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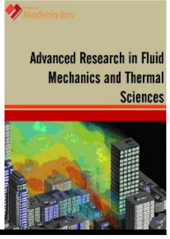

Storage System Manufacturability, Portability and Modularity for a Pico Hydro Turbine

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ABSTRACT

Pico hydro (<5 kW) is a type of power plant that could solve the problem of electricity access in remote, hilly regions with a water source, because investment and operational costs for such systems are lower than for wind turbines or solar PV. One obstacle often encountered in the use of pico hydro turbines is low RPM. It is possible to solve this problem using a DC generator and battery. This study will examine the design for a portable storage system that is easy to manufacture and operate. Three pieces of equipment are needed in designing such a storage system: a power source (DC generator), a battery with a capacity of 13-15 volts and 6 amperes, and a DC-to-AC converter. Storage system reliability is tested with four load variations: 12 Watts, 18 Watts, 37 Watts, and 46 Watts. In a 12-Watt load test, the storage system can operate for 355 minutes, while an 18-Watt test results in 137 minutes of operation, a 37-watt test lasts for 54 minutes, and a 46-Watt tests operates for 44 minutes. A Pelton turbine (<20 Watts) is used to charge the system. The Pelton turbine requires 905 minutes to charge a battery from a capacity of 23% to a capacity of 97%. To ensure the storage system operates well, charging is also enabled using solar PV (30-40 watts). By using solar PV, the storage system was charged within 476 minutes (08:42-16:38 IWST). Such a storage system provides good modularity because it weighs only 38 kg and takes up a volume of 0.016 m^3; it is also portable, easy to use, and easy to manufacture, as the key components are a battery and a DC-to-AC converter.

Keywords:
pico hydro, storage system, battery

1. Introduction

Pico hydro (<5 kW) is a type of power plant that could solve the problem of electricity access in remote, hilly regions [1] with a water source, because investment and operational costs for such systems are lower than for wind turbines or solar PV [2]. Currently, there are approximately 2519 villages in Indonesia without access to electrical energy [3]. However, one obstacle often encountered in the use of pico hydro turbines is low RPM. This leads to design requirements for pico hydro turbines that are different than those for larger plants [4].

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Numerous studies have examined ways to improve turbine types and performance. Williams and Simpson [5] examined penstock size while keeping investment costs as low as possible. Lahimer *et al.,* [6] examined the cost effectiveness of turbines with high efficiency at low head and flow rates specific to remote areas. Ramos *et al.,* [7] optimised the energy converter (blades or buckets) in low head conditions using CFD and experimental methods; their optimisation method used the theory of turbomachinery to evaluate hydrodynamics behaviour. Tasneem *et al.,* [8] studied the effect of flow rate at low head conditions (<10 meters), determining that a suitable turbine was a propeller. Williamson *et al.,* [3] conducted a quantitative and qualitative analysis of 13 types of pico hydro turbines through a literature review. Ridzuan *et al.,* [9] analysed the piping system used in pico hydro; their analysis aimed to determine the electrical potential of power contained by water to maximise turbine performance, and their test results led to the conclusion that pico hydro is feasible for electrical energy storage systems and has potential for further improvement and future research.

There are three main components in a pico hydro plant: the turbine, the transmission system, and the generator. Haidar *et al.,* [10] concluded that the typical generator suitable for use with a pico hydro turbine is a DC generator. DC generators are considered suitable because they can generate electricity at low RPM, and they are low-priced for sizes below 2 kW [11]. With an AC generator, the voltage is relatively low; if it is directly connected to the load (light and other electronic equipment), the result can be reduced lifetime of the electronic equipment. Gladstone *et al.,* [12] recommended a battery as a suitable electrical storage system for pico hydro. Thus, the power from a pico hydro DC generator must first be stored and then converted to AC, due to the fact that so much electronic equipment uses AC current.

To function as an effective electrical energy storage system, the battery should ideally be portable. Portability is also an important aspect for systems used in remote areas. However, a review of the literature found no study that explains in detail how to easily manufacture and operate a pico hydro turbine electrical energy system. This study will design a portable electrical energy storage system that is easy to manufacture and operate. In addition, this system will use simple electronic components so that, if damage occurs, parts can easily be repaired or replaced.

2. Methodology

Two main components are needed in this storage system design: a battery of 14.4-15 volts and <6 amperes, and a DC-to-AC converter as shown in Figure 1. Voltage and current measurements are taken using a multimeter. A Phocos-type CNX is used to record data (voltage and current) to a desktop. Battery capacity is measured and recorded as a percentage. Data was collected four times based on four load variations: 12 watts, 18 watts, 37 watts, and 46 watts. The reliability of the storage system was tested based on how long it performed until the battery capacity reached 23%.

Testing was performed on a Pelton turbine with a capacity of 20 watts at a head of 5 m and a flow rate of 2.7 litres/s [13]. Charging began at 08.42 IWST (Indonesia Western Standard Time). For reliability, charging was also performed using two solar PV panels arranged in parallel to increase the current [14]. In addition to generating a DC current, the system can also save power generated in a storage system. Testing took place in the tropical region of Depok West Java Indonesia in July and August [15].

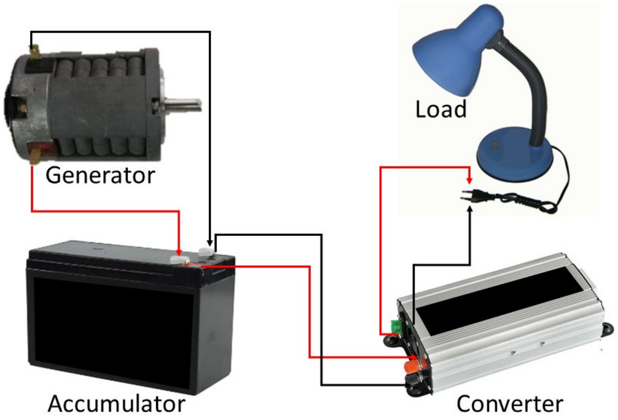

Fig. 1. Schematic of storage system

3. Results and Discussion

3.1 Storage System Operational Time

As designed, the storage system performed as depicted in Figure 2, which shows that, the greater the power or load, the shorter the operational time of the storage system.

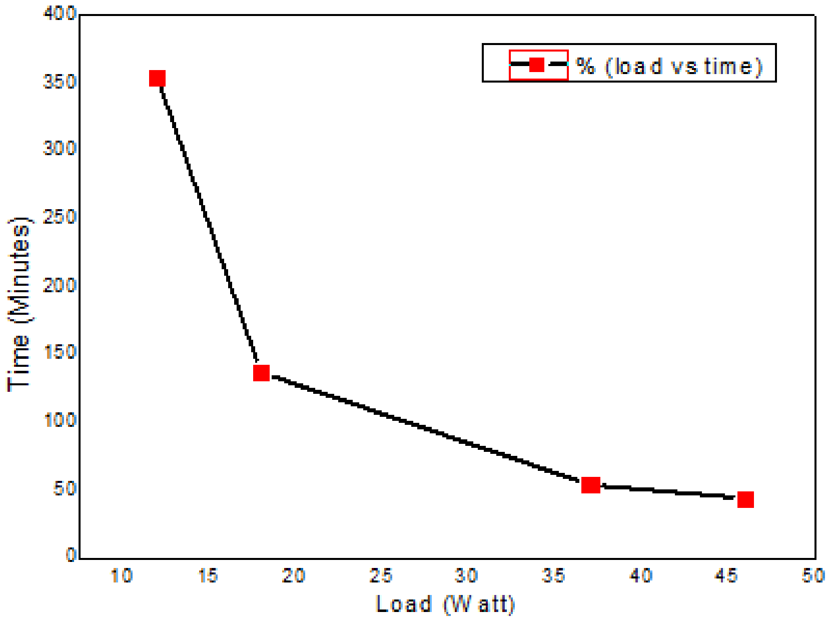

Fig. 2. Loads and operational times

Storage system testing began at a battery capacity of 97%. Figure 2 shows the following performance results: a 12-watt system can operate for 355 minutes, an 18-watt system can operate for 137 minutes, a 37-watt system can operate for 54 minutes, and a 46-watt system can operate for 44 minutes. Test results showed that, with a load of 46 watts, the storage system was working properly, with 60 watt-hours of battery storage.

3.2 Storage System Charging Time

The storage system was charged using a Pelton turbine. The turbine generates 83 watts of mechanical power with 83% efficiency. When the turbine was coupled to the generator, a 2/3 turbine speed was used to rotate the generator, because of the turbine's small torque of 3.2 Nm. Test results showed the voltage and current generated by the turbine was 14-16 volts and 0.8-1.2 amperes. As Figure 3 shows, the storage system charging rate for the Pelton turbine was relatively constant when compared with solar PV; this is because there is no fluctuation of head and flow rates. The storage system reached a capacity of 97% at 23.47 IWST, for a charging time of 905 minutes.

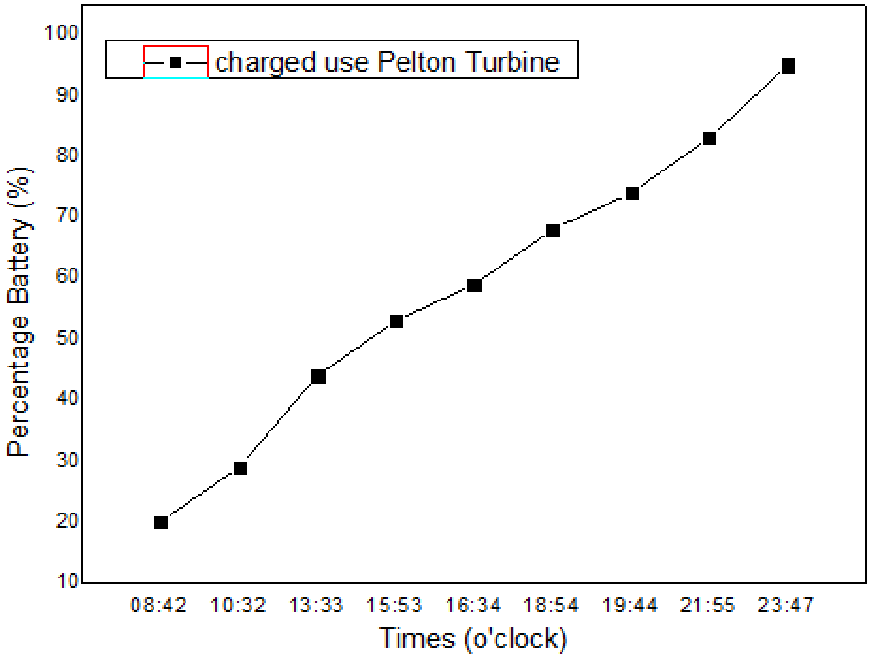

Fig. 3. Charging time using Pelton turbine

Charging by solar PV also began at 08.42 IWST. This was to ensure the maximum intensity of sunlight from the beginning to the end of charging. This resulted in an improved storage system charging rate between 10.22 – 14.56 IWST. At 08:42-10:22 IWST, the voltage and current of the storage system measured 13.6-15.6 volts and 0.9-1 amperes; at 10:22-14:56 IWST, the voltage and current of the storage system measured 19 volts and 1-1.9 amperes. This is because, at that time range, sunlight was at maximum intensity. In addition, at this time, Depok (West Java-Indonesia) was experiencing the peak of the dry season, so that the heat energy generated by the sun was maximised. The charging process by solar PV is shown in Figure 4. The storage system reached a capacity of 97% at 16.36 IWST, for a charging time of 476 minutes. Charging by solar PV is faster than for the Pelton turbine because it has a capacity of 200 watts with 15-20% efficiency (30-40 watts). Based on these test results, a hybrid storage system using both solar PV and a water turbine can save charging time.

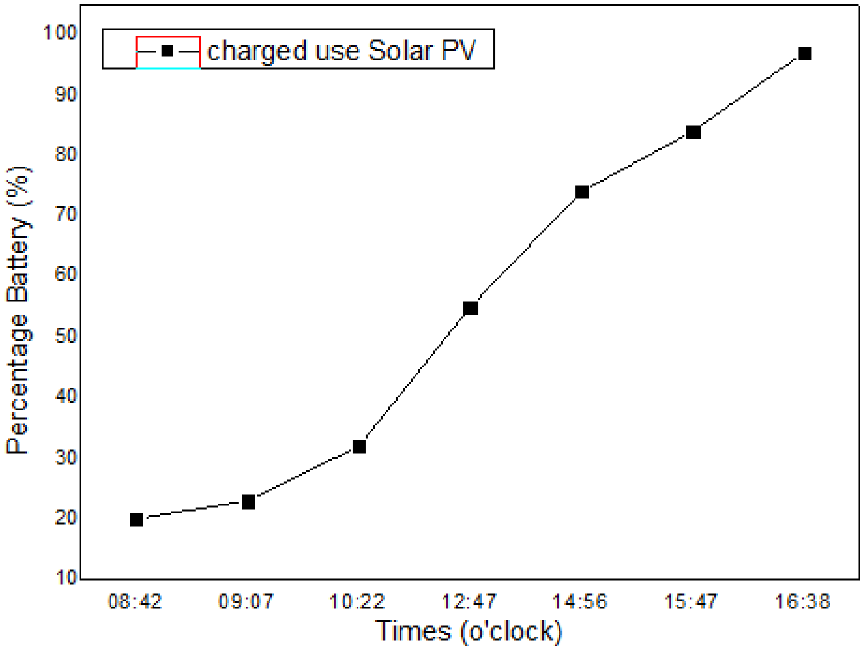

Fig. 4. Charging time using solar PV

3.3 Discussion

Storage systems are designed to operate normally within a defined range of capacity percentage. This can be seen from the total operating time for each load used and the capacity of power that can be stored by the battery. If a higher cost can be supported, the battery can be replaced by one with a larger capacity, in accordance with a maximum power converter of 500 watts. In the charging process for such a storage system, the time for charging with solar PV is dependent on the location's weather as well as where the solar PV is installed; charging with the Pelton turbine can continue without solar PV, although the time required is longer. Consequently, a hybrid system can be used to increase storage system reliability.

Battery storage system reliability was also studied by Maher *et al.,* [16]. The results of that study, with an investment of $70, were almost the same as those for this study, which had an investment of $90. The investment in this case is higher because the saved power can be converted to AC power directly. In addition, this storage system can both save and discharge power to loads at the same time.

4. Conclusions

The results of this study demonstrate that a battery storage system is suitable for electrical energy generated by pico hydro. The design of such an electrical energy storage system offers good modularity, with a weight of only 38 kg and a volume of 0.016 m^3. Manufacturing such a system is easy, as the key components are a battery and a DC-to-AC converter, and the system is also portable and easy to use directly. The storage system can be charged on a continuous basis using a Pelton turbine, and can be combined with solar PV to create a hybrid system with increased reliability. Such a storage system can both save and discharge power to loads at the same time, and can be built for an investment of only $90.

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