Research Article

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Development of Solar-Powered Water Pump with 3D Printed Impeller

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Abstract: This study discusses a solar-powered water pump system with 3D printed impeller which was developed to serve as water irrigation to small and medium farms in Bataan, Philippines. One kW solar PV system was used to power an electric motor that drives the centrifugal pump with impeller. In order to minimize the power consumption of the pump, the material of its impeller was changed from brass to plastic using 3D printing technology. The water system was also made automatic so that the water pump will run and stop at the desired schedule of the farmer. Furthermore, in order to provide power at night, storage batteries which are enough to supply the load, were incorporated in the system. Through a series of testing, it is concluded that it is more economical to use a 3D printed plastic impeller than metal impeller in watering small and medium farms considering that there were appreciative changes observed in relation to their water output and power consumption.

Keywords: Solar energy, water pump, impeller, PV system, 3D printing

1 Introduction

For crops to stay healthy and alive, water irrigation is highly needed. Through water pumps, the water is being transported from one place to another. Water pumps are widely used in the Philippines for irrigation purposes and centrifugal pumps are the most used because of its capability of transporting water at various capacity and elevation.

Investment costs for solar powered irrigation systems is dropping down and becoming viable option for farmers. In rural areas, solar powered irrigation are evidently being used where electric grid is not provided and diesel fuel is

quite expensive. The first PV pumping systems used centrifugal pumps that are usually driven by a DC or AC motor.

3D printing, more formally known as Additive Manufacturing (AM), is already being adopted for rapid prototyping and rapid manufacturing [1]. AM or 3D Printing processes build parts by adding material one layer at a time. AM processes require no special tooling or fixtures, so initial setup costs are kept to a minimum. 3D Printing is predominately used with plastics and nowadays for metals [2]. Some technologies can produce parts from ceramics, wax, sand, and composites. In 3D printing, the machine operator first prepares the digital file and then sends it to the machine, where it is printed with little human intervention. When printing is complete, the part needs to be cleaned and post-processed, which is the most labor-intensive aspect of the 3D printing manufacturing workflow [3].

The 3D printing of water pump components can be an option for manufacturers and users who desire to improve the parts or components and to create the pump itself more efficiently and at a lower cost. Incremental costs are not increased to produce 3D printed pump components, hence it allows the manufacturers and users to experiment with complex designs or customizations because some of parts or components when broken or lost are currently unavailable on the market [4].

In the observation on the performance of parts or components of conventional centrifugal water pumps particularly the impeller, this part needs not to be made of metal even though it plays a vital part in the pump system. An impeller is a rotating component or part of a centrifugal pump which transfers energy from the motor that drives the pump to the fluid being pumped by accelerating the fluid outwards from the center of rotation. The velocity achieved by the impeller transfers into pressure when the outward movement of the fluid is confined by the pump casing. An impeller is usually a short cylinder with an open inlet (called an eye) to accept incoming fluid, vanes to push the fluid radially, and a splined, keyed, or threaded bore to accept a drive shaft [5].

Generally, plastics have lower strength than metals but they have lower density and higher strains at failure. In some cases, plastics will have higher strength per

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unit weight than metals. Therefore, considering its lower cost and manufacturability with complex designs, plastics could have more advantages in many applications [6]. The impeller, in reference to its function and purpose, may be fabricated as plastic of lower density and high strains at failures. As a substitute to metal impeller, aside from lower cost and manufacturability, the plastic impeller lightened the load carried by the shaft which is driven by the motor. Thus, motor operating at lighter load consumes less electricity. However, sometimes motors are designed to be oversized depending on the application because sometimes they must accommodate peak conditions, such as when a pumping system must satisfy occasionally high demands [7].

The general objective of this study is to develop a solar-powered water pump for small and medium farms and ease small farm owners from spending at high electricity or gasoline bill consumed by their irrigation pumps. The research also aims to automate the water pump system and modify the impeller to minimize the power consumption of the motor. The vital results of this study could be highly significant and thoroughly beneficial to the farmers or farm owners. The automated water irrigation of the farm can be a big help to the production of crops. And due to the automation of the water irrigation, manpower is less needed in the process of watering the crops.

2 Solar-Powered Water Pump

Figure 1 depicts the battery-operated water pump system consisting of photovoltaic (PV) panels, charge control regulator with inverter, batteries, timer and water pump. The electric current produced by the PV panels during daylight hours charges the batteries, and the batteries in turn supply power to the pump anytime water is needed. Further-

Figure 1: System Overview

more, during at night and gloomy periods the system, can still deliver a constant source of power to water the farms.

The solar-powered water pump can be operated manually or automatically through the use of time relay device. The hybrid inverter, on the other hand, has more technological functions than a regular inverter. This inverter has its own protection from short circuit, overloading and overheating. It is also a smart technology because it can supply power which is directly coming from the solar panels and at the same time, charging the storage battery through the solar charge controller inside it. At the unavailability of the power from solar panels, it will automatically switch the source to the storage cells. To further protect the system from overcurrent, DC and AC circuit breakers were connected. The design of the prototype done in Autocad is depicted in Figure 2.

Figure 2: Design of Solar-Powered Water Pump System

It is known that the production of energy of the solar PV depends mainly on the weather condition. To be able to compensate the poor production of energy at night, Gel type battery storage was incorporated in the system for reliability. The developed solar powered water pump system was able to irrigate the adopted farm anytime of the day and night. Excess generated energy was also used in household needs like in lighting, radio and charging of gadget.

In the developed solar powered water pump system as shown in Figure 3, the system pumps water automatically at pre-set time from the reservoir and transports the water to a farm of about 10-meter distance at normal pressure. In the Philippines, because of the usual hot weather, the

Figure 3: Developed Solar-Powered Water Pump as installed in a small farm in Bataan

adopted farm is being watered three to four times a day for optimum harvest.

3 3D Printed Water Pump Impeller

3D printing or additive manufacturing is a process of making a three-dimensional solid object of practically any shape from a digital model. 3D printers print objects from a digital template to a physical 3-dimensional object. The printing is done layer by layer using plastic, metal, nylon, and over a hundred other materials. Its applications are continually increasing and it's proving to be a very promising technology.

Formlabs Form 2 SLA 3D printer was used to 3d print the impeller. It has a class 1, 405 nm violet laser and a build volume of $145 \times 145 \times 175$ mm. It has a laser spot size of $140 \mu\text{m}$ and a power of 250 mW. The printer can achieve printing resolutions (layer thickness) of 25, 50, 100 μm .

While for the material, Formlabs White Standard Greyscale Resins were used. The Grey Pro Resin, as commonly called, offers high precision, moderate elongation, and low creep. This material is great for concept modeling and functional prototyping, especially for parts that will be handled repeatedly [8].

The printed prototype from these materials has a matte surface finish, opaque appearance, and precise details. Moreover, Grey Resins are ready to use right off the printer and their neutral undertone also makes a great base for parts that will eventually be painted or undergo other finishing processes [9].

Commercially available 3D printers like Form 2 and Form 3 are consistently producing high-quality results

Figure 4: Metal and Plastic Impeller

with less time and effort. 3D printing the impeller was not difficult at all, in fact, it was easy and fast in three major steps. The printed plastic impeller is shown in Figure 4.

The first step in the 3D printing process conducted was the designing of the impeller 3D file using an ordinary CAD software. Then the CAD file was imported into the PreForm print preparation software which has the options for automatically orienting, supporting, and laying out the 3D models. The second step was the printing using the Form 2 printer. Its peel mechanism, wiper, and heated resin tank created a consistent, reliable print process of the impeller. Lastly, to come with best results and mechanical properties, all SLA parts were required with IPA rinsing, post-curing and post-processing.

4 Results

From several tests conducted using the prototype, parameters such as current in ampere, operating Voltage and flow rate were measured to support the claim of this study.

From the Tables 1 and 2 above, the average current consumption of the water pump motor with plastic impeller is 3.08 A with an average flow rate of 1.07 L/s. On the other hand, the average current consumption of the water pump motor with its original (metal) impeller is 3.64 A with an average flow rate of 1.10L/s. The current has decreased by 15.38%. At 220-V operating voltage, it follows that power consumption has also decrease by 15.38%.

In Table 3, at same volume of water being pumped and delivered to the farm, though the number of hours of operation was a little longer, the energy consumed using the plastic impeller was found to be lesser. Thus, it also follows that there will be cost reduction when the energy consumed is monetized at Php 10.00 per kW-hr.

Table 1: Testing the Pump using Plastic Impeller

TEST	Plastic Impeller			
	Ampere	Voltage	Power	Flow Rate
1	3.10 A	220 V	668.36 W	1.13 L/s
2	3.05 A	220 V	650.87 W	1.06 L/s
3	3.10 A	220 V	661.54 W	1.06 L/s
4	3.08 A	220 V	657.27 W	1.10 L/s
5	3.10 A	220 V	661.54 W	1.11 L/s
6	3.00 A	220 V	640.20 W	1.03 L/s
7	3.10 A	220 V	661.54 W	1.04 L/s
8	3.10 A	220 V	661.54 W	1.11 L/s
9	3.10 A	220 V	668.36 W	1.04 L/s
10	3.08 A	220 V	664.04 W	1.07 L/s

Table 2: Testing the Pump using Metal Impeller

TEST	Metal Impeller			
	Ampere	Voltage	Power	Flow Rate
1	3.62 A	220 V	780.47 W	1.11 L/s
2	3.65 A	220 V	786.94 W	1.09 L/s
3	3.60 A	220 V	776.16 W	1.10 L/s
4	3.62 A	220 V	780.47 W	1.13 L/s
5	3.70 A	220 V	789.58 W	1.10 L/s
6	3.63 A	220 V	774.64 W	1.10 L/s
7	3.68 A	220 V	785.31 W	1.09 L/s
8	3.66 A	220 V	789.1 W	1.11 L/s
9	3.63 A	220 V	782.63 W	1.11 L/s
10	3.61 A	220 V	778.32 W	1.11 L/s

Table 3: Summary of Output and Consumption

Material	No. of hours operating	Volume filled	Energy Consumed	Cost of Consumption
Metal	300.00	1188000L	251.16 kW-hr	P 2511.60
Plastic	308.41	1188000L	218.48 kW-hr	P2148.80

5 Conclusion

The general objective of this research is to ease the small and medium farm owners from spending in high electricity or gasoline bill consumed by their water pumps; through the development of solar PV powered water pump system with 3D printed impeller. This is attained through the following conclusions:

1. The developed solar water pump system was able to irrigate the adopted farm anytime of the day and

night. Excess generated energy was also used by the farm owner in his household needs like in lighting, radio and charging of gadgets.

2. The current has decreased by 15.38% when the 3D printed plastic impeller was substituted to the original metal impeller of the water pump. By 3D printing the water pump component (impeller), the water pump itself was innovated into more electrically efficient machine and can be reproduced at lower cost.
3. There was a slight change in the output volume of water pumped with the impeller changed into plastic. The pump with metal impeller can supply 1188000 liters in 300 hours while the modified pump with plastic impeller can supply 1188000 liters in 308.41 hours. However, the power consumption of the pump with plastic impeller, based on the measurement and computation, was found to be lower as compared to the power consumption of the pump with metal impeller.
4. The 3D printed plastic impeller was found to be reliable and rigid to perform the function of a conventional metal impeller through the series of testing conducted. Though, small chipping and cracks were observed in the 3D printed plastic impeller after more than 300-hour run. It is suggested the use of Rigid Resin materials which have the highest modulus of all Formlabs materials and has great heat resistance and stability [10].

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