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Small scale hybrid power generation for remote area electrification

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Abstract. Javan Langur Centre (JLC) is a facility dedicated to the treatment of langur, an endangered primate species. To support the maintenance and rehabilitation activities, the need for electrical energy is a vital. In this facility, electrical energy is needed for lighting and baby primate's incubator with a total power of around 120 watts. There is no electricity grid included in this area and the supply of electrical energy is still very dependent on the gen-set owned by the residents which is located approximately 2 km from JLC, making it less efficient. In terms of natural energy resources, JLC has the availability of water sources that originate from small streams making it possible to develop pico-hydro technology. There has been built a pico-hydro power generation with a potential electric power that can be generated approximately 300 watts. However, the water discharge of the river stream in that area is quite low, around 0.00035 m3/s, that makes the efficiency of the power generation is 10% only. In other words, the actual electrical power that can be generated is around 30 watts. So as to meet the electrical power needs at JLC, another electrical energy source is needed. One alternative is to install solar cells or photo voltaic (PV) with a capacity of 100 watts peak. The output power of these two energy sources can be combined and regulated by applying Hybrid Power Generation technology. With the application of this technology, the need for electrical energy in the JLC area can be met.

1. Introduction

Javan Langur Centre (JLC) is the Javan Langur conservation centre, one of the primate species that is protected due to extinction, which is located 10 km from the centre of Batu City, East Jaw, Indonesia. To support daily activities, JLC has difficulties in meeting electricity needs. So far, electricity in the JLC has been supplied from the Coban Talun tourist area, which is more than one kilometer away.

Currently, a pico-hydro power plant has been developed in the area with an installed generator power of 600 watts. However, the actual power that can be generated from this generator is only around 120 watts. This is related to the very low flow of water flowing in the JLC area, which is around 0.00035 m3 / second. Low water discharge results in low turbine speed. In the end, the generator output is also low. To overcome the shortage of electricity supply in the JLC of approximately 120 watts, photo voltaic (PV) with a capacity of 100 watts peak was installed.

These two generators, namely pico-hydro and PV, are operated in a hybrid power generation system, with an output power of about 130 watts. This total power will be able to meet the electricity needs of the JLC.

2. Hybrid power plant

Hybrid Power Plant is a type of power plant that has two or more energy sources to generate electrical energy. A power plant with a hybrid system is an alternative that can be used to meet electricity needs in areas far from the existing distribution network [1].

One example of a hybrid power plant is a combination of a Pico-hydro Power Plant (PHPP) and a Solar Power Plant (SPP). In terms of system reliability, this generating combination is very beneficial, especially in areas with abundant water sources and adequate sun exposure. The Pico-hydro Power Plant can operate and produce output power 24 hours a day, as long as the water source is still available. Meanwhile, a solar power plant can operate as long as there is solar radiation, generally 10 hours a day.

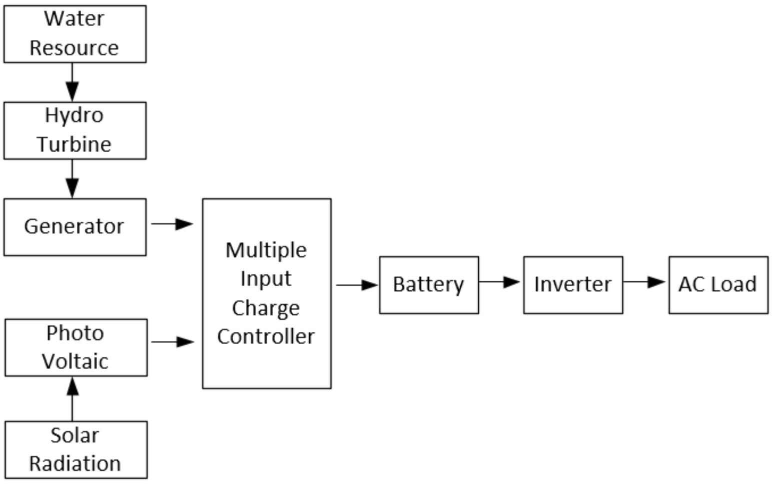

Figure 1. Block diagram of PHPP-SPP hybrid power plant.

From Figure 1, it can be seen that the hybrid generator above requires a Multiple Input charge controller, namely a charge controller that has more than one input. The input can be either AC voltage or DC voltage, depending on the type of multiple input charge controller itself. Furthermore, the output of multiple input charge controllers will be connected to the battery / accumulator. Then connected to the inverter, before finally connected to the AC load.

2.1. Solar Power Plant (SPP)

Solar Power Plant (SPP) is a power plant that utilizes solar energy sources to generate electrical energy using photovoltaic (PV) or what is often called solar cells [2-4]. Solar energy is renewable, environmentally friendly and easily converted to electricity. Even though SPP is a new, renewable energy that will never run out, this energy has one weakness, namely the unavailability of continuous energy sources because solar energy is only available during the day. So that at night, there is no electric energy that is charged into the battery [6,7].

Conventional solar cells work using the p-n junction principle, which is a junction between p-type and n-type semiconductors. When photons hit or strike a semiconductor material, such as silicon, then the material will release electrons and cause a potential difference to form between the surfaces exposed to the sun's photons [2].

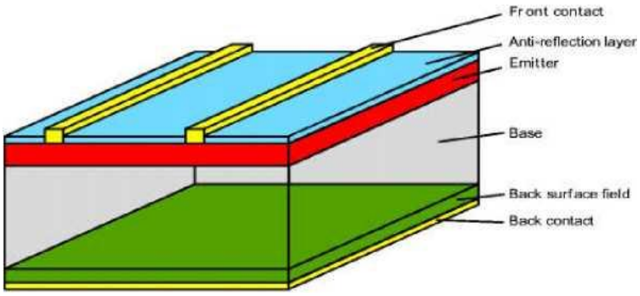

Figure 2. Inside a photovoltaic cell [2].

The maximum output power can be calculated by the formula:

$$\text{Pmaks} = \text{Vmodul x Imodul}$$

P is the maximum power of the Solar Panel (W), V is the Maximum Voltage (V), and I is the Maximum Current (A) [2].

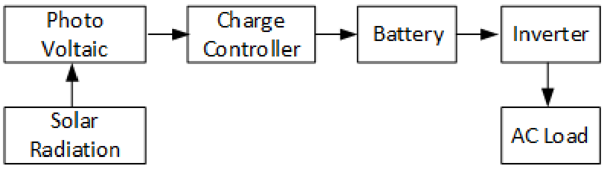

Figure 3. Block diagram of a solar power plant.

As seen in Figure 3, a Solar Power Plant utilizes PV to convert solar radiation into electrical energy. The output from the PV will be entered into the charge controller. The output from the charge controller will be used to charge the battery. Furthermore, the battery is connected to the inverter to convert the DC voltage from the battery into AC voltage which is then used to supply AC loads.

2.2. Pico-hydro Power Plant (PHPP)

The Pico-hydro Power Plant is in principle the same as other hydroelectric power plants, utilizing different heights and the amount of water discharge in the flow of irrigation channels, rivers or waterfalls [8]. This water flow is used to generate electrical energy by using a water turbine installed with a generator and the energy is stored on the battery, through a charge controller. Before it can be used to supply AC loads, the output of the battery must pass through the inverter, to convert the DC voltage into AC voltage.

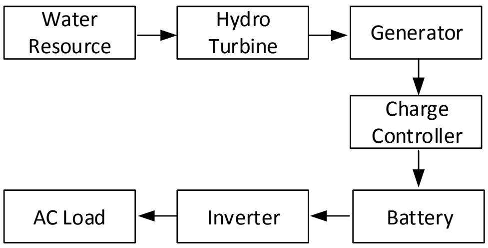

Figure 4. Block diagram of Pico-hydro power plant.

In PHPP (figure 4), the water flow model uses an intake from the river flow and flows the water through a water channel with a small slope towards a reservoir. Furthermore, water from the reservoir is flowed through a rapid pipe to the turbine housing to drive the turbine. The water turbine is coupled with a generator to generate electric power. The power (power) generated can be calculated based on the following formula [8]:

$$P = \rho.Q.h.g$$

P is the output power (watts), p is the density of the fluid (kg / m3), Q represents the water discharge (m3/s), h represents the effective height (m), and g is the gravitational force (m/s2).

3. Workflow and system design

3.1. Problem solving workflow

The method used in this research follows the order of work as mentioned below:

- Calculation of electric power requirements for lighting and incubator machines in the Javan Langur Centre area.
- Calculation of the potential electric power that can be generated from water flow and solar radiation in the Javan Langur Centre area.
- Construction of reservoirs and intake paths for pico-hydro power plants and determining the location of PV installation.
- Designing a turbine to suit the existing conditions in the Javan Langur Centre river basin.
- Build turbines and test turbines according to design.
- Determination of generator power, PV capacity, multiple input charge controller specifications, and battery capacity required in the planned hybrid generating system.
- Testing of generators in the lab. Electric machines Malang State Polytechnic. The test includes testing the characteristics of open circuit, short circuit generator and load characteristics.
- PV testing and multiple input charge controllers to determine the value of charging and discharging currents in the battery.
- The design of electrical installations for the energy supply needs of the Javan Langur Centre including the protection system including the needs of batteries, charger controllers and inverters.
- Comprehensive work implementation which includes: installation of pico-hydro and solar power plants, as well as installation of LDP panels in suitable locations,

3.2. PHPP-SPP hybrid power plant design

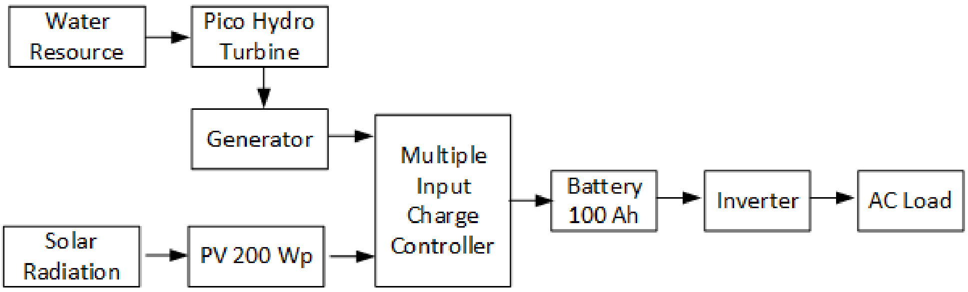

Figure 5. Block diagram of the Pico-hydro-PV hybrid power generation system at JLC.

The Hybrid Power Generation System developed at the Javan Langur Centre consists of 2 types of power plants, namely the pico-hydro power plant with a capacity of 300 watts and the solar power plant with PV with a capacity of 100 Wp.

The pico-hydro power plant has an efficiency of about 10%, so the actual power that can be utilized is 30 watts. So, to increase the supply of electrical energy, this plant is operated in a hybrid manner with PV 100 Wp to produce an output power of 130 watts, which can be used to supply lighting and incubator machines for baby langurs in the JLC area.

3.3. *Component specifications in a hybrid power plant*

3.3.1. *Hydro turbine*

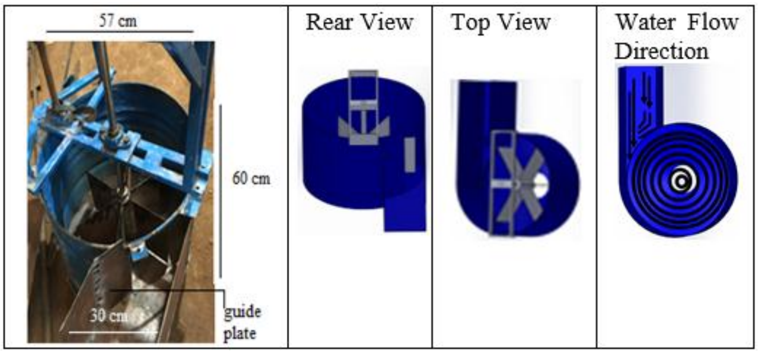

Figure 6. Water turbine design at a Pico-hydro power plant [9].

As shown in figure 6, the design of turbine house number has a water flow steering guide mounted on an iron channel. There is a drain in the middle with a diameter of 20 cm. The overall weight of the turbine and turbine house is around 22 kg.

The test results show that when water is thawed into the turbine house, the flowing water is directed to crash into the circular turbine house wall. So that a spiral whirlpool is formed immediately and the turbine rotates with a higher speed, which is around 90 rpm.

3.3.2. Generator. The generator used is a vertical axis generator, AC 3 phase, 300 W, 48 volts, and a maximum rotation of 750 rpm. This generator has a diameter of 175 mm, a height of 100 mm, a shaft diameter of 12 mm, a shaft length of 60 mm and a weight of 8 kg.

3.3.3. PV. The PV used has optimal power (peak): 100 Wp, optimal voltage: 17.8 V, optimal current: 5.62 A (Source Manual Book SOL-M24 200W).

3.3.4. Multiple input charger controller. Multiple Input Charger Controller is a charge controller which has more than one input. It may contain of two DC voltage inputs or one DC voltage and one AC voltage inputs [10]. So, in practice, it can be utilized for two different power generations, such as wind power plant and solar power plant, or solar power plant and hydro power plant.

Multiple Input Charger Controller used has specifications: rated Voltage (12/24 V), Input Power of Solar Panel (400Wp), Input Power of Pico-hydro (600W), maximum charging current of 37.5 A, Equalization Charge or the ability of multiple inputs charge controller to equalize the charging voltage of each cell battery (28.8 V +/- 1%).

The selected multiple input charge controllers also have the ability to over discharge - disconnect (21.8 V +/- 1%), Over Voltage - Shut Off (32 V +/- 1%). In addition, this device has Solar Cell Anti-Reverse Protection, which prevents backflow from the battery to the PV because it can cause the PV to break down.

3.3.5. Battery. The battery used has a nominal voltage specification of 24 volts and a capacity of 100 AH.

3.3.6. Inverter. The inverter used has specifications: rated power 500W, pure sine wave output, 220/230 V output voltage, 50 Hz output frequency, 12 V rated voltage, 52 A maximum input current, and is equipped with battery reverse protection in the form of fuse protection.

3.3.7. Load. The load supplied by the hybrid generator at the JLC consists of 6 lamps with a power of 10 watts each and an incubator machine with a power of 60 watts. So the total load supplied is 120 watts.

3.3.8. Electrical panel. The electric panel contains the electrical components mentioned above, including the multiple input charge controller, battery, and inverter, as shown in Figure 7.

Figure 7. Electric panel hybrid generation system at JLC.

4. Testing and analysis data

4.1. Water discharge measurement
Water discharge measurements in the JLC area were carried out at 2 different locations, namely the river flow and the water turbine intake flow. Measurements are made by placing a 1.5 litre bottle in the water line and recording the time it takes to fill the bottle completely. From the measurement results, the value of river water discharge is around 0.00035 m3/s, and the turbine intake water discharge is around 0.00023 m3/s.

4.2. Output voltage measurement
Measurements were made to determine the output voltage of the 3-phase AC generator installed on the pico-hydro electric generator and the output voltage of the PV. The measurement results can be seen in the table.

Table 1. Measurement results of generator output voltage.

No	Turbine 1 Rotation (rpm)	Generator Rotation (rpm)	Generator Output (Vac)
1	78.3	391.5	21.6
2	76.1	380.5	20.4
3	76.7	383.5	20.4
4	78.3	391.5	21.6
5	78.2	391.0	21.6
Average	77.5	387.6	21.12

From table 1 it can be seen that the average turbine rotation is 77.5 rpm. After being connected through the pulley system, it produces a generator rotation of 387.6 rpm. This generator rotation will produce an output voltage of 21.12 volts. As for solar power plants, the output voltage of the PV is measured at 18 Vdc.

4.3. *Battery charging current measurement*

Table 2. Charging current measurement results.

Charging Current (A)		Charging Time for a 40 Ah Battery
Generator	0.75	53.3333
PV	1.10	36.3636
Total	1.85	21.6216

From the table above it can be seen that the charging current for the generator from the pico-hydro power plant is 0.75 A. While the charging current from the PV is measured at 1.1 A. Then the total charging current entering the battery is 1.85 A. charging current is 1.85 A, then the time required to fully charge the battery is 21.62 hours.

However, PV can only operate in the presence of solar radiation, that is, in the morning to evening, as long as sunlight is not blocked from reaching the PV surface. Therefore, in a period of 1 day (24 hours) PV is considered to be able to operate for only 10 hours out of a total of 24 hours in a day.

Table 3. Calculation of charging time.

Charging Current (A)		Charging Time in 1 day (hours)	Stored Capacity (Ah)	Charging Time for a 40 Ah Battery (days)	Charging Time for a 40 Ah Battery (hours)
Generator	0.75	24	18		
PV	1.1	10	11		
Total			29	1.3793	33.1034

From the table it can be seen that by using the PHPP and PV hybrid system, the time required to fully charge a 40 Ah battery is 1.34 days or 33.1 hours.

4.4. *Generator efficiency and PV efficiency calculations*

4.4.1. Generator efficiency. By referring to the generator specifications, namely 3 phase, 48 volts, 300 watts, the nominal current of the generator can be calculated:

$$I\ \text{nominal} = 300 : (1.732 \times 48) = 3.6\ \text{A}$$

The generator output current can be seen by referring to the generator charging current value, which is 0.75 A. The measured output voltage of the generator is 21 volts. Then you will get the generator output power of:

$$P\ \text{output} = 1.732 \times 21 \times 0{,}75 = 27{,}3\ \text{watts}$$

So that the efficiency of the generator can be calculated as below:

$$\text{Generator efficiency} = (\text{Actual Power} : \text{Rated Power}) \times 100\%$$

$$= (27{,}3 : 300) \times 100\% = 9{,}1\%$$

4.4.2. PV efficiency. Based on previous information, it is known that the installed PV capacity is 100 Wp. Meanwhile, the measured value in the battery charging process is the charging current of 1.1 A and the charging voltage is 18 volts. Then the PV output power can be calculated as below:

$$P\ \text{output} = 18 \times 1{,}1 = 19{,}1\ \text{watts}$$

So that the PV efficiency can be calculated as below:

$$\begin{aligned} \text{PV efficiency} &= (\text{Actual Power} : \text{Rated Power}) \times 100\% \\ &= (19{,}1 : 100) \times 100\% = 19{,}1\% \end{aligned}$$

5. Conclusion

- The water discharge in the JLC area is around 0.00035 m3 / s. This value is classified as very small for pico-hydro power plant applications. As a result, the water turbine rotation and generator rotation are low, which in turn results in a low generator output value. From the calculation results, the value of the generator efficiency is less than 10% with the power generated around 27.3 watts.
- Solar radiation in the JLC area can be used as a source of solar power using PV with a capacity of 100 watts peak. From the measurement and calculation results, the PV efficiency value was 19.1%.
- The Hybrid system that is applied in the JLC area combines the output of a Pico-hydro power plant and a solar power plant to meet the electricity needs in the JLC area

6. Future Work

In order to increase the output power of Pico-hydro Power Plant, it is recommended to enlarge the dimension of the waterway for turbine intake. If the water discharge higher, the rotation and torque of the water turbine increases, so that the generator rotation will also be faster and will produce a higher output voltage.

In terms of Solar Power Plant, it is recommended to install more PV's in Javan Langur Centre to produce a lot more electricity.

Acknowledgements

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