Performance analysis of Pico Hydro-Solar Photovoltaic Hybrid System

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Abstract. This paper presents experimental results from the operation of the prototype of Pico Hydro-Solar Photovoltaic Hybrid System. This device includes a pico hydro power with a capacity of 600 VA, a 3x200 WP solar panel, 4x60Ah energy storage, solar charge controller, a 1500 W inverter, and a 15-200 watt variable load. In this experiment, measurements of the current flow and terminal voltage were carried out at the output of photovoltaic, picohydro, battery, and inverter at various different load values, ranging from 15 watts to 200 watts. Measurements are made during the day when the intensity of solar radiation is quite high. The measurement results show that the output voltage on each component is relatively stable at various load values, and the load energy requirements are supplied more by solar photovoltaic components in sunny weather and more by pico-hydro in cloudy weather.

1. Introduction

Indonesia is one of the countries with the highest growth rate in energy consumption in the world. The total final energy consumption (without traditional biomass) in 2018 was around 114 MTOE derived from 40% transportation, 36% industry, 16% household, 6% commercial sector and 2% other sectors [1]. This total energy consumption has increased by 3.17% from 2017 which was 110.5 MTOE [2].

The declining fossil energy production especially crude oil and the global commitment in reducing greenhouse gas emission have encouraged the government to increase the role of new and renewable energy continuously to maintain energy security and independence. As stated in Government Regulation No. 79 of 2014 on National Energy Policy, new and renewable energy mix target is at least 23% by 2025 and 31% by 2050. Indonesia has respectable potential of new and renewable energy to meet the primary energy mix target as seen in Table 1 below [1].

Table 1. Renewable energy potential [1].

| Energy Source   | Potential          |
|-----------------|--------------------|
| Hydro           | 94.3 GW            |
| Geothermal      | 28.5 GW            |
| Bioenergy       | Bio PP: 32.6 GW and |
|                 | Biofuel: 200 Thousand bpd |
| Solar energy    | 207.8 GWp          |
| Wind            | 60.6 GW            |
| Ocean energy    | 17.9 GW            |
The total renewable energy potential is equivalent to 442 GW for power plant, while 200 thousand bpd (barrel per day) of biofuel and biogas are used as fuel in transportation, household, commercial sector and industry. New and renewable energy (NRE) for power plant in 2018 was 8.8 GW or 14% from the total 64.5 GW of power plant capacity (fossil and non-fossil).

NRE and alternative clean energy generation technologies have attracted a lot of concern because they have several advantages such as being able to reduce dependence on fossil energy use, especially coal and oil; can provide electricity on a regionally local scale; able to utilize the potential of local energy resources, and environmentally friendly. Although Indonesia’s geographical condition has the potential for renewable energy development, the transition to this energy is still a major challenge. The low NRE utilization for electricity generation is due to the high NRE power plant production cost. Thus, it is difficult to compete with fossil fuel power plant especially coal. Furthermore, the lack of support to domestic industry concerning renewable energy power plant components and the difficulty in obtaining low interest-financing have contributed to the slow development of renewable energy.

Another thing that causes NRE to be less competitive compared to conventional energy sources is uncertainty and intermittence caused by dependence on weather, and high initial costs [3]. Therefore, extensive research on renewable energy technology has been carried out throughout the world that has resulted in significant developments in renewable energy materials, reduced costs of renewable energy technologies, and increased efficiency. The results of these studies are the development of a power generation system that integrates two or more energy sources and operates them in hybrid system mode. Hybrid Renewable Energy Systems (HRES) can be a combination of one renewable energy source and one conventional energy source, or more than one renewable energy source with or without conventional energy sources, working in a standalone mode or connected to a pre-existing network [3-5]. With hybrid systems, several alternative energy sources are expected to complement each other to a certain extent and achieve higher total energy efficiency than can be obtained from a single renewable energy source.

Related to renewable energy sources, just behind the Electric Power Engineering Laboratory, Department of Electrical Engineering Education, Indonesia University of Education (UPI), there is a river flow based on measurement results having an average discharge of 0.23 m$^3$/s with a water fall height of 2.8 m (head). At 50% system efficiency [4], the potential power generated is around 3.16 kW. Based on this potential, this research will design and build a power plant in the form of a Pico Hydro Power Plant (PHP). Furthermore, this PHP will be combined with a Solar Photovoltaic (SPV) which will also be developed at the site to form a prototype of Hybrid Power Plants (HPP). Based on data from Surface meteorology and Solar Energy (SSE), NASA, in 2017, the average solar radiation energy at that location is 10.02 kWh/m$^2$/day, which is very potential to produce solar electricity.

2. Hybrid Power Plants (HPP)

Hybrid Power Plants (HPP) is a system that combines several types of power plants, in general between fossil fuel-based power plants and renewable energy-based power plants. Generally, power generating systems that are widely used for HPP are diesel generators, solar photovoltaic (SPV), microhydro, and wind power plant. HPP is a solution to overcome the fuel crisis and the lack of electricity in remote areas, small islands and also in urban areas.

The HPP can operate parallel connected to the main grid (on-grid operation), stand alone (off-grid operation) or connected to a micro grid, with other generators working in parallel (grid supporting mode). The configuration of stand-alone hybrid systems can be divided into three types consisting of serial, parallel and switched systems; while the grid-connected hybrid system consists of centralized dc-bus, centralized ac-bus and distributed ac-bus. This configuration can be seen in figure 1 and 2 [3,6].
Figure 1. Various stand-alone hybrid system configurations.

(a) DC-Series

(b) AC-Series

(c) Parallel

(d) Switched

Figure 2. Various grid-connected hybrid system configurations.
3. Systems design
The system developed in this study has the configuration of stand-alone hybrid switched systems, as shown in figure 3.

![System Diagram](image.png)

**Figure 3.** Pico Hydro-Solar Photovoltaic Hybrid System scheme.

The hybrid renewable energy system developed consists of the following components:

- The pico hydro power plant consists of an induction generator with a rating of 220V / 600VA, 50 Hz which is driven by Propeller Open Flume Turbine. Water flow used to drive turbines has an average flow of 0.23 m$^3$/s and a head of 2.8 m. This generator is equipped with an Automatic Load Controller to adjust the load balance.
- Solar panels with 3x200 Wp capacity equipped with MPPT Solar Charge Controller. This solar panel serves to convert the sun's radiant energy into electrical energy. The average solar radiation energy at the study site during 2017 can be seen in figure 4.
- A battery with a capacity of 4x60 Ah which functions to store direct current energy.
- Rectifiers that convert AC electrical energy from generators into DC electric energy. This rectifier functions to change the voltage 220VAC to 12VDC.

![Irradiance and Insolation Clear Index](image.png)

**Figure 4.** Solar irradiance and insolation clear index in UPI-Bandung, 2017.

(Data processed from: [https://power.larc.nasa.gov/data-access-viewer/](https://power.larc.nasa.gov/data-access-viewer/))
• Inverter which functions to change the voltage 12VDC to 220VAC, 50 Hz, with a capacity of 1500 watts.

In this system, AC loads can be supplied in two ways: (1) directly from the AC generator; or (2) from a DC source that is converted into an AC source by an inverter. This DC source can come from batteries, from solar cells, or from AC generators that have been converted into DC by rectifiers. This research is focused on the performance of hybrid energy systems that supply AC loads through (2).

4. System performance analysis

After the installation process of the developed HPP is carried out, the next step is the testing process to find out its performance. This testing is done by measuring current and voltage in parts as shown in figure 5. In this test, measurements of current and/or voltage on solar cell output <1>, MPPT solar charge controller <2>, rectifier <4>, battery <5>, inverter input <6>, and inverter output/load input <7>.

![Figure 5. Measurement scheme.](image)

After taking measurements during September and October 2019 in the time range of 10:00 to 14:00 WIB, the average value of the measured quantities was obtained. The results of these measurements are shown in table 2 for relatively sunny weather conditions and table 3 for relatively cloudy weather. Referring to Figure 5, according to Kirchoff's Law I, the DC bus applies that \( I_2 + I_4 = I_5 + I_6 \). By considering the electric current data in Table 1, it can be seen that in general, the value of \( I_2 + I_4 \) is almost the same or close to the value of \( I_5 + I_6 \), which means that the performance of the current divider is appropriate. However, at certain loads, this has not been fulfilled, for example at 100, 175 and 150 watt installed loads. The greatest deviation in this condition (sunny weather) occurs at a 175 watt installed load. Data on relatively cloudy weather conditions (table 3) also shows the same results, with deviations occurring at installed loads of 100, 125, and 175 watts and the deviation at 125 watts load has the greatest value.

Ideally, the difference in current flow should be zero. In the measurement data table, it can be seen that there is no zero current difference; some are close to zero, and some are greater than zero. This is possible because the reading of the measuring instrument is not done simultaneously and a sudden decline in the output of the solar cell due to changes in the intensity of solar radiation.
Table 2. Current and voltage measurement results in Pico Hydro-Solar Photovoltaic Hybrid System in relatively sunny weather conditions.

| Solar PV Output | MPPT Output | Rectifier Output | Battery | Inverter Input | Inverter Output |
|-----------------|-------------|------------------|---------|----------------|----------------|
| Installed Load  | $V_1$ (V)   | $I_2$ (A)        | $V_2$ (V) | $I_4$ (A)      | $V_4$ (V)      | $I_5$ (A)      | $V_6$ (V)      | $I_7$ (A)      | $V_7$ (V)      | $P_{load}$ (W) |
| 0 W             | 18.83       | 15.60            | 11.79    | 12.36          | 12.97          | 13.28          | 0.47           | 13.21          | 0.87           | 239.4          |
| 15 W            | 236.7       | 236.8            | 237.1    | 237.3          | 237.8          | 239.3          | 0.87           | 239.4          | 0.87           | 239.4          |
| 25 W            | 239.4       | 239.8            | 240.3    | 240.6          | 241.0          | 241.3          | 0.87           | 241.6          | 0.87           | 241.6          |
| 50 W            | 242.0       | 242.3            | 242.6    | 242.9          | 243.2          | 243.5          | 0.87           | 243.8          | 0.87           | 243.8          |
| 75 W            | 245.4       | 245.7            | 246.0    | 246.3          | 246.6          | 246.9          | 0.87           | 247.2          | 0.87           | 247.2          |
| 100 W           | 248.8       | 249.1            | 249.4    | 249.7          | 250.0          | 250.3          | 0.87           | 250.6          | 0.87           | 250.6          |

Note: The negative sign (-) on $I_5$ indicates the battery is discharging, and the positive (+) sign indicates the battery is charging.

Table 3. Current and voltage measurement results in Pico Hydro-Solar Photovoltaic Hybrid System in relatively cloudy weather conditions.

| Solar PV Output | MPPT Output | Rectifier Output | Battery | Inverter Input | Inverter Output |
|-----------------|-------------|------------------|---------|----------------|----------------|
| Installed Load  | $V_1$ (V)   | $I_2$ (A)        | $V_2$ (V) | $I_4$ (A)      | $V_4$ (V)      | $I_5$ (A)      | $V_6$ (V)      | $I_7$ (A)      | $V_7$ (V)      | $P_{load}$ (W) |
| 0 W             | 239.4       | 239.8            | 240.3    | 240.6          | 241.0          | 241.3          | 0.87           | 241.6          | 0.87           | 241.6          |
| 15 W            | 242.0       | 242.3            | 242.6    | 242.9          | 243.2          | 243.5          | 0.87           | 243.8          | 0.87           | 243.8          |
| 25 W            | 245.4       | 245.7            | 246.0    | 246.3          | 246.6          | 246.9          | 0.87           | 247.2          | 0.87           | 247.2          |
| 50 W            | 248.8       | 249.1            | 249.4    | 249.7          | 250.0          | 250.3          | 0.87           | 250.6          | 0.87           | 250.6          |
| 75 W            | 252.4       | 252.7            | 253.0    | 253.3          | 253.6          | 253.9          | 0.87           | 254.2          | 0.87           | 254.2          |
| 100 W           | 255.8       | 256.1            | 256.4    | 256.7          | 257.0          | 257.3          | 0.87           | 257.6          | 0.87           | 257.6          |

Note: The negative sign (-) on $I_5$ indicates the battery is discharging, and the positive (+) sign indicates the battery is charging.

Considering the output voltage, this prototype also showed quite stable performance, especially the MPPT solar charge controller ($V_2$) output voltage, picohydro output voltage after passing the rectifier ($V_4$), battery voltage ($V_5$), and inverter output voltage ($V_7$). There is a decrease in voltage on these components with an increase in load, but relatively insignificant. While the input voltage of the inverter ($V_6$), its value tends to decrease with the increase in installed load. The performance of this voltage can be seen in figure 6.

Figure 6. The output voltage as a function of the installed load for the data in: (a) Table 1 (sunny weather); (b) Table 2 (cloudy weather).
The data in Tables 2 also show that with the increase in installed load, the output current generated by solar photovoltaic and generators both increases. However, the magnitude of the current in the solar photovoltaic ($I_2$) is much greater than the magnitude of the current in the generator ($I_4$) for a relatively equal voltage ($V_2 \approx V_4$). This shows that the electrical energy needs of the load is more supplied by solar photovoltaic. For more details, consider the graph in Figure 7 (a) below. A different phenomenon is shown by the data in Table 2. In cloudy weather conditions, an increase in installed load will increase the generator output current, but does not increase the solar photovoltaic output. This can be seen in Figure 7 (b).

![Figure 7](image)

**Figure 7.** The output current of solar photovoltaic and generators as a function of the installed load for the data in: (a) Table 1 (sunny weather); (b) Table 2 (cloudy weather).

5. Conclusion

Based on the experimental results on the hybrid energy system the following conclusions are obtained:

- The system has a relatively stable output voltage, especially at the MPPT solar charge controller output voltage, the Pikohidro output voltage after passing through the rectifier, and the battery voltage. While the input voltage of the inverter, its value tends to decrease with the increase in installed load.

- In supplying load energy demand, in sunny weather conditions, electrical energy derived from solar photovoltaic is more dominant than electrical energy from pikohidro, and in cloudy weather conditions, electrical energy derived from pikohidro is more dominant.

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