not needed [1].

The proponents thought of converting this squandered water energy from diesel pump irrigation system of Palay Farmers in Bataan, into useful kinetic energy to propel a Pico-scale hydroelectric system. Specifically, the project study aims to generate renewable electricity from the diesel pump irrigation systems to be used to minimize or somehow lower the electricity consumption of users by providing free electricity to light their houses at night. Moreover, it can be of great help as a charging station during long power outages [2].

To be able to generate more power, the proponents opted to maximize the speed by making the propeller made of durable plastic. It is hypothesized that the metal propeller of usual pico-hydro electric generator shall be substituted with 3D printed durable plastic. So that the propeller would be light and easy to turn by water, hence, it can drive the generator more rapidly [3]. 3D printing technology, also known as additive manufacturing, is a method of creating a three-dimensional object layer-by-layer using a computer created design. 3D printing is an additive process whereby layers of material are built up to create a 3D part. 3D printing is also perfectly suited to the creation of complex, modified items, making it ideal for rapid prototyping.

Literature Review

Portland in Oregon now generates electricity from turbines installed in city water pipes. Portland has replaced a section of its existing water supply network with Lucid Energy pipes as shown in Figure 3 containing four forty-two-inch turbines. As water flows through the pipes, the turbines spin and

power attached generators, which then feed energy back into the city's electrical grid. It is known as the Conduit 3 Hydroelectric Project, Portland's new clean energy source is scheduled to be up and running at full capacity in March 2019.

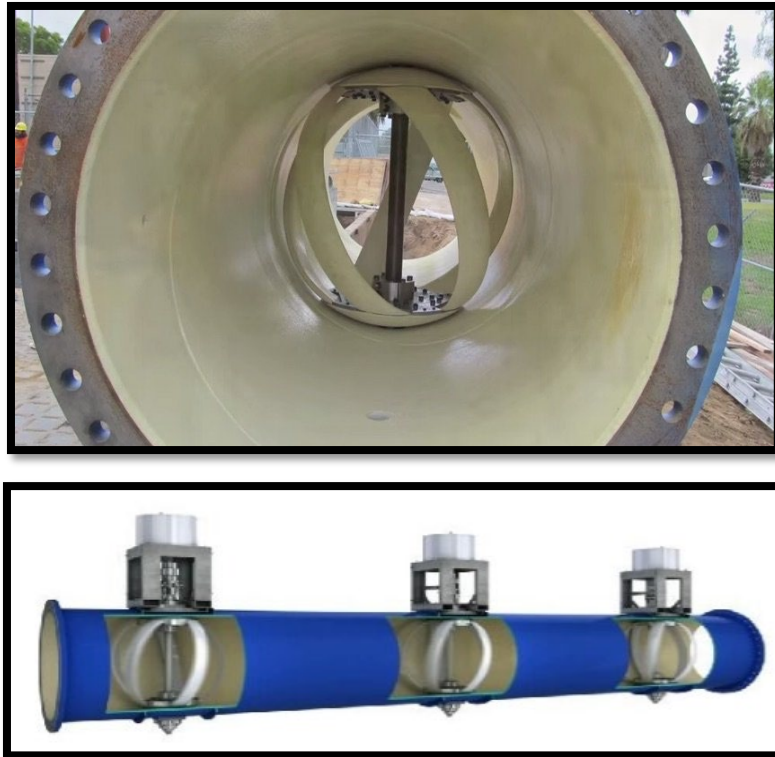


Fig. 3. Lucid Energy Pipes

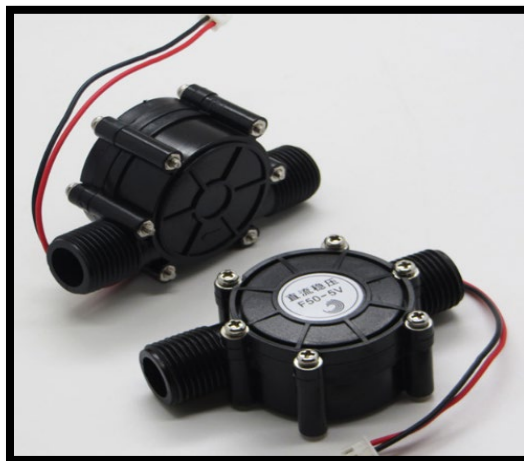


Fig. 4. Micro Hydro Generator

In order to be cost and energy effective, Portland's new power generators were installed in pipes where water flows downhill, without having to be pumped, as the energy necessary to pump the water would negate the subsequent energy gleaned. However, it is noted that the system does more than simply provide electricity: It can monitor both the overall condition of a city's water supply network as well as assess the drinking quality of the water flowing through it. This study helps the proponents on how harness of some excess pressure to generate environmentally – friendly hydropower without disrupting water delivery, with the use of turbines installed inside of water pipelines, as the water flows through the turbine spin converting the excess pressure into a renewable energy. The design does not harm ecosystem and it can be operated day and night, rain or shine and 24/7, the idea was efficient and reliable.

Depicted in Figure 4 is the Micro Hydro generator which generates DC power from a source such as a stream running down a hillside. Water is channeled into a pipeline with enough drop (head) to build up sufficient pressure. It can also be used with water systems that are under pressure like the water in city supplies.

The water passes through a small nozzle where it gives up pressure for velocity. The water then passes through the turbine runner which converts the energy in the water into shaft power and spins the generator. This electric power is first alternating current (AC) that is converted into direct current (DC) with a device called a rectifier. The power then goes to the output terminals (binding posts) where it is available to charge batteries or use directly with suitable appliances.

Both Lucid Energy pipes and Micro Hydro Generators (MHG) are the inspirations behind this study. Lucid Energy pipes are macro hydro generator while MHG is the opposite extreme. The concept of pipes and the construction of MHG are incorporated to come with a pico-hydroelectric generator suited for typical diesel water pump used by farmers in irrigating their crops.

Methodology

The common process of generating electricity using Pico-hydro generation is shown in Figure 5. The main components of this system are water, inlet, penstock, turbines, drive system, generator, rectifier, battery, inverter and load are required.

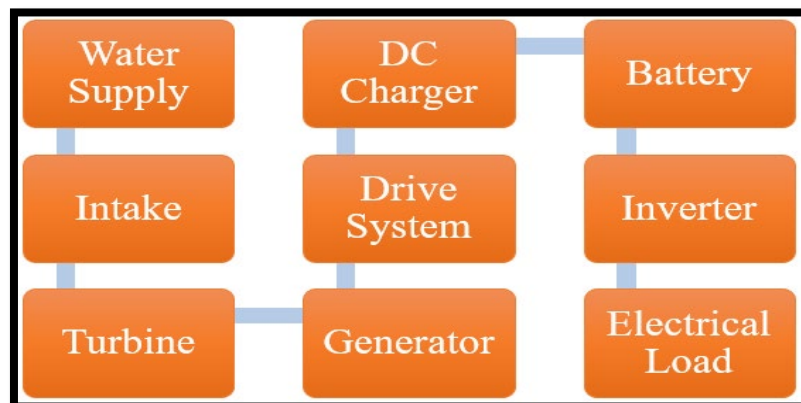


Fig. 5. Operation of Pico-Hydroelectric System

Typical to prototyping, the study has gone through design, fabrication and assembly processes. The case of the prototype was patterned to the micro hydro generator which was discussed in the related literature. A small hole in the inlet pipe was mounted into the case to create a significant pressure. This was accomplished by welding the inlet pipe to the fabricated case, which was also done with water outlet. The turbine propeller was then placed in the case where it can be connected to the generator shaft. The turbine propeller has a 1 cm air gap between the casing and the propeller blades. The turbine propeller was made sure not to collide with the casing's side walls. The generator then was securely fastened to the casing with screws to avoid any movement or vibration in the device. The DC charger, battery, and inverter were all properly installed where they needed to be protected from getting wet, and the alternator was set up in accordance to the system design.

Testing of prototype were conducted in an hourly intervals during daytime of one cropping season. Researchers were able to accomplished ten trials for two a half months and most of them during sunny days. The testing set-up is depicted in Figure 6. The prototype was connected to a 6 HP diesel water pump, which is used to irrigate one-hectare farm land. A 3-inch diameter PVC pipe was used to connect the prototype to the diesel water pump. A one-meter head was also provided in the set up to maximize the power output. The diesel pump was operated and the measurement of needed data using various equipment was conducted. The set-up for the measurement of speed is shown in Figure 7.



Fig. 6. Installed Pico Hydro Electric Generator



Fig. 7. Speed Measurement

The measurement of the current flowing from the generator to the load was done using a multi tester. The probes of the tester were placed in series between the two terminals where generator DC current can be measured. Another but easier method used was by using clamp ammeter. The conductor connecting the inverter and the loads were clamped to measure the AC current that flows through the loads as shown in Figure 8.

The measurement of the voltage induced by the alternator was done using a multi tester. The probes of the tester were placed in parallel between the two terminals where alternator DC voltage can be measured and also parallel to the loads to measure the AC voltage.

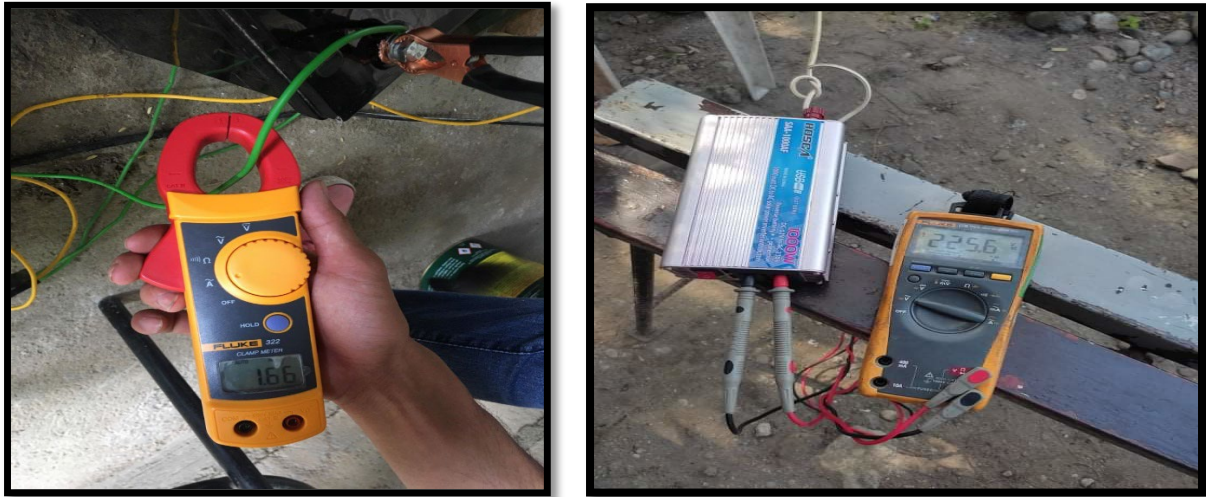


Fig. 8. Current Measurement

3D Printed Turbine

Figure 9 depicts the 3D printed Pelton turbine which was assembled or glued together and then painted to look more presentable. The Anycubic Mega S 3D printer used to print the turbine propeller is shown in Figure 10, which is owned by BPSU-AMREL. The material used was acrylonitrile butadiene styrene (ABS). The printing layer Height was set to about 0.2 mm and 50% infill. The printing took 8 hours to finish per part.

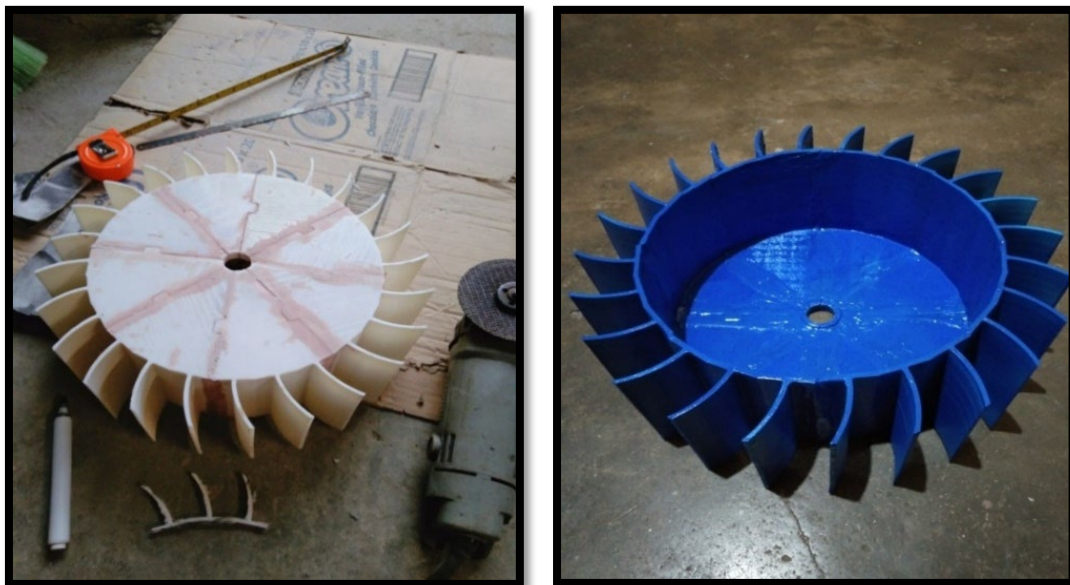


Fig. 9. Assembled 3D printed Turbine

ABS has chemical formula of $(C_8H_8 \cdot C_4H_6 \cdot C_3H_3N)_n$ and is produced by emulsion or continuous mass technique. The natural material is an opaque ivory color and is readily colored with pigments or dyes. The chemical properties of ABS are high resistance to diluted acid and alkalis, moderate resistance to aliphatic hydrocarbons, poor resistance to aromatic hydrocarbons, halogenated Hydrocarbons and alcohols [4].

ABS also shows excellent mechanical properties like hardness and toughness in nature and thus has good impact strength. Its flexibility stiffness is about 1.6 to 2.4 GPa while the tensile yield strength and toughness at low temperature are 29.6 to 48 MPa and 20 to 160 J/m respectively. The mentioned mechanical properties of ABS manifest viability as substitute to metal in terms of the water pressure

impact and rotational applications. ABS has also high dielectric strength and resistivity. Its dielectric strength is about 15.7 - 34 kV/mm while the resistivity is ranging from 14 to 16×10^{15} ohm-cm. This property of ABS indicates the amount of voltage required to reach electrical breakdown and become electrically conductive.

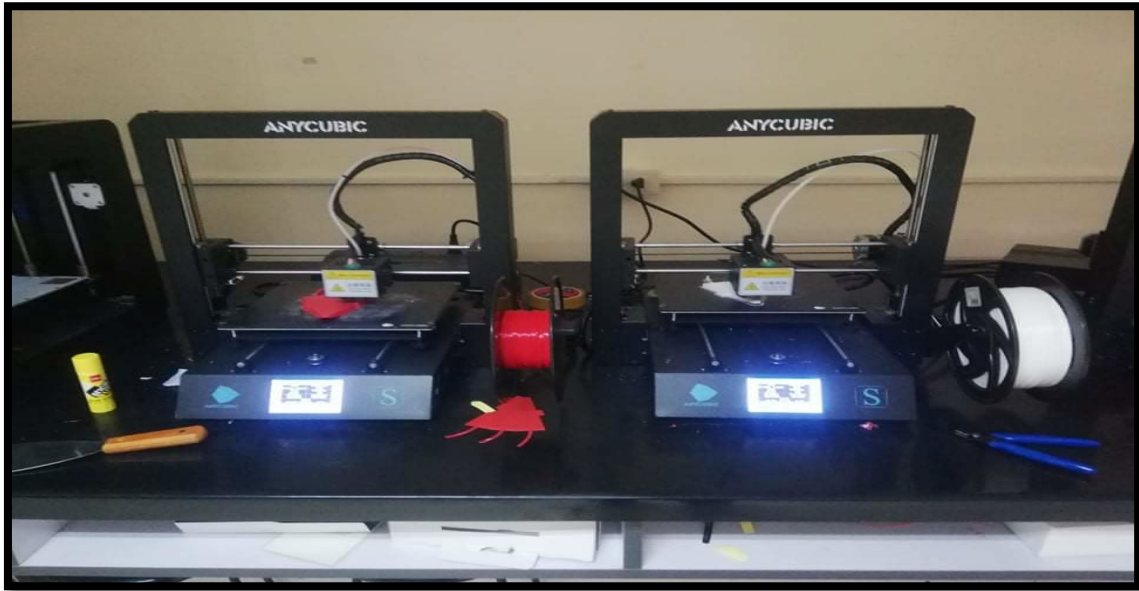


Fig. 10. Printing of the Turbine

Results and Discussion

The Pico-hydroelectric generator was tested to determine the mechanical parameters such as torque and speed, which are the two most critical factors to consider when evaluating the mechanical power [5].

Table 1. Volume Flow Rate Measurement

Trial	INTERVAL	AREA(m ²)	VELOCITY(m/s)	VOLUME FLOW RATE (m ³ /s)
1	9:00AM-10:00AM	0.00811	1.110m/s	0.009
2	10:00AM-11:00AM	0.00811	1.356m/s	0.011
3	11:00AM-12:00PM	0.00811	1.603m/s	0.013
4	12:00PM-1:00PM	0.00811	1.850m/s	0.015
5	1:00PM-2:00PM	0.00811	1.850m/s	0.015
6	2:00PM-3:00PM	0.00811	1.480m/s	0.012

In the diesel pump site, the available water flow rate was also measured. Table 1 shows that the flow rate varies from trial to trial among the six trials conducted on a specific day. It is learned that the flow rate increases from morning up to 2:00 PM and then slightly decreases from 2:00 PM onwards.

Table 2 shows the tabulated results of the measured alternator speed during the testing. The researchers performed six trials in different times of the day. It can be seen from the results that the alternator speed ranges from 475.8 rpm to 573.4 rpm based on the readings of a tachometer while the frequencies fall in the range of 52 to 57 Hz.

Table 2. Generator Speed and Frequency Analysis

TRIAL	INTERVAL	NO LOAD SPEED (RPM)	FULL-LOAD SPEED (RPM)	POLES	FREQUENCY
1	9:00AM-10:00 AM	475.8	470.8	12	52
2	10:00AM-11:00 AM	498.2	493.2	12	54
3	11:00-12:00 PM	533.7	528.7	12	56
4	12:00PM-1:00 PM	573.4	568.4	12	57
5	1:00PM-2:00 PM	573.4	568.4	12	57
6	2:00PM-3:00 PM	513.5	508.5	12	55

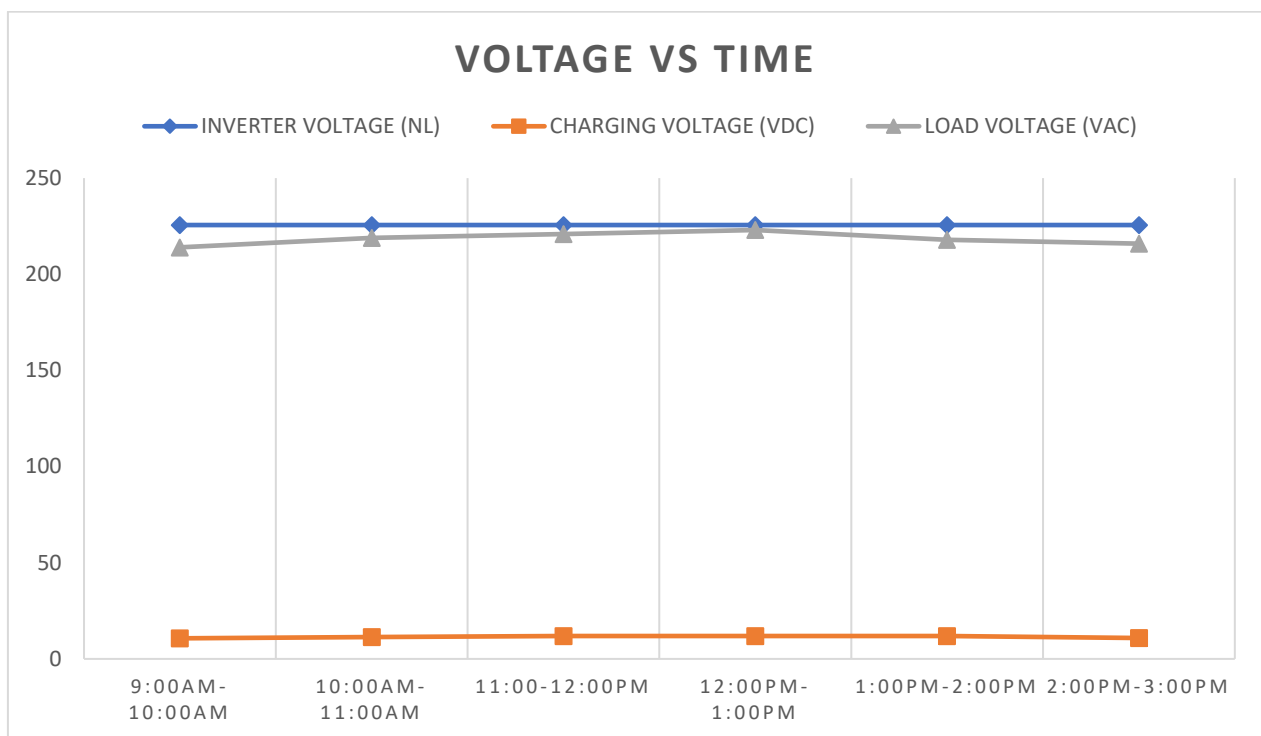


Fig. 11. Voltage Output

In one of the conducted tests, Figure 11 shows the voltage generation at different times of the day. The output voltages of the developed pico-hydro electric generator with 3D printed propeller were ranging from 10.7 V up to 11.9 V at speed 470 rpm to 568 rpm. In ten trials during one cropping period, the maximum voltage generation always occurred at 11 AM to 2 PM when the water flow rate and turbine speed were high. Generated voltage was DC because the alternator used and it was inverted to AC to be able to supply AC lighting loads.

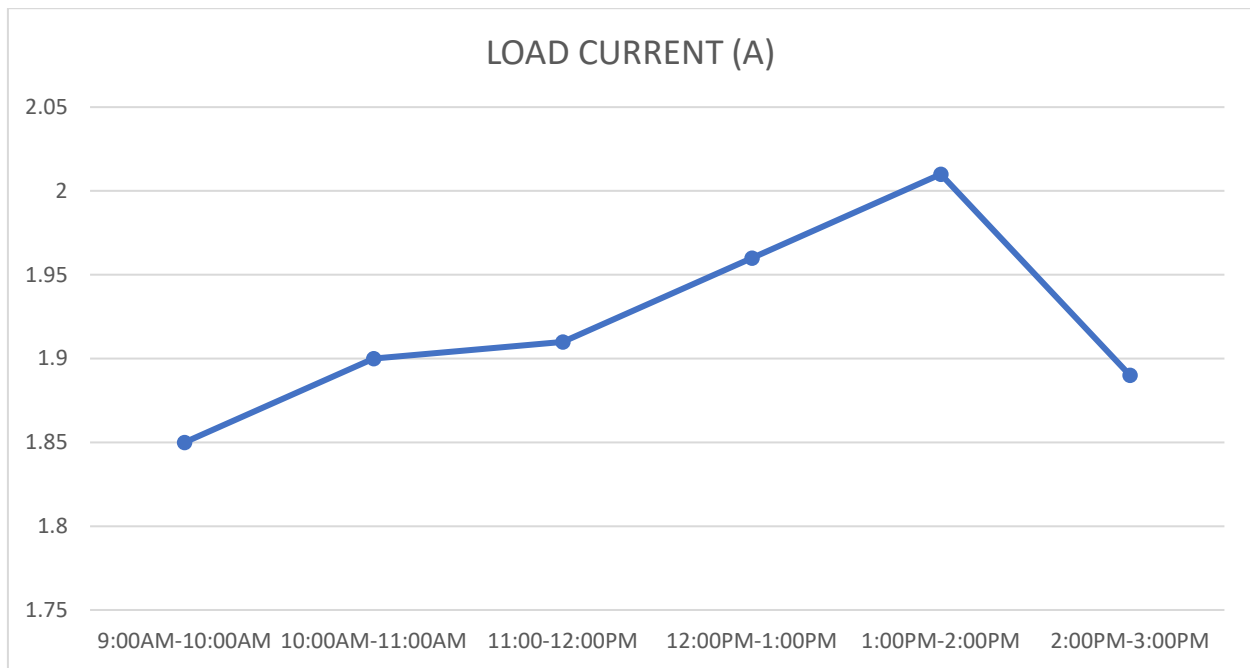


Fig. 12. Load Current

While the output currents of the prototype, as depicted in Figure 12 were ranging from 1.85 amperes up to 2.01 amperes at same speed range of 470 rpm to 568 rpm. Currents continually increased from 9:00 AM to 2 PM but drooped down from 2:00PM to 5:00 PM. This was also when the water flow rate and turbine speed were high.

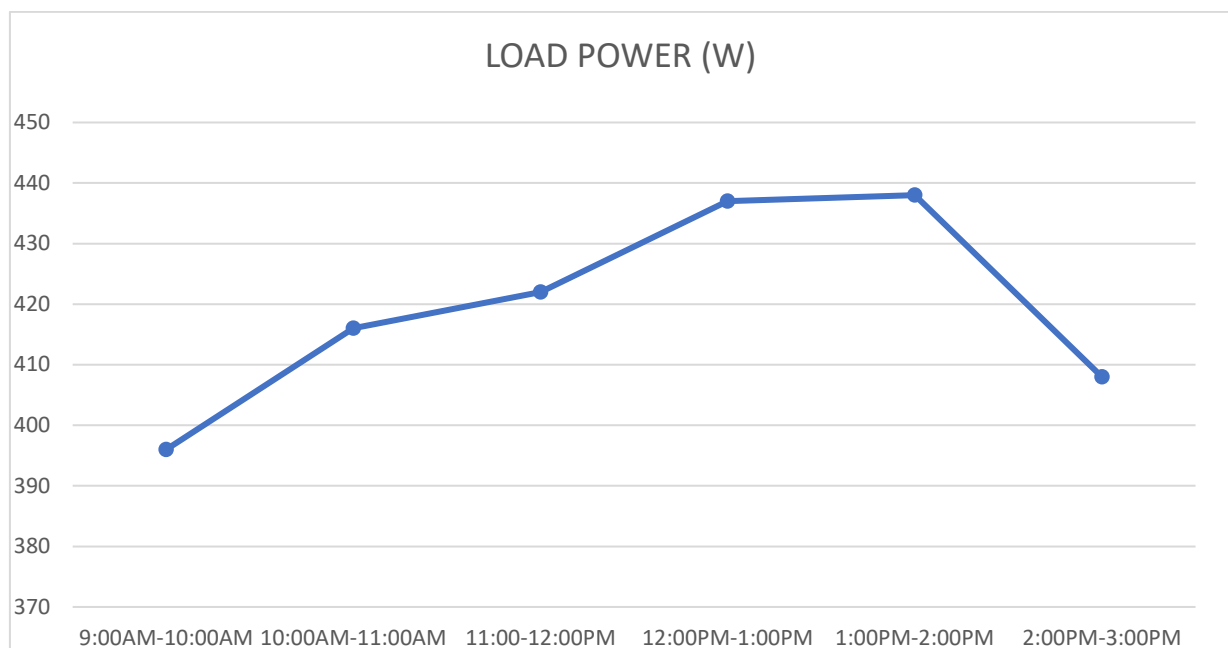


Fig. 13. Power Output

As a product of voltage and current, the output power in Figure 13 were ranging from 396 watts up to 438 watts at same of speed 470 rpm to 568 rpm. The graphical characteristics of the power generation in a day manifested instability and dependence to water flow rate and speed of rotation, therefore battery maybe used as storage for reliability.

Based from the results, the prototype can only generate small power suited for small electrical loads such as lighting. This can be of used to those farmers who want to light up their houses during night time by charging the battery using the prototype. The 250 AH battery is expected to be fully charged in 13 hours and can be used reliably for 8 hours lighting system during nighttime for a porch or patio.

Conclusion

The developed Pico Hydroelectric generator with 3D printed propeller was capable of producing 350 W to 400 W output power which can be used in lighting loads. In this study, the prototype was successfully customized to the diesel pump irrigation system used by Palay Farmers in Samal, Bataan.

The 3D printed Pelton type propeller was made useful as substitute to metal propeller. Plastic propeller that is sturdy, light weight and more economical than metal is one of the highlights of this study.

The over-all cost of the pico-hydro generator can be further minimized by considering other parts such as inlet and outlet pipes to be 3D printed plastic. Therefore, with fast 3D printing production, the ROI can also be shortened further.

However, the study needs further tests such as fatigue test on the 3D printed turbine to account interfacial mechanical weakness between layers as well as durability and to conclude the values of other mechanical properties based on its actual shape, placement and operational movements.

Acknowledgment

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