Development of a Solar Water Pumping System in Karsts Rural Area Tepus, Gunungkidul through Student Community Services

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Abstract

This paper present stages of development solar water pumping system (SWPS) as renewable energy application to solve water supply problem in Purwodadi Village, Tepus district located at karsts area of Gunungkidul. This SWPS has been able to lift water as far as 1,400 metres horizontally with total head 218.34 metres. This system uses 32 solar panels to produce 3,200 Wp maximum power then used to operate 2 submersible pumps with total head of 250 meters. The flow rate of water produced is about 0.4 – 0.9 litres/second.

Keywords: karsts; rural area; water crisis; solar water pumping system; submersible pump; head loss

Nomenclature

\begin{itemize}
\item \(h_d\) dynamic headloss (m)
\item \(h_s\) static head (m)
\item \(h_t\) Total head (m)
\item \(I_{pv}\) Current of the solar panel (A)
\item \(N_c\) Number of branch
\item \(N_{seri}\) The amount of solar panel in series
\item \(P\) System power’s need (W)
\item \(V_{pv}\) Voltage of the solar panel
\item \(V_{pv\ seri}\) The amount of voltage in series (V)
\item \(V_{sistem}\) Minimal voltage of the system
\end{itemize}

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1. Introduction

Puwodadi Village located in Tepus District, Gunungkidul Regency is a karsts area that has trouble with clean water supply annually. During rainy season, people collect rain water in tank collector and use it for daily live. During dry season they have to spend money about IDR 100,000 for 5,000 litres to obtain clean water from private water supplier provided by local company. There is nearest water spring as far as 2 km from residential, called Kali Sureng. In 2007, Department of Public Works had a program assistance to lift the water using generator set, but the operational cost of the system was expensive about IDR 81,000 per day, with 10 litres of diesel fuel used, that only be able to operate the generator for 4 hours.

Started in 2010, a team consisting of lecturers and students from Department of Engineering Physics, Universitas Gadjah Mada (UGM) has been researching for the opportunity in implementing renewable energy technology particularly photovoltaic solar systems to solve the problem. One of the important applications of PV stand alone systems is for water pumping, particularly in rural areas that have a considerable amount of solar radiation and have no access to national grids [1]. The potential of solar irradiation in Purwodadi area, located in the south coast of Yogyakarta, is about 5.66 kWh/m²/day [2]. Based on this potential, a program aimed to optimize the solar energy to power water pumping system was developed.

In 2011, an Institutional Competition Grant Program (PHKI) from the Directorate General of Higher Education, Ministry of Education and Culture, run by the Department of Engineering Physics UGM was aimed to produce a Detailed Engineering Design (DED) for implementing the Solar Water Pumping System (SWPS). In 2012, through program of SPEKLOK and PKPP grants from Ministry of Research and Technology (RISTEK), the plan was then implemented through Student Community Services Program UGM.

Now, the SWPS has been installed in Kali Sureng replacing a diesel powered water pumping system operated before. This new system has been constructed by involving Komunitas Mahasiswa Sentra Energi (Kamase), Department of Engineering Physics, Institute of Research and Community Service (LPPM) UGM through Student Community Services – Community Empowerment Learning program 2012, Ministry of Research and Technology (RISTEK) Republic of Indonesia, and Ministry of Public Works (PU). The development of solar water pumping system in Tepus District is expected to be a model of installation water supply system in other rural areas and also as reference to do more advanced research and to optimize the system.

2. Material and method

2.1. General research methodology

The general methodology used in this research is as follow:

- **Literature study**
  
  This step is study on design solar water pumping system and data of water need that has been researched by Arrohman [2], that was integrated by an Institutional Competition Grant Program (PHKI). Another similar project also has been completed before through international cooperation between Department of Engineering Physics Universitas Gadjah Mada, Indonesia and Curtin University, Australia to develop a sustainable power and water supply by mean of mini-grid hybrid power system, for remote areas and disaster response and reconstruction in Indonesia. This project obtained a Mondialogo Engineering Award 2007 from UNESCO and DAIMLER and deployed through Student Community Services UGM from 2008 - 2010[3].

- **Case study on an installed solar water pumping system in Banyumeneng, Giriharjo Village that is located in Panggang District, GunungKidul through Student Community Services 2008 - 2010.**

- **Field survey**
  
  Field survey was aimed to obtain data and documentation about water resource and the piping system.
• Analysis on water resources and renewable energypotentials.
  This step was aimed to collect quantitative parameters about flow rate of water, area elevation, size of reservoir as well as measurement of solar irradiation. This field survey and mapping area was done by Student Community Services Program of Universitas Gadjah Mada in 2012.

• Power system planning
  This step consists of analysis on piping system and consideration of pump’s type selection as well as array configuration of solar panels. This step will be explained in particular method below.

• System construction

This system construction was based on power system planning and constructed by involving Kamase, Department of Engineering Physics, Institute of Research and Community Service (LPPM) UGM through Student Community Services – Community Empowerment Learning program 2012, Ministry of Research and Technology (RISTEK) Republic of Indonesia, and Ministry of Public Works (PU).

• Evaluation and Sustainability Planning
  This step was aimed to make the system become sustainable by performing transfer of knowledge and to create sosial community that able to maintain the system.

Flow diagram of the methodology used in this research project can be summarized in Fig. 3.
2.2. Piping system analysis and choosing appropriate pump

Piping system analysis is aimed to know total head of the system. The total head is the sum of measurement static / elevation head and calculation of dynamic headloss. The headloss is pressure drop due to friction between the fluid and inner surface of the pipe. In closed pipe flow, the head loss is divided into major head loss and minor head loss. Major head loss occurs because of fluid flow through the length of piping system, whereas minor head loss is resulted from change of distribution’s track, such as direction’s modification, change of size and connection of the pipe as well as valve’s existence[4]. Another method involves the assessment of losses through the pipe and other accessories by using Poiseuil, Blasius and Blench laws in order to calculate accurately, the hydraulic head can be studied in[5].

Design of water pumping system is aimed to pump the water from Kali Sureng water spring toward a reservoir. This pumping system is one stage directly. Based on measurement performed by geodetic teams from Student Community Services UGM 2012, static head from KaliSureng’s source to the reservoir is 102.73 metres, whereas the horizontal distance is 1765.75 metres. To determine the headloss, this developing system refers to research that previously has been done. The research divides arrangement of the pipes into two stages that are from KaliSureng’s source to hill reservoir and from hill reservoir to the final reservoir. The result calculations of variation effect of flow rate against dynamic head loss for both stages are presented in Table 1 and Table 2 [2].
Table 1. Variation effect of flow rate against dynamic head loss from Kali Sureng to the reservoir on the hill.

| Flow rate (l/s) | Head loss (m) | Total head (m) |
|----------------|---------------|----------------|
| 0.1            | 0.14          | 94.14          |
| 0.2            | 0.65          | 94.65          |
| 0.3            | 1.02          | 95.02          |
| 0.4            | 1.74          | 95.74          |
| 0.5            | 2.64          | 96.64          |
| 0.6            | 3.71          | 97.71          |
| 0.7            | 4.97          | 98.97          |
| 0.8            | 6.40          | 100.41         |
| 0.9            | 8.02          | 102.02         |
| 1.0            | 9.81          | 103.81         |
| 1.1            | 11.78         | 105.78         |
| 1.2            | 13.93         | 107.93         |

Table 2. Variation effect of flow rate against dynamic head loss from hill reservoir to the reservoir.

| Flow rate (l/s) | Head loss (m) | Total head (m) |
|----------------|---------------|----------------|
| 0.1            | 1.48          | 16.48          |
| 0.2            | 4.92          | 19.92          |
| 0.3            | 10.05         | 25.05          |
| 0.4            | 16.75         | 31.75          |
| 0.5            | 24.96         | 39.96          |
| 0.6            | 34.63         | 49.63          |
| 0.7            | 45.72         | 60.72          |
| 0.8            | 58.21         | 73.21          |
| 0.9            | 72.07         | 87.07          |
| 1.0            | 87.28         | 102.28         |
| 1.1            | 103.83        | 118.83         |
| 1.2            | 121.69        | 136.69         |

To determine an appropriate water pump that will be used, it is necessary to know total head of the system [2]. The total head refers to Equation (1). In this design, it is assumed that flow rate of water inside the pipe is 1.1 l/s. This value ensuring actual water flow rate product is big enough due to fluctuation of solar power. So, the total head loss of this piping system is 115.61 metres and total head is 218.34 metres resulted from summation of real head and total head loss. A submersible pump Lorentz PS1800 HR-05HL [6, 7] is chosen for pumping water with the total head 218.34 metres. The specification of this pump is shown in Table 3.

\[
h_t = h_s + h_d
\]  

(1)

Table 3. Specification of submersible pump PS1800 HR-05HL.

| Maximum Total Dynamic Head (TDH) | 250 m |
|----------------------------------|-------|
| Maximum Flow Rate                | 4.0 m³/h |
| Maximum Power Voltage (Vmp)      | > 102 VDC |
| Open Circuit Voltage (Voc)       | Max. 200 VDC |
| Voltage Range                    | 72-96 VDC |
| Battery Operation : Nominal voltage | 96 VDC |

Based on the above specification of the submersible pump, ideally it should be capable to pump the water to an elevation of 250 m. The submersible pump has some special characteristics. The performances of the pumping system depend closely on the climatic conditions (temperature and solar radiation). The variations in the solar radiation intensity change the overall efficiency and the pumping flow-rate. Also it has been observed that system performance is maxum around mid day and is degraded with the disturbance of the solar radiation and ambient temperature. The PV pumping system will start at level of solar radiation around 300 W/m². The pump flow rate increases with solar radiation during the morning period and decrease in the afternoon. On the other hand, the global efficiency of the system depends on the ambient temperature and the level of the solar radiation. The difference between the ambient temperature and that of the PV module reaches 30° C towards noon [8].
2.3. Power system planning

PV cells are made of semiconductors. Crystalline and thin films are the most common types of materials for PV cells. There are various kinds of factors such as efficiency of light absorption and energy conversion, or manufacturing technology and cost of production [9]. The solar water pumping system installed at Kali Sureng uses monocrystalline type of PV cells. The PV generator converts the solar radiation into electric DC power which is converted via an inverter to AC power that serves to supply the asynchronous motor [8]. The specification of solar panel is shown in Table 4.

Table 4. Specification of solar panel.

| Specification               | Value   |
|-----------------------------|---------|
| Max. Power at STC           | 100 Wp  |
| Optimum operation voltage (Vmp) | 18 V   |
| Optimum operating current (Imp) | 5.56 A |
| Open circuit voltage (Voc)  | 22.36 V |
| Short circuit current (Isc) | 6.02 V  |

The calculation of power system was started from wiring or array configuration to fulfill the minimum voltage needed by the pump. As an example about PV array for outdoor conditions in purpose to determine its maximum power point (MPP) can be studied in [10]. The MPP is the product of the voltage from the total PV cell area can produce and the current that the total PV cell area produce at a given level of irradiance, so that the result gives the maximum value. In series configuration, the total voltage resulted is the sum of each panel, whereas in parallel configuration, total current is sum of each panel [11]. To fulfill the minimal operating or loading voltage, it is then necessary to calculate solar panels in series configuration refer to Equation (2) [2].

$$N_{\text{seri}} = \frac{V_{\text{system}}}{V_{\text{pv}}}$$  \hspace{1cm} (2)

To fulfill total power needs by the system, it is then necessary to calculate number of branch for the configuration refer to equation (3)[2].

$$N_c = \frac{P_{\text{system}}}{P_{\text{pv}}/I_{\text{pv}}}$$  \hspace{1cm} (3)

3. Result and discussion

The PV array consists of an array of PV modules connected in series - parallel combinations to provide the desired DC voltage and current [12]. Some conditions have been considered to fit the power supply system by construct the PV array with the power need by the pumps. Under loading condition or when solar panels are connected to the pump, the optimum operation voltage (Vmp) is used in the calculation. Refer to Table 4, Vmp is 18 V. Based on Equation (3), the minimum panels are arranged 7 panels in series to fulfill the minimum voltage i.e. 102 V. When the configuration of solar panels and the pump is assumed on no loading or open circuit condition, the sum of solar panel’s voltage as an input to the pump is not allowed to exceed open circuit voltage, i.e. 200 Vdc. Because of the Voc of each panel is 22.36 V, the maximum series configuration that can be allowed is 8 solar panels with total voltage 178.88 V. This 8 series configuration is also resulting 144 V that fulfills the minimum voltage needed by the pump, i.e. 102 V, in loading condition. To ensure the system works properly, series configuration with 8 solar panels was chosen.

Input power of the pump is referred to head total of the system and flow rate of water. The input power of the pump can be seen from Figure 2.
Based on total head calculation in piping analysis system, the total head is 218.34 metres, so from Figure 4, it uses head’s chart of 250 metres. In this design, the flow rate is wanted to be 0.8 m$^3$/h or 0.22 l/s, so the input power needed by the pump is about 900 Watt. The power resulted in loading condition from one series configuration is about 800.64 Watt. From Equation (3), the minimum branch needed is two branches for one pump. In SWPS that have been installed, there are two pumps connected parallel, so there are four branches consisted of 8 solar panels in series configuration for each branch.

This parallel connection of the similar pump can produce flow rate of water twice or even more. The measured flow rate of the water in the reservoir is about 0.4 – 0.9 l/s. The total solar panels used in this system are 32 panels that can produce power about 3200 Watt peak.
4. Conclusions

This paper presents development of solar water pumping system in a karst rural area Tepus District, Gunungkidul. Two important aspects in designing solar water pumping system are analyzing piping system to determine the type of pump used and the power system planning to ensure the system operates properly. Based on the analysis of the piping system, the horizontal distance is about 1,400 metres with total head is 218.34 metres and the suitable pump used is submersible pump PS1800 HR-05HL with maximum total dynamic head 250 metres. Power system is constructed utilizing total of 32 solar panels consists of four branches with 8 solar panels in series configuration for each branch. This power system produces about 3200 Wp to power the two submersible pumps with water flow rate resulted is about 0.4 – 0.9 l/s.

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