Solar Photovoltaic Application for Contributing Power Supply of Community Clean Water Provider

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Abstract. The need of clean water for human daily life is about crucial. Due to the inadequate capability of government water supply company, it is becoming common for a community to establish their own water supply system. This includes a deep well, high water reservoir, and submersible pump. The pump is normally supplied with power from electricity grid. The extensive availability of sunlight may be used to generate electric power using Solar Photovoltaic (PV) panels for supplying power for the pump. This paper presents the application of Solar PV panels to generate power that contributes power for the pump at the system of clean water provider. A 1000-WP solar panels system is employed to generate the voltage and a 60-A MPPT is used to regulate the voltage for supplying 2 x 150-Ah Li-ion battery. A 3000-W inverter is used to provide AC power for 3-hp 220-V pump. Considering the capacity of Solar PV panels and the continued availability of sunlight, the hybrid supply for the pump is established. This integrates the supply from solar PV and utility grid controlled with Automatic Transfer Switch (ATS). This determines the power supply for the pump either from Solar PV or electricity grid. This system is implemented in the community water supply at Sidomulyo, Krikilan, Sragen. The hybrid strategy enables solar PV to contribute supplying power for the pump and reduce the need of power from utility.

1. Introduction
One of the basic needs of human-being is clean water. For some households, this need is fulfilled by the government water supply company. The capability of the company to continuously provide the clean water is a problem, mainly at the dry season. Some households experience the difficulty to have sufficient water supply during this season [1]. Some households have their own well to get their water need supplied with 2 sources. However, at dry season the water available in the well is limited while the supply from government company is also not continuously available. This situation has motivated some communities to establish the private water supply system in order to satisfy the water need of households in this community [2].

Sidomulyo is one of districts under the village of Krikilan, at the regency of Sragen. This area is located next to the main road from city of Surakarta to east java. From the geographic standpoint, the altitude of this area is higher than other surrounding areas. This situation safes the area from any possible flood at rainy season. In the contrary, the people have the difficulty of getting sufficient clean water at dry season. Bore water from the people’s well is no longer sufficient while the water from the government water supply company is difficult to reach this area, in particular during the peak load. The high contour of this area causes low pressure of water flow at the peak load due to the customers use the water at the same time.
Considering the aforementioned problem, the people of Sidomulyo have established a deep well including the high placed water storage. To lift the water from the well to the storage, a 3-horsepower (hp) submersible pump is employed. A test has been carried out to evaluate the capacity of water from the well and the performance of the pump to lift the water to the storage. From 3-day operation, it was confirmed that the capability of the well is very enough to fulfil the water need of Sidomulyo people.

Upon successful operation of water supply system, energy management is the next step to plan. It deals with satisfaction of water demand with minimum energy that therefore minimizes the cost [3]. The system is supported with 3-hp submersible pump that requires power of 2500 Watt. This pump enables providing high water debit yet requires high power leading to high operational cost. Therefore, it is necessary to control the pump operation such that it may optimize the operational cost [4]. An electronic-based control is developed to control pump operation. It determines the start/stop of the pump assuring sufficient water reserve while minimizing energy consumption. This control system is equipped with a number of water level sensors that detect water volume whose measurements are further processed by the controller to decide the on/off status of the pump. The controller features setting that enables adjustment of reservoir water volume. This may lead to pump operation schedule with minimum energy consumption.

For the purpose of reducing power consumption from utility grid, some Solar PV panels are used as a supporting power supply. The pump only operates based on controller command and does not requires continuous power supply. Therefore, the panel installed will not be as high as pump’s need and the generated power can be saved in battery. When the pump is on, the power will be taken from the battery and when the pump is off, the battery is charged by panels. Some additional equipment are required, including battery, Solar Charger Controller, and inverter. This scheme will also enable the pump to operate at the night using energy stored in battery [5].

Considering the availability of sunlight with sufficient intensity, the power supply system should involve 2 sources of power supply i.e. electricity grid and Solar PV panels. This hybrid scheme enables solar PV to assist supplying power therefore minimizing the need of power drawn from utility grid [6]. An Automatic Transfer Switch (ATS) is necessary to manage the supply depending on battery capacity. If the battery capacity is sufficient, the pump is supplied with the energy stored in the battery. But, if it is not enough then the supply is taken from the electricity grid [7]. This transfer should be possible even when the pump is operating. The capacity of battery that enables supplying power to the pump is based on its voltage [8]. Hence ATS should detect the battery voltage and changes the power source to the electricity grid if the voltage has achieved 23 Volts.

### Table 1: Specification of 100 WP monocrystalline Solar PV

|                      | Specification         |
|----------------------|-----------------------|
| Maximum Power        | $P_{max}$             |
| Maximum Power Voltage| $V_{mp}$              |
| Maximum Power Current | $I_{mp}$             |
| Open Circuit Voltage | $V_{oc}$              |
| Short Circuit Current | $I_{sc}$              |
| Nominal Operating Cell Temp | NOCT                   |

|                      | 115 W                  |
|----------------------|------------------------|
| Maximum Power Voltage| 18.8 V                 |
| Maximum Power Current | 6.12 A                |
| Open Circuit Voltage | 23.0 V                 |
| Short Circuit Current | 6.48 A                |
| Nominal Operating Cell Temp | 45 ± 2°C              |

### 2. Solar Photovoltaic Panels for Water Supply

The system of hybrid power supply for water provider system is shown in Fig.1. This includes 2 power sources, Solar PV panels and electricity grid. The power from electricity grid may be
directly supplied to the pump. On the other hand, the power generated by Solar PV is controlled by Solar Charger Controller (SCC) that regulates the voltage assuring the current flows into the battery. The system employs a 1000 WP consisting of 10 panels with 100 WP each. The type of the panel is monocrystalline with the specification given in Table 1. Open circuit voltage is the voltage of Solar PV panel when it receives sunlight intensity that leads to maximum voltage and the it does not supply any load. The short circuit current is the current flowing through the solar panel when the voltage across the panel is zero, i.e. when the panel is short circuited. The energy from Solar PV panels is stored in 2 battery of 12V, 150 Ah each. These batteries are connected in series becoming 24 V, 150 Ah. To supply the pump a 3000 W inverter is used to convert DC power of battery into 220 V AC power.

From the 2 available sources, ATS will determine the power supplying the submersible pump, either from the electricity grid or from the battery. Nevertheless, the battery firstly detected. If the capacity is enough then the power is taken from the battery. When it is not enough, then the power from utility grid will be used. This transfer may also take place even when the pump is running. The operation of pump is driven by water level control [9]. This is equipped with a number of sensors that control the level of water triggering the pump to start or stop. This water level control may be adjusted to assure optimal motor operation. This balances the frequent pump operation and sufficient water availability. Furthermore, this device may also be

Figure 1: Hybrid power supply system (Solar PV-Grid) for water provider
manually controlled to anticipate if the pump should be operated according to specific situation e.g. sudden run/stop of the pump.

The physical facilities of the system include well, water reservoir and plumbing. The well with the deep level of 81 m has been constructed assuring the water capacity enough to supply the need of Sidomulyo people. This level is decided to also assure that the lifted water is from the water source, which is deeper than the bore water normally used by people. A 4-dim PVC pipe was inserted to the well’s hole acting as wall of the well. Besides avoiding the ground to drop and block the water, this also guarantees not to lift the water except from the deep level.

Water storage is another physical component of the system. This is a civil constructed structure with the size of \((w \times l \times h)\) \(2.4 \times 2.4 \times 2\) m\(^3\). The height from the ground to the storage base is 7.4 m. This is expected to enable water flowing with sufficient pressure at the ground level. To lift the water up to the storage, a 3-hp, 2500 W submersible pump is employed. This pump is able to lift the water with the debit of 18 m\(^3\) per hour.

3. Results and Discussion

At the beginning of system operation, the system was tested by running the pump to fill in the storage. For the given storage size, the time required to fill was recorded about 30 minutes. Once the storage was fully filled, the speed of water flowing out at the ground level was tested. It was observed that the water flowing at that position was very fast. It is therefore expected that the water may reach the house of Sidomulyo families with sufficient pressure. The capacity of the well to provide sufficient water was also tested. The water was therefore pumped out from the well and it was confirmed that from the 3-day pumping, the well was still able providing water with sufficient debit without any cut-off. It therefore assures enough capacity of the well to provide water for 34 households of Sidomulyo people.

The abovementioned description demonstrates that the system of water supply is ready and may properly operate to fulfill the water demand of Sidomulyo people. The next concern is the electricity supply for the pump. At the beginning the electricity supply for the pump was from National Electric Company. The main cost to operate the system is electricity and therefore it may be lessen by establishing the Solar PV panels to contribute energy for the system.

For operating the system using electricity drawn from the grid, the following assumption and calculation are used. According to the report of Sidomulyo Authority, the average daily water consumption is 0.5 m\(^3\) per household. If the consumption is assumed to be 1 m\(^3\) per household per day, then the total water consumption for the 34 family of Sidomulyo is 34 m\(^3\). The volume of water that can be filled in the storage is:

\[
v = 2.4 \times 2.4 \times 2 = 11.52 \text{ m}^3 \quad (1)
\]

However, the storage cannot be fully filled with water. If it is assumed that the storage is filled with water up to the height of 1.75 m, then the volume of water in the storage is:

\[
v = 2.4 \times 2.4 \times 1.75 = 10.08 \text{ m}^3 \quad (2)
\]

From the operational standpoint, the pump should again run before the water in the storage completely finish. Once the remaining water is about 25% the pump must again operate. Therefore, for every pumping operation, the volume of water that should be lifted to the storage is 75% \(\times 10.08\text{m}^3 = 7.56\text{m}^3\). For the total water consumption of 34 m\(^3\) for all Sidomulyo households, the number of pump operation is

\[
\text{Pump operation number} = \frac{34}{7.56} = 4.5 \text{ or } 5 \text{ times per-day} \quad (3)
\]

From the test of filling the storage the time required by the pump to fully fill the storage is less than 30 minutes. It may be taken that the time to fully fill the storage is 30 minutes. If it is
assumed that the time of pump operation is proportional with the volume of lifted water, then for lifting the water of 7.56 m$^3$, the required time ($t$) is:

$$t = \frac{7.56}{11.52} \times 30 = 19.7 \text{ minutes}$$  \hspace{1cm} (4)

For filling the storage 5 times per-day, the total time required by the pump for the whole day is:

$$T_{tot} = 5 \times 19.7 = 98.5 \text{ minutes}$$  \hspace{1cm} (5)

For the use of electrical power from the National Electric Company, the energy consumption ($E$) of 2500 W water pump in kWh may be calculated as follows:

$$E = 2.5kW \times \frac{98.5}{60} \text{h} = 4.1 \text{kWh per-day}$$  \hspace{1cm} (6)

It is fortunate that the people of Sidomulyo get the project from The Office of Research and Community Development (Lembaga Penelitian dan Pengabdian pada Masyarakat/LPPM) Universitas Muhammadiyah Surakarta through the program of University Social Responsibility. It is the program where a community or group of people may apply some funding for establishing a project to support their development or to solve their problem. The people of Sidomulyo receives the funding and it is used to purchase 10 Solar PV panels and some related equipment to be installed in the project. The system of Solar PV panels with the capacity of 1000 WP is used to contribute the power required by the pump.

From the test of power generation on Monday, January 27, 2020 some data are recorded as given in Table 1. The data was taken from the duration of 09.00 a.m. – 01.30 p.m and the data was recorded for every 30 minutes. The duration is considered to be sufficient to represent the fluctuation of voltage and current of battery. On the other hand, this may be calculated to predict the power generation for the extended time at the whole day. The type of solar PV is monocrystalline where the generation of voltage is considered to be steady even the sunlight intensity level is about low [10]. However this still considered as estimation. The fluctuation of voltage and current of battery is shown in Fig. 2.

| Time       | Lux | Solar PV Voltage (V) | Battery Voltage (V) | Battery Current (A) | Temperature (°C) |
|------------|-----|---------------------|---------------------|---------------------|------------------|
| 09.00 a.m. | 29800| 106.1               | 27.6                | 15.9                | 40.7             |
| 09.30 a.m. | 29800| 105.7               | 27.7                | 17.0                | 43.7             |
| 10.00 a.m. | 29600| 105.5               | 29.0                | 11.8                | 42.7             |
| 10.30 a.m. | 29500| 105.6               | 28.8                | 10.3                | 42.7             |
| 11.00 a.m. | 29400| 103.1               | 28.8                | 9.7                 | 43.6             |
| 11.30 a.m. | 29700| 103.1               | 28.8                | 10.0                | 41.7             |
| 12.00 a.m. | 29800| 150.7               | 28.9                | 10.0                | 43.8             |
| 12.30 p.m. | 29850| 106.5               | 28.9                | 10.0                | 32.5             |
| 01.30 p.m. | 28600| 100.6               | 28.9                | 6.5                 | 33.6             |

Table 1 also indicates that the change of light intensity changes the voltage of Solar PV panels. It is also indicated that the sunlight intensity corresponds to the panel temperature. The contribution of Solar PV panels on supplying energy for the pump may be calculated as the
energy generated by the panels for the total energy required by the pump. Power generated by Solar PV panels supplied to the battery may be calculated considering the voltage and current of the battery. This calculation is carried using Eq. 7 and the results are shown in Table 2.

\[ P = v \times i \text{ (Watt)} \quad (7) \]

In this study the measurements are taken for every 30 minutes. With the assumption that the voltage and current supplied to the battery do not significantly change for the period of 30 minutes, the energy stored in the battery may be calculated taking into account the power and time. If the energy is expressed in Wh, then the calculation may be calculated by multiplying the power with the time of 0.5 h (30 minute). This is given in Eq. 8.

\[ E = P \times t \text{ (Wh)} \quad (8) \]

The calculation of energy is accumulated for the measurement period and it is shown in Table 2. It may be observed that the total energy stored in the battery during the measurement period is 1440.895 Wh or 1.44 kWh. Taking into account the total energy requirement of the pump, Solar PV panels contributes about 35%, as shown in Fig. 3.

It may be noted that the calculation only considers the period of data measurement from 09.00 a.m. to 01.30 p.m. While the power generation from Solar PV panels are more extensive in time. Therefore the energy contribution from the panels may be higher. However, the energy stored in the battery also depends on the capacity of battery. It may happen that the battery is fully charged and the pump does not operate meaning that the stored energy is not used. In this case, the power generated by Solar PV panels cannot be saved in the battery. On the other hand, it may happen that the pump must operate while the energy stored in the battery is not sufficient since the charging process has not given sufficient energy to the battery. The time of the pump to operate is about stochastic depending on water use and therefore charging of the battery may lead to condition of either fully charged but not used or insufficiently charged but must be used. The optimal condition is that the pump regularly operates and, therefore, Solar PV panels get enough time recharging the battery before the next pump operation.

The data considered in this study are from battery instead of from Solar PV panels. This is due to the data from battery are the effective values. The voltage generated by the panels should be regulated by SCC that implies some losses. Therefore the nett power to be used by the pump is from the battery, not from Solar PV panels.
Table 3: Calculation of Power and Energy supplied to the battery by Solar PV panels

| Voltage (Volt) | Current (Amp) | Power (Watt) | Energy (Wh) |
|---------------|---------------|--------------|-------------|
| 27.6          | 15.9          | 438.84       | 219.42      |
| 27.7          | 17.0          | 470.9        | 235.45      |
| 29.0          | 11.8          | 342.2        | 171.1       |
| 28.8          | 10.3          | 296.64       | 148.32      |
| 28.8          | 9.7           | 279.36       | 139.68      |
| 28.8          | 10.0          | 288          | 144         |
| 28.9          | 10.0          | 289          | 144.5       |
| 28.9          | 10.0          | 289          | 144.5       |
| 28.9          | 6.5           | 187.85       | 93.925      |

Total Energy (Wh) 1440.895

Figure 3: The Contribution of Electricity Source for the Pump

The energy contribution from Solar PV panels as discussed in the preceding description is an estimation. The real data from day to day may be different depending on factors such as sunlight intensity and water consumption. The energy contribution of Solar PV panels is only calculated for 4.5 hours meaning that more contribution may still be given. The minimum power recorded in Table 2 is 187.85 W, which is much smaller than the maximum capacity of 1000 Wp. If this power is considered to calculate the energy of Solar PV panels taking into account the effective generation time from 7 a.m. to 4 p.m. (9 hours) than the energy that can be contributed by the Solar PV panels is 1690.65 Wh or 1.69 kWh. For the total energy requirement of 4.1 kWh as calculated in Eq. 6, the contribution of Solar PV panels is 41.22%. This contribution is considered to be significant and it may increase if the number of panels is increased. However, the capacity of battery should also be increased accordingly.

4. Conclusion
The Solar PV panels are installed to contribute energy to the existing power supply from the electricity grid. This hybrid power generation is employed to provide the energy for clean water supply system for the people of Sidomulyo, Krikilan, Sragen. To enable Solar PV panels contributing the energy, some supporting devices are used including Solar Charger Controller, Battery and Inverter. Since the power from Solar PV panels may either be insufficient or
unavailable, the power supply can interchange between the two sources. For this purpose, an Automatic Transfer Switch is employed to switch the source from the battery to electricity grid if the remaining battery capacity is no longer enough to provide power for the pump. This device can again return the source back to the battery once its capacity is sufficient. The switching process may be carried out even the pump is running. The experiment indicates that the Solar PV panels may contribute 35% for the total energy requirement and it may increase if the number of panels increases. However, the capacity of battery must also be increased.

Acknowledgments
The Authors would like to gratefully acknowledge that this project is financially supported by the Office of Research and Community Development (Lembaga Penelitian dan Pengabdian pada Masyarakat/ LPPM) Universitas Muhammadiyah Surakarta, under the scheme of University Social Responsibility at the year of 2019.

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