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Optimization of Own Electricity Usage with Electricity Supply from Solar Cells at Darajat Geothermal Power Plant

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Abstract:
At Darajat Geothermal Power Plant there is the use of the generator's own electricity for equipment such as cooling water pumps, lubricating oil pumps, oil transfer pumps, lighting lamps, heaters and others. The cost of own-use electricity used by the equipment based on the selling price of electricity from geothermal power plants to Indonesian electrical company (PLN) is 1,119.74 Rp / kWh. With the potential of solar radiation of 4.90 kWh/m2 per day, optimization of electricity consumption using solar cells and batteries will be carried out. The price of the solar cell is assumed to be 12,000,000 Rp/kW, the battery inverter is 2,000,000 Rp/kW and the battery is 2,350,590 Rp/kW. The lifespan of solar cell equipment and batteries is 20 years. This paper will be simulated in 4 cases and the result will be the price of electricity based on the value of capital divided by the total electricity produced by solar cells and batteries for 20 years. Case 1 when using solar cell day and night using batteries and the result of electricity price for case 1 is 718.648 Rp kWh. Case 2 when using solar cell day and night using its own electricity from the generator and the result of electricity for case 2 is 990.952 Rp/kWh. Case 3 when using solar cell and battery, at night using battery and the result of electricity for case 3 is 711.77 Rp/kWh. Case 4 when using solar cells and batteries, at night using electricity itself from the generator and the results of the case 4 electricity price is 978.005 Rp/kWh. Based on the 4 case simulations, the price of electricity will be cheaper if during the day using a solar cell plus battery and night using a battery, as in case 3, the price of own electricity power plant is 711.77 Rp/kWh..

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I. INTRODUCTION

Geothermal power plants, have equipment to support the performance of these plants such as cooling water pumps, lubricating oil pumps, oil transfer pumps, lighting lamps, heaters and others. This equipment uses electricity from the generator called the use of electricity itself. The generator's own use is electrical energy derived from the generator itself. In calculating the sale of electric power generators, the use of electricity itself becomes a deduction from the total electricity production generated by the plant. Means the total revenue of a generator is subtracted from the total electrical energy used by the generator's own equipment. In power plant with high electricity sale prices, the electricity used by the generator's own

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electricity usage when converted to sales price will reduce profit of corporation. With the potential of solar energy in the Darajat Geothermal Power Plant area are 4.647 kWh/m2 per day, the use of electricity alone will be optimized using solar cells and batteries. In this paper, solar cells with monocrystalline materials and efficiency of around 18% - 20% will be used. The price of a solar cell is around 12,000,000 Rp/kWp (including installation costs). The inverter used has a price of 2,000,000 Rp/kW and the price of a battery with a type of lithium is around 2,350,590 Rp/kW. Optimizing the use of electricity itself using solar cells and batteries will be simulated with several cases.

II. Data and Case Model

The following data and case models are made to make the comparison which is the cheapest.

A. Data

To optimize the use of electricity itself at the power plant, it needs data from the energy used. Each generator has a meter to measure electrical energy. And the power usage data itself can be obtained from these measurements. The following data is from the Darajat geothermal power plant's own electricity usage:

Table 1. Darajat Power Plant Load Profile

Hour	Load (kWh)
00:00	615.0644
01:00	682.1816
02:00	654.4238
03:00	694.7774
04:00	733.2598
05:00	709.5703
06:00	710.1484
07:00	646.8066
08:00	613.1016
09:00	421.707
10:00	342.1465
11:00	425.8692
12:00	503.3145
13:00	513.4297
14:00	462.6152
15:00	643.6367
16:00	607.9434
17:00	572.998
18:00	534.0508
19:00	680.2012
20:00	625.8457
21:00	581.0215
22:00	593.834
23:00	588.623

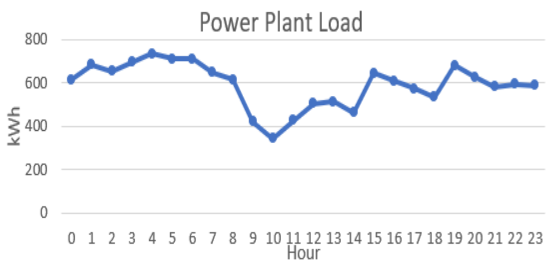

Figure 1. Load Profile of Darajat Power Plant during day and night.

And the following solar radiation data based on a yearly average:

	Horizontal global irradiation	Horizontal diffuse irradiation	Temperature
	kWh/m².day	kWh/m².day	°C
January	4.57	2.34	24.9
February	4.69	2.39	25.0
March	4.89	2.30	25.2
April	4.83	2.04	25.3
May	4.86	1.72	25.1
June	4.67	1.58	24.7
July	4.91	1.59	24.2
August	5.28	1.77	24.1
September	5.43	2.06	24.2
October	5.17	2.29	24.5
November	4.60	2.33	24.6
December	4.83	2.30	24.7
Year ?	4.90	2.06	24.7

Figure 2. Solar radiation data is taken from the PVSyst application

B. Case Model

In this paper 4 cases will be made to find the cheapest solar cell design.

- Case 1: Daytime uses solar cells and nighttime uses batteries

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During the day the solar cell will supply electricity to power plant's equipment and also charge the battery for use at night.

- Case 2 : Daytime uses solar cells and nighttime uses electricity itself

  During the day the solar cell will supply electricity for power plant's equipment and at night it will use its own electricity as a supply.

- Case 3 : Daytime uses solar cells plus batteries and nighttime uses batteries

  During the day the solar cell will supply electricity for power plant's equipment and batteries. During daylight hours and peak loads, power plant equipment will use electricity from batteries. When the night will use the battery as a supply.

- Case 4 : Daytime uses solar cells plus batteries and nighttime uses electricity itself

When during the day the solar cell will supply electricity for power plant's equipment and supply batteries. When peak load time, the power plant's equipment will use electrical energy from the battery. When the night will use its own electricity as a supply.

With data - data such as electric power consumption itself Darajat Geothermal Power Plant will be processed based on a simulation case that has been made.

III. METHOD AND CASE SIMULATION

Based on the data of Darajat geothermal power plant's own power consumption and the potential for solar radiation in the Darajat area will be calculated so as to get the most optimal case simulation. To get the capacity of the solar cell needed based on the existing load, you can use the following equation:

$$P_{sc} = \frac{E_c}{H_{sun} * \eta_{system}} \quad (1)$$

Where :

P_{sc} = Solar cell capacity needed (kWp)

E_c= Energy consumed by power plant's equipment (kW)

H_{sun}= The duration of the sun is shining (Hours)

η_{system} = System Efficiency (%)

Ec or energy consumed is obtained from the calculation of the use of electricity itself PLT Darajat in one day. While the length of the sun shines based on data from the Central Statistics Agency. And for the efficiency of the system refer to one of the references [1] where the project is in the same country and almost uniform solar radiation levels are Indonesia.

For calculations in each case the model is more or less the same but there is a slight difference because it considers the efficiency of the battery, and the scenario 4 case simulation. In case 1, the total energy consumption of the generator's own electricity is distinguished between day and night. For the afternoon calculation use equation (2).

$$P_{sc\ day} = \frac{E_{c\ peak\ day}}{\eta_{system}} \quad (2)$$

Where:

$P_{sc\ day}$ = Solar cell capacity needed during the day (kWp)

$E_{c\ peak\ day}$ = The peak energy load is consumed by the equipment during the daytime (kW)

After getting the solar cell capacity in case 1, the total energy that will be generated by the solar cell case 1. There will be more electrical energy that will be stored in the battery. This more energy will reduce the total electricity demand for the night so as to get the additional solar cell requirements for the night load is as follows:

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$$E_{sc\ delta} = E_{sc\ day} - E_{c\ day} \quad (3)$$

Where :

$E_{c\ day}$ = Energy consumed by power plant's equipment during the day (kW)

$E_{sc\ delta}$ = Energy stored in the battery is due to more power than the capacity of the solar cell during the day (kW)

As for the calculation of solar cells to supply night electricity that will be stored in batteries using equation (1). But the total energy is then divided by the efficiency of the battery and the inverter which is 0,96.

$$P_{sc\ night} = \frac{E_{c\ night} - E_{sc\ delta}}{H_{sun} * \eta_{system}}\ x\ \frac{1}{0{,}96} \quad (4)$$

Where :

$P_{sc\ night}$ = Solar cell capacity needed at night (kWp)

$E_{c\ night}$ = Energy consumed by power plant's equipment during night (kW)

After getting the solar cell capacity during the day and night, the total solar cell capacity can be calculated by the equation below:

$$P_{sc\ total} = P_{sc\ day} + P_{sc\ night} \quad (5)$$

Where :

$P_{sc\ total}$ = Total solar cell capacity needed (kWp)

Because in case 1 when using the battery at night the solar cell energy during the day will be stored in the battery. And the equation for battery case 1 capacity is as follows:

$$P_{bat\ night} = E_{c\ night} \quad (6)$$

Where :

$P_{bat\ night}$ = battery capacity needed at night (kW)

For case 2 because during the day you use the solar cell and at night you use your own electricity, you don't use batteries at all, so the capacity of the solar cell will use the peak load divided by the efficiency of the system. The equation used to get the total capacity of solar cell case 2 is equation (2).

$$P_{sc} = \frac{E_{c\ peak\ day}}{\eta_{system}}\ x\ \frac{1}{0{,}96} \quad (7)$$

As for case 3 during the daytime use equation (1) so we get the value of solar cell capacity when daylight is needed.

$$P_{sc\ day} = \frac{E_{c\ day}}{H_{sun} * \eta_{system}} \quad (8)$$

The capacity of solar cells during the day based on the equation will supply only during the day. When the load is low, the solar cell will store excess energy in the battery and when the load is more than the solar cell electricity supply, the electrical energy in the battery will be supplied to meet the load requirements. Batteries during the day will use batteries used at night so that they are the same as case 1, which is equation (6). And for the needs of the electricity load at night will be supplied with the capacity of the night solar cell, and the calculation is the same as the following equation:

$$P_{sc\ night} = \frac{E_{c\ night}}{H_{sun} * \eta_{system}}\ x\ \frac{1}{0{,}96} \quad (9)$$

The equation of total solar cell capacity to supply electricity generating equipment during the day and night in case 3 is as follows:

$$P_{sc\ total} = P_{sc\ day} + P_{sc\ night} \quad (10)$$

In case 4 when using solar cell plus battery and night using electricity alone, to calculate solar cell needs will use equation (7) and battery capacity for case 4 to be optimal, will be calculated from the average load per hour reduced by the lowest load in the noon period is then multiplied by the number of hours the sun shines. Here is the equation to find the battery capacity in equation 4:

$$P_{bat\ day} = \left(E_{c\ ave} - E_{c\ \min\ day}\right)\ x\ H_{sun} \quad (11)$$

Where :

$E_{c\ ave}$ = The average energy consumed by the equipment during the day (kW)

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$E_{c\ min\ day}$ = The lowest energy consumed by equipment during the day (kW)

After getting the capacity of the solar cell and battery. Calculate the solar cell area needed so that it can be a consideration in choosing which case is the most suitable.

IV. Result and Discussion

Based on the data from the electricity usage load itself, Darajat geothermal power plant and the simulation of the 4 cases will get the results of the comparison of the electricity costs of generating equipment. The following is an example of a simulation calculation based on the equation mentioned. The sun shines effectively around 8 hours a day based on data obtained from Badan Pusat Statistik, so this determines $E_{c\ day}$ between 09:00 and 16:00. And $E_{c\ night}$ around 16 hours starting at 17:00 until 08:00. Then the result is:

$E_{c\ day}$ = 3,920.66 kW

$E_{c\ night}$ = 10,235.91 kW

$E_{c\ day}$ and $E_{c\ night}$ values are then entered into the equation in each case. In addition, the value of $E_{c\ max\ day}$ and $E_{c\ min\ day}$ will be searched to be calculated in equations to get the capacity of solar cells and batteries. While the system efficiency will refer to the system efficiency in the reference that is equal to 0.447256 [2].

$E_{c\ peak\ day}$ = 643.63672 kW

$E_{c\ min\ day}$ = 342.1465 kW

Here is an example calculation of one case. Case to be taken is case 1. To get the total power for solar cells during the day using equation (2).

$$P_{sc\ day} = \frac{E_{c\ peak\ day}}{\eta_{system}} = \frac{643{,}63672}{0{,}447256}$$

$$P_{sc\ day} = 1439.08\ kWp$$

With a solar cell capacity during the day of 1439.08 kWp and with the sun that can shine for 8 hours. Then the total energy produced by solar cell capacity during the day is still left over when the total energy produced is reduced by the burden during the day.

$$E_{sc\ day} = P_{sc\ day} * H_{sun} * \eta_{system} = 1439.08 * 8 * 0.447256$$

$$E_{sc\ day} = 5149.09\ kW$$

The total electrical energy produced by the solar cell during the day is greater than the load during the day so there is residual and will later be stored in the battery is used at night.

$$E_{sc\ delta} = E_{sc\ day} - E_{c\ day} = 5149.09 - 3920.66$$

$$E_{sc\ delta} = 1288.43\ kW$$

Because the need for loads at night is compensated for by the remaining energy during the day, calculating the need for solar cells for night loads using equation (4).

$$P_{sc\ night} = \frac{E_{c\ night} - E_{sc\ delta}}{H_{sun} * \eta_{system}}\ x\ \frac{1}{0{,}96}$$

$$= \frac{10235.91 - 1288.43}{8 * 0{,}447256}\ x\ \frac{1}{0{,}96}$$

$$P_{sc\ night} = 2622.32\ kWp$$

After getting solar cell needs based on the load during the day and night, the total solar cell needed in one day is as follows:

$$P_{sc\ total} = P_{sc\ day} + P_{sc\ night} = 1439.08 + 2622.32$$

$$P_{sc\ total} = 4061.40\ kWp$$

With the capacity of the solar cell, the batteries needed to supply the load at night will be calculated. The batteries needed will be equated with the capacity of the load needs at night in accordance with equation (6).

$$P_{bat\ night} = E_{c\ night} = 10235.91\ kW$$

For cases 2,3 and 4 will follow in accordance with the equations previously explained. And here are the results of the capacity of solar cells and batteries from cases 1,2,3 and 4. In case 2 the solar cell capacity is 1,439.08 kWp and does not use batteries. For case3 the solar cell capacity is

4,002.16 kWp and the battery capacity is 10235.91 kW. And case 4 solar cell capacity is 1,095.75 kWp and battery is 1,183.49 kW. Then calculate the investment costs of solar cells, batteries, inverters, land area needed. All total investment will be calculated to get the price of electricity Rp / kWh for electricity usage on generating equipment. The cost of electricity Rp / kWh will be compared in each case so finding which case is the cheapest. The value of Rp / kWh will be calculated based on the total investment, divided by the electricity generated during the lifetime of the PV and the battery which is 20 years. The price of the solar cell used is Rp. 12,000,000.00 and the price of the battery is Rp. 2,350,590.00 while the price of the inverter is Rp. 2,000,000.00. And for the price of electricity for the generator's own use the selling price of the power plant to PLN is 1,119.74 Rp / kWh. The capacity of the inverter will adjust the peak load of existing data. The following is an example of calculating Rp / kWh for case 1. Total investment from case 1 of the data is:

- solar cell investment = 4,061.40 * 12,000,000.00 = Rp. 48,736,792,308.26
- Battery investment = 10,235.91 * 2,350,590.00 = Rp. 24,060,423,526.36
- Inverter investment = Rp. 1,470,000,000.00
- Investment total of case 1 = Rp. 74,267,215,834.62

Then look for the total investment value of cases 2,3 and 4:

- Case 2 = Rp. 42,779,371,600.84
- Case 3 = Rp. 73,008,502,065.27
- Case 4 = Rp. 17,400,954,044.21

With this investment, the assumption of electricity from solar cells and batteries in 20 years is 103,342,963.41 kW. Then look for the value of Rp / kWh of the investment value and the total energy that will be produced in those 20 years. The following Rp / kWh in case 1:

$$\frac{Rp}{kWh} = \frac{Capital\ Cost}{kWh\ total} = \frac{74{,}267{,}215{,}834.62}{103{,}342{,}963.41}$$

$$= 718{,}648\ Rp/kWh$$

And for cases 2,3 and 4 the following investment value and Rp / kWh are as follows:

- Case 2 = 990.5 Rp/kWh
- Case 3 = 711.77 Rp/kWh
- Case 4 = 978.01 Rp/kWh

Table 2. Total Investment And comparison

	Total Solar Cell (kWp/h)	Total Investment (Rp)	Rp/kWh
Case 1	4,061.40	74,267,215,834.62	718.648
Case 2	1,439.08	18,738,948,074.48	990.953
Case 3	4,002.16	73,556,379,301.68	711.77
Case 4	1,141.41	17,400,954,044.21	978.001

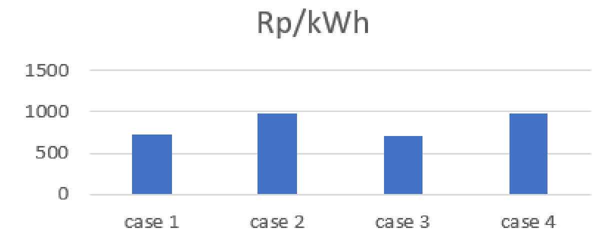

Figure. 3 Rp / kWh comparison between cases

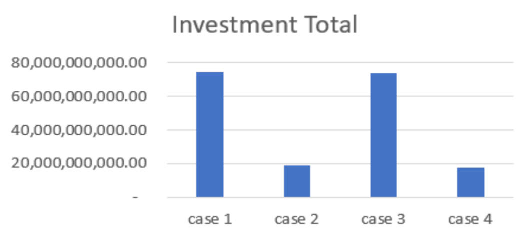

Figure. 4 Investment Total comparison between cases

After getting the value of Rp / kWh, you will also find the area of land needed for the solar cell from the type case. The land area needed for solar cells per kWp is 0.61776 HA / MWP. Then each case will be compared based on, Rp / kWh and required land area. The following comparison table:

Tabel 4. Land Area comparison

	Rp/kWh	Land Area Needed (ha)
Case 1	718.648	2.509

Case 2	990.953	0.889
Case 3	711.77	2.472
Case 4	978.001	0.677

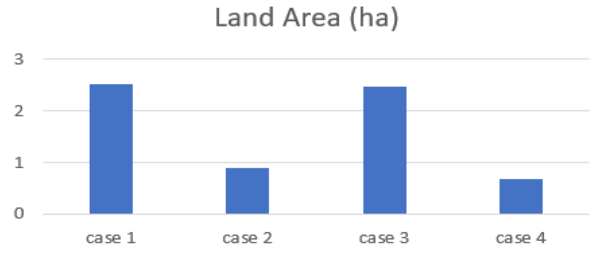

Figure. 5 Land Area comparison between cases

Based on these data case 3 will be chosen because it has the lowest Rp/kWh value. In addition, the land area used for solar cell installations is smaller compared to case 1.

V. Conclusion

With a solar potential of 4,647kWh / m2 per day a solar cell system is made to optimize the use of the generator's own electricity. Using 4 case simulation, we will find which case has the lowest value. In Case 1 when using solar cells day and night using batteries and the result of electricity price for case 1 is 718,648 Rp / kWh. The difference between case 1 and the selling price of electricity from the power plant with PLN is 401.08 Rp / kWh. the results of the price of electricity case 2 when using solar cell day and night electricity itself is 990.952 Rp / kWh and has a difference of 128.78 Rp / kWh. Case 3 when using solar cell and battery, at night using battery and the result of electricity for case 3 is 711,769 Rp / kWh and the difference in selling price to PLN is 407,966 Rp / kWh. Case 4 when using solar cells and batteries, at night using electricity itself from the generator and the results of the case 4 electricity price is 978,005 Rp / kWh and the difference with the price to PLN is 141.73 Rp / kWh.

Based on the 4 case simulation, the price of electricity will be cheaper if during the day using a solar cell and at night using a battery, as in case 3, the price of electricity for self-use is 711,769 Rp / kWh .The value is also 407,966 Rp / kWh cheaper than using the generator's own electricity. with the selling price of the power plant to PLN. And seeing solar cell and battery prices continue to decline, the study in this paper can be considered feasible to carry out in the future.

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