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Redesigning Solar Water Pumping System at Giricahyo, Gunungkidul Regency, Yogyakarta: HOMER Analysis Approach

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Abstract

HOMER, the software for micro-power applicable as renewable energy optimization, was used to analyze solar water pumping system based on deferrable-load and primary-load methods at Giricahyo. The 12 kWp solar PV and 30 kW generator were used to power the standing-aline system.. Unfortunately, the system has been idle since 2010. Research to redesign and analyse solar water pumping system has been conducted by Ministry of Public Works together with the Department of Physics Engineering UGM to bring it into normally. Furthermore, this study was aimed to obtain recommendation and to conduct analysis on system performance using HOMER. As a result in deferrable-load method, generator is inappropriate to be implemented because fossil fuel will be very expensive and rare. Besides, the 12 kWp Solar PV could meet 31.4 % of demand load. In primary-load method, capacity shortage of 1.5 kW pump is at 3.2 % and 3 kW pump is at 9.9 % which means that to deal with fluctuation of solar radiation the use of the 1.5 kW pumps were recommended. The demand that can be fulfilled by 1.5 kW pump is at 22.4 %.

Keywords: capacity shortage; giricahyo; HOMER; redesign; solar water supply system.

Nomenclature

D	= diameter of pipe (m)	**g**	= acceleration of gravity ($m \cdot s^{-2}$)
V	= fluid flow ($m \cdot s^{-1}$)	**Re**	= Reynolds number
ρ	= fluid density ($kg \cdot m^{-3}$)	e	= roughness pipe factor
μ	= absolute viscosity ($kg \cdot (m.s)^{-1}$)	$\mathbf{h_M}$	= minor head-loss (m)
v	= kinematics viscosity ($m^2 \cdot s^{-1}$)	**Ki**	= minor head-loss coefficient. i = 1, 2...n. number of fitting
$\mathbf{h_L}$	= mayor head-loss (m)	**L**	= length of pipe (m)
f	= friction factor		

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1. Introduction

District Purwosari, Gunungkidul Regency is one of rural areas at Yogyakarta that always experiences shortage of water supply every year. However, underground water supplied in Plawan Giricahyo cave is enough to satisfy the water demand. Evidently, in 2007 the water supply system could be built and powered by generator and solar PV with total head of 245 m through the cooperation of Waterplant Community (community), Universitas Gadjah Mada (academic), and the Ministry of Public Works [1]. In addition, the Ministry of Public Works through Unit Works of PK-PAM Yogyakarta with the Department of Physics Engineering UGM was conducted in cooperation to evaluate and redesign just solar water pumping system on it.

The study was focused on the redesigning system based on HOMER software. HOMER itself is software which used to analyze and design micro-energy systems for both off-grid and grid for various purposes, especially for the renewable energy application. HOMER is able to calculate possibilities of optimization using special algorithm from variables, such as design of system, demands, source power, cost, capacity shortage, etc. [2]

2. Material and method

2.1. Material

- GPS; used to look for astronomy position of solar PV in Giricahyo.
- Microsoft Excel; for processing data.
- HOMER v2.58; software of optimization of micro-energy with student-license.

2.2. Diagram

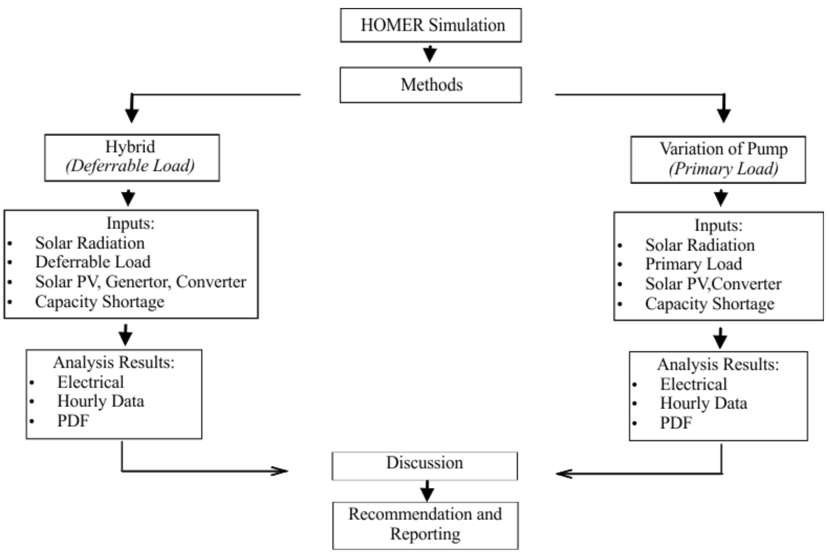

Fig. 1.Diagram of methods.

2.3. Analysis of redesign

Deferrable-load method is designed by HOMER to analyze electrical load that must be met within particular period, but the exact timing is not important such as water pumping system. In contrast, primary-load method is designed to analyze electrical load that must be met immediately in order to avoid unmet load.

In this analysis, deferrable-load method was used to analyze possibility of hybrid energy powered from generators and solar PV in water pumping system. Primary-load method was used to choose the optimum pump between load variation of 1.5 kW pump and 3 kW pump. Moreover, the electrical results of HOMER from those methods will be discussed especially on electrical: capacity shortage, excess of electricity, the power generated and consumed by the system. As well as the needs of the PV, generators and inverters will be utilized to see the optimum of system.

For the analysis itself, HOMER needs some instruments including: load, electrical design of water supply, solar radiation, power of solar PV, generator, and inverter with expenses for procuring, building, operational and maintenance system [3]. Constraints parameter such as annual capacity shortage and renewable energy factor were also provided by HOMER to widen analysis range.

2.4. Instrument analysis of HOMER

Requirement load of HOMER is in kWh that can be derived from water demand and existing head.

- *Water demand and pump debit*

Water demand was obtained by projection of population for next 10 years multiplied by base of needs water (30 L· (person·day^{-1})$^{-1}$) and safe factor (20 %) [4].

Projection of population was formed by equation:

$$Pn = Po(1+r)^n \tag{1}$$

The data from Giricahyo Regency Office state that there were 4 164 people in the year of 2013 with 1 206 households and population growth ratio per year of 0.28 %. Thus, the amount of inhabitants in the next 20 yr will be counted as:

Pn = 4 164 (1+0.28)^{10}

Pn = **4 176 people**

Then, total water demand everyday will be

Water demand = inhabitants x 30 L· (person·day^{-1})$^{-1}$
= 4 176 x 30
= 125.3 L·day^{-1} = 125.3 m^3·day^{-1}

As a fact, piping will always be occurred losses because of the existences of convolution, bolt, etc. Anticipating this situation, it has to be multiplied by safe factor (20 %).

Total of water demand = water demand + safe factor
= 125.3 m^3·day^{-1} + (125.3 x 20 %) = **150.3** m^3·day^{-1}

In conclusion, total of water demand at Giricahyo village will be 150.3 m^3·day^{-1}.

If the duration of working pumps is 10 hours, the needs of water debit will be:

Q = 150.3 m^3·day^{-1}: 10 hours
= 15 m^3·h^{-1} = **4.2** L·s^{-1}

- *Head-loss of pipe system transmission*

$$Re = \frac{\rho DV}{\mu} = \frac{DV}{v} \quad (2)$$

Head-loss occurred in pipe transmission has been calculated to determine the powers and types of the pumps. Characteristics of the water flow inside the pipe are determined through Reynolds number.

The processed data showed water flow in the transmission pipe was turbulent. Head-loss was occured as a result of friction between the surface of the fluid in the pipe and fluid passed through pipe accessories. This loss was divided into two, namely the major and minor head-loss.

Major head-loss

Major head-loss was caused by fluid flowing in piping systems throughout the network. The formulation used for calculating the major head-loss is Equation

$$h_L = f\,\frac{L}{D}\frac{v^2}{2g} \quad (3)$$

and the value of friction factor can be determined by Equation [5].

$$f = \frac{0.25}{\left(log_{10}\left(\frac{\varepsilon}{3{,}7D} + \frac{5.74}{Re^{0.9}}\right)\right)^2} \quad (4)$$

Minor head-loss

Minor head-loss was caused by a disturbance in the pipeline. The disorders could be in the forms of bending, altering the size of the diameter of the pipe, linkage on pipes and valve. The formulation used to determine this value is [5].

$$h_M = \Sigma Ki\,\frac{V^2}{2g} \quad (5)$$

In this redesign, former pipeline system will not be replaced because it was still good enough. Then, secondary-data on high-discrepancy points and curves existing on a transmission pipeline which were used to calculate head-loss total was obtained by previous researches [6,7].

Head total of subsurface = head + head-loss
= 104 m + 1.653
= 105.65 m
Then, head total of subsurface (R_0) was 105.65 m
Besides, head total of surface (R_1) was
Head total of surface = 135.84 m + 11.94
= 147.78 m

In conclusion, total head of pump which was required to lift the water from the bottom of the cave to the main reservoir at the highest point discharge of pump whose water debit of 4.175 $L\cdot s^{-1}$ were 105.65 + 147.78 = **253.44 m**.

3. Results and discussion

3.1. The early water supply system

The first pumping system had been energized by generator 30 kW then the system was complemented by Solar Water Pumping System (SWPS) in 2007, yet those were not hybrid system. This system had been lifted in two steps: step 1 was from base reservoir (pool at the bottom of cave) to the reservoir in opening cave (R_0) whose head of 104 m. Then, from R_0 to the highest elevation in highest point (R_1) whose head of 135.84 m. Capacity of reservoir in R_0 and R_1 were 10 m^3 and 50 m^3 [8].

Solar Pumps utilized in these were 5 pieces of pumps in R_0 and 5 others in R_1. Total capacity of solar PV were 120 kWp of each array that capable to generate 1.2 kWp [8]. Distribution of water was performed by utilizing gravity.

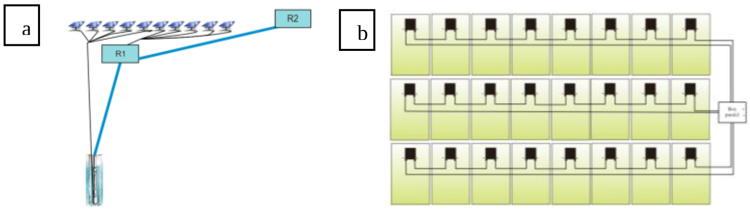

Fig. 2. System of solar water pumping in Giricahyo, (a) schema of water lifting system and (b) circuit arrangement in one array of solar PV.

3.2. Deferrable-load analysis

Deferrable-load analysis was used to analyze the possibility of a hybrid energy (generator and solar PV) and also optimization of inverter with sensitivities started from 1 kW to 10 kW. Instruments that had been entered as inputs of HOMER were costs of procurement, operational and maintenance. Furthermore, PV, generators, inverters were given sensitivity of quantity to see HOMER optimization analysis. Sensitivity of annual capacity shortage was also used ranging from 10 % to 90 %.

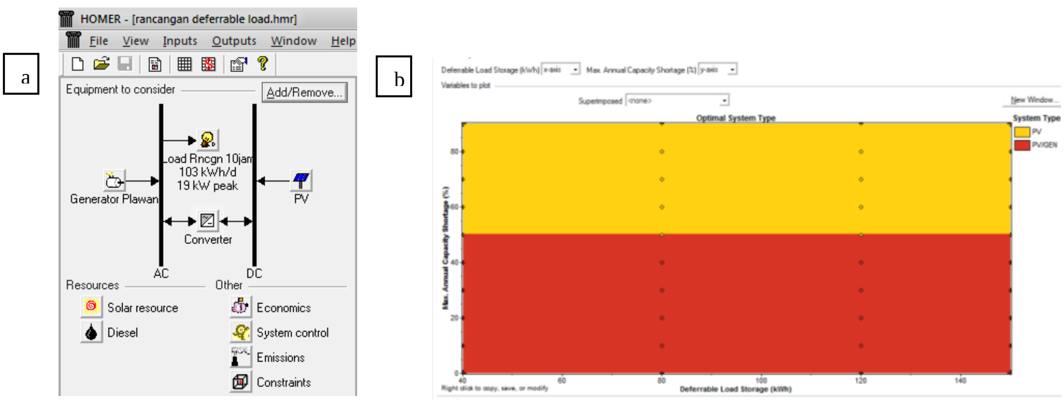

Fig. 3. Analysis in HOMER: (a) input system in HOMER and (b) graph analysis result of deferrable-load in HOMER.

Similiarity on percentage of generator in Figure 3 (b) can be interpreted that the use of generators as energy backup was still high. This would become a problem since quantity of fossil fuels will decrease in its availability and as the consequence, the price will increase besides lower-class of economic of Giricahyo's people . Thus, the using of generator is inappropriate and not recommended for social community at this village.

The orange area that shortage sensitivity were 50% is the highest load demand that can be fulfilled by solar PV. It can be interpreted that solar PV could produce electricity along daylight or from 6:00 a.m. to 6:00 p.m. because HOMER calculates 24 $h \cdot yr^{-1}$. In reality, this would not happen because solar radiation in Indonesia whose average of 5.6 $kWh \cdot m^{-2}$ has only maximum time of radiation for 5 h. As electrical results show demand that can be fulfilled by solar PV are 31.4 %.

Capacity storage which is storage tank or reservoir in kWh of energy needed to fill the tank was used to be another constraint to calculate in HOMER . There is no significant change of constraint values of hybrid chance along 60 kWh, 80 kWh, 120 kWh. It can be seen the use of storage tanks will be same as before which were 10 m^3 (R_0) and 50 m^3 (R_1). Unfortunately, deferrable-load method could only analyze how much energy will be met to fulfill the demand, but not for specific pump. For finding specification of the optimum pump, primary-load method should be used based on variation of pumps analysis.

3.3. Primary-load analysis

This analysis was used for discovering the best power of pumps by using variation in pump load. The pumps that used for this was Grundfos sumbersible pump and it was decided into two scenarios as shown in Table 1.

Table 1. Analyses of scenarios in primary-load method.

Scenario	Pump spec.	Power (kW)	Sum of pump	Debit ($m^3 \cdot h^{-1}$)
1	SP-3A-25	1.5	8	I = 3.2 II = 0.9
2	SP-5A-33	3.0	4	I = 5.6 II = 4.2

- *Scenario 1*

Scenario 1 is where the 1.5 kW pumps had been inputted in HOMER according to solar radiation and considering the performance of initial pump lifting the water as the first time as shown in Table 1. Performance of initial pump is needed to be known in order to measure how much water could be lifted. Moreover, pump load would be entered in January as rainy season and September as dry season then the HOMER would randomize to the months in one year.

Table 2. Pump performance and debit of 1.5 kW.

No.	Power (kW)	Debit ($L \cdot s^{-1}$)	Explanation
1	0.8	I = 0.5 II = 0.06	Debit of initial lifting on pump
2	1.5	I = 0.9 II = 0.15	Maximum debit of lifting pump

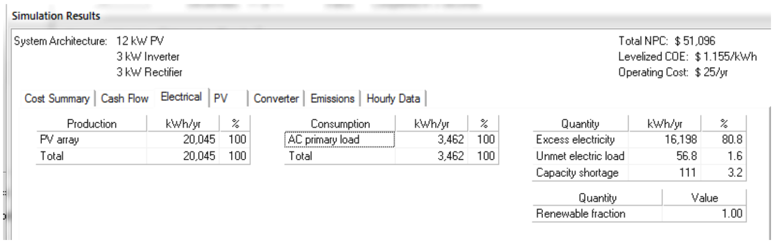

Fig. 4. Electrical results in scenario 1.

Result of optimization analysis, Figure 4, could be interpreted that the 1.5 kW pumps and 3 kW inverter could produce the capacity shortage at 3 %. Total production from 12 kW PV in a year are 20 045 kWh·y^{-1} and load that could be fulfilled are 3 462 kWh·yr^{-1}. Moreover, unmet load are 1.8 % and excess of electricity or power that could not be used by system was 80.8 %.

- *Scenario 2*

Scenario 2 is where the pump 3 kW are inputted and analyzed as shown in Table 3.

Table 3. Pump performance and debit of 3 kW.

No.	Power (kW)	Debit ($m^3 \cdot h^{-1}$)	Explanation
1.	1.6	I = 0.7 II = 0.1	Debit of initial lifting on pump
2.	3	I = 1,5 II = 0.2	Maximum debit of lifting pump

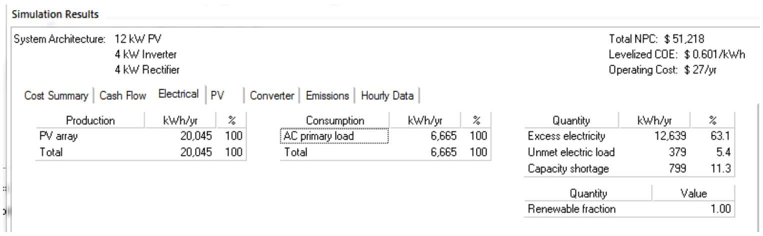

Fig. 5.Electrical results in scenario 2.

The electrical results of Scenario 2 showed in Figure 5 Could be explained that the 3 kW pump with the 4 kW inverter could produce capacity shortage of 11.3 %. Total production from PV 12 kW in a year are 20 045 kWh·y^{-1} which as same as in Scenario 1 and load that can be fulfilled are 6 665 kWh·y^{-1}. Moreover, unmet load are 5.4 % and excess of electricity or power that could not be used by system are 63.1 %.

3.4. Discussion

Table 4. The differences of electrical results in scenario 1 and scenario 2.

Scenario	Pump (kW)	Conv.	Prod. PV ($kWh \cdot y^{-1}$)	Capac. shortage	Excess electricity	Unmet load
1	1,5	3	20.045	3.2	80.8	1.6
2	3	4	20.045	11.3	63.1	5.4

Electrical results illustrate that capacity shortage for 1.5 kW pumps (Scenario 1) is lower than 3 kW pumps. Besides, 96.8 % of the total demand could be completed by 1.5 kW pump and it is higher than 3 kW pump that only completed 90.1 % of total demand. Although the excess of electricity (power that cannot be used by system) of 1.5 kW pump was larger at percentage compared to 3 kW pump, but unmet load is smaller than 3 kW pump. In conclusion, the 1.5 kW pump is more optimal based on HOMER analysis.

This result also supports how in reality it will be because of high fluctuation in the amount of solar radiation. Due to the presence of fluctuations in the solar radiation, accordingly, the power which supplies the pumps and inverters also fluctuates. This has to be considered for the reliability of pumps and inverters. By using a low-power pump (1.5 kW or lower but still considering head lifted) the fluctuations can be resolved by using an optimal low power of pump. Furthermore, reliability of pumps and inverters itself can be maintained.

Final recommendations are:

- It is inappropriate and not recommended to use generator to the application of water pump system because of negative alter-effect of fossil fuel use in the future.
- The recommended pump is the 1.5 kW pump. It needs eight pumps mounted parallel to meet the total power 12 kW of solar PV in Plawan area.
- The 3 kW inverter is the best complementary for the 1.5 kW pump.

4. **Conclusion**

- The system operated using fuel with generator is not recommended since the availability of fuel will decrease in every single year and cause expensive cost for the system whereas most people in this area are low-economic. So that, PV using is more recommended to meet the water demand.
- The using of 1.5 kW (or lower but still considering head lifted) pumps is recommended. Moreover, it will be needed to implement 8 pumps in parallel to meet the total power of 12 kW PV system as needy requirement of Plawan area.
- The using of 1.5 kW pumps mounted into parallel of 8 arrays can fulfil the load as much as 22.14 % of total demand.

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