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Planning Of A 70 kW Solar Power Plant In Magersari Village

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ABSTRACT

Keywords
Battery
Battery Charger regulator (BCR)
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PLTS
Solar Power Plant
Magersari Village

Magersari Village is one of the small villages on West Java, which is in the administrative area of Magersari Regency, this village has not been reached by the PLN electricity network, which causes disturbances for residents in carrying out activities at night. This study aims to utilize solar energy developed into electrical energy (solar power plant). One of the supporting factors this area produces is a very large solar energy potential with average daily insolation of 5.71 kWh/m²/day. In planning this solar power plant, several components consist of 376 housing units, 2 elementary school units, 3 village maternity hut units, and 1 unit of worship place. Based on the analysis and calculations results, the PV power generated to supply electrical energy in Magersari Village is 75,000 Watt Peak, generated by 375 PV modules, and the panel capacity is 200 Wp with 2 PV array placement area of 460 m². Battery Charger Regulator (BCR) used as many as 36 pieces with a capacity of 24V/80A. The number of batteries used is 219 pieces with a capacity of 24V/240Ah. The inverter used is 10 kW as many as 7 units with a voltage on the system that is 24V with a total initial investment cost for Solar Power Plant components of Rp.2,473,165,000,-

1. Introduction

Magersari Village is located in the administrative area of Magersari Regency with a population of ± 1,593 people consisting of 376 families with an area of ±3.76 Km². This is one of the villages that has not received electricity supply from State Electricity Enterprise[1]. This causes Magersari Village to be completely dark at night and residents cannot carry out activities at night. Magersari Village is located on West Java, 65 Km from the capital city of Magersari Regency. Access to West Java can only be done by sea. Therefore, it is natural that Magersari Village is one of the villages that does not receive electricity from State Electricity Enterprise. In the morning to evening residents can carry out their activities as usual because of the hot sun. However, at night, the village becomes pitch black and residents find it difficult to carry out various activities.

Magersari Village gets enough sunshine all year round. One of the supporting factors produced by this area is the enormous potential for solar energy with average daily insolation of 5.11 kWh/m²/day. The potential of Magersari Village. From the background of the problems above, in this study, a solar power plant was planned as an alternative energy source used to meet the electricity needs in Magersari Village[2]. The planned solar power plant uses an Off-Grid system[2], which is a stand-alone generator. The final result of planning this solar power plant is to obtain electrical energy that can meet the electricity needs in Magersari Village.

2. The Proposed Method

2.1. Solar Energy Utilization

Solar energy in the form of electromagnetic radiation emitted to the earth in the form of sunlight consisting of photons or solar energy particles that are converted into electrical energy. The solar energy that reaches the earth's surface is referred to as global solar radiation which is measured by the power density on the surface of the receiving area. The average value of the solar radiation of the Earth's atmosphere is 1,353 W/m which is expressed as the solar constant. The intensity of solar radiation is influenced by the time of the earth's rotation cycle, weather conditions including the quality and quantity of clouds, the change of seasons, and the position of latitude. The intensity of solar radiation in Indonesia lasts 4-5 hours per day[3].

2.2. PV System Components

1) Solar Module.

   The main components of PV that can produce DC electrical energy are called solar panels or solar modules. Solar panels are made of semiconductor materials (generally silicon) which when illuminated by sunlight can produce an electric current[3]. The number of solar panels needed for PV can be calculated by the equation:

   $$\text{Number of PV Panels} = \frac{\text{P(Watt peak)}}{\text{PMPP}} \qquad (1)$$

   Where:
   P = Awakened Power
   P_{MPP} = Maximum Output Power of PV Panel

2) Battery (Accumulator)

   The energy stored in the battery serves as a backup, which is usually used when the solar panels do not produce electrical energy, for example at night or during cloudy weather, besides that the output voltage to the system tends to be more stable. The unit of energy capacity generated in the battery is the ampere hour (Ah), which means the maximum current that can be issued by the battery for one hour. In the process of discharging the battery (discharge), the battery should not be emptied to the maximum point, because this affects the service life (lifetime) of the battery[4]. The discharge limit of the battery is called the depth of discharge (DOD) expressed in percent. A battery has 80% DOD, this means that only 80% of the available energy can be used and 20% remains is in reserve. The deeper the DOD applied to a battery the shorter the cycle of the battery.

3) Battery Charger Regulator (BCR)

   The Battery Charger Regulator (BCR) is a device that regulates the charging of electric current from the battery/accumulator of the solar module and vice versa. When the remaining battery power is 20% to 30%, the regulator will disconnect the load. The Battery Charger Regulator (BCR) also regulates the battery overcharging and overvoltage of the solar module. The benefits of this tool are also to avoid full discharge and overloading and monitor battery temperature. Overvoltage and overcharging can reduce battery life. The battery controller is equipped with a protective diode which prevents DC from the battery from re-entering the battery's solar panel. The load on the power solar plant system takes energy from the BCR. The current capacity flowing in the BCR can be determined by knowing the maximum load installed[5].

4) Inverter

   The inverter is a device that converts DC current to AC according to the need for the electrical equipment used. This tool converts DC current from solar panels into AC current[5].

2.3. PV Technology Design

Calculate the total usage load per day. The formula used is as follows:

$$\text{Usage load (W)} = \text{Power} \times \text{Use time} \qquad (2)$$

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The electrical energy needs are added up with the assumption of losses. In the system, the amount of losses for system components that use new equipment according to Mark Hankin is 15%[6]. So the amount of energy needed (ET) is:

$$\begin{aligned} \mathrm{ET} &= \text{Electrical Energy Requirement} + \text{System loss} \\ &= \text{Electrical Energy Requirement} + (15\% \times \text{Electrical Energy Requirement}) \end{aligned} \quad (3)$$

Calculate the Array Area using the following equation:

$$\text{PV Area} = \frac{E_t}{G_{Av} \times \eta_{pv} \times TCF \times \eta_{out}} \quad (4)$$

Where:

$E\,t$ = Energy consumption (kWh/day)
$G\,Av$ = Average daily solar insolation (kWh/m/day)
ηpv = Solar panel efficiency
TCF = Temperature correction factor
ηout = Inverter efficiency

Calculating the power generated with the following equation:

$$\text{P Watt peak} = \text{Area array x PSI x } \eta\text{pv} \quad (5)$$

Where:

PSI (Peak Solar Insolation) : 1000 W/m^2
ηpv : Solar panel efficiency

Calculate the capacity of the BCR. The current capacity flowing in the BCR can be determined by knowing the maximum load installed and the maximum load system voltage. then the capacity of the current flowing in the BCR can be determined by the equation:

$$I_{maks} = \frac{Pmax}{Vs} \quad (6)$$

Where:

P_{max} = Maximum load
Vs = Maximum load system voltage

Calculate the capacity of the battery/accumulator. The unit of energy (in WH) is converted to Ah which corresponds to the unit of battery capacity as follows:

$$AH = \frac{Et}{Vs} \quad (7)$$

Where:

Vs = Maximum load system voltage
Et = Usage load

2.4. Cost Analysis

Solar power plant energy costs are different from energy costs for conventional plants. In this study, the costs for this solar power plant component consist of costs for purchasing solar panels, inverters, BCRs, and batteries[7][8]. For the calculation of maintenance and operational costs, the following equation is used:

$$M = 1\% \times \text{total invesment cost} \quad (8)$$

For the calculation of life cycle costs (LCC) the following equation is used:

$$LCC = C + M_{pw} \quad (9)$$

Where:

LCC = Life Cycle Cost
C = The initial investment cost is the initial cost incurred for the purchase of solar power plant components, Installation costs, and other costs such as costs for support racks.
Mpw = Present value costs for the total cost of maintenance and operations during the year or over the life of the project.

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The present value of annual costs that will be incurred sometime in the future (during the life of the project) with a fixed amount of expenditure, is calculated by the following formula:

$$P = A\left[\frac{(1+i)^n-1}{i(1+i)^n}\right] \quad (10)$$

Where:
P = Present value of the annual cost of the life of the project.
A = Annual fee
i = Discount Rate
N = Life of project

The discount factor is a factor used to assess current and future revenues so that they can be compared with current expenditures, while the discount rate used to assess current and future receipts be in the form of market interest rates (multiple interest rates). The discount factor formula is follows:

$$DF = \frac{1}{(1+i)^n} \quad (11)$$

Where:
DF = Discount factor
i = Discount rate
n = Period in years (life of investment)

Energy cost is the ratio between the total annual cost of the system and the energy it produces over the same period. The calculation of solar power plant energy costs (COE) is determined by life cycle costs (LCC), capital recovery factor, and annual production kWh. Then the following equation is used:

$$COE = \frac{\text{LCC X CRF}}{\text{AkWh}} \quad (12)$$

Where:
COE = Cost of Energy (Rp/kWh)
CRF = Capital recovery factor
LCC = Life Cycle Cost
AkWh = Energy generated yearly (kWh/year)

The capital recovery factor for converting all life cycle cost (LCC) cash flows into a series of annual cost is calculated by the following formula:

$$CRF = \left[\frac{i(1+i)^n}{i(1+i)^n}\right] \quad (13)$$

Where:
CRF = Capital Recovery Factor
i = Discount rate
n = Period in years (life of investment)

Mean while, the annual production kWh of Solar Power Plant is calculated as follows:

$$A\ kWh = kWh\ \text{daily production} \times 365\ \text{days} \quad (14)$$

Based on the calculation results of LCC, CRF, and annual production kWh, then energy costs (COE) can be calculated using the formula in equation (12).

3. Method

3.1. Research Flowchart

The research flowchart as shown in figure 1 is used to determine the steps taken in the research to plan a solar power plant in Magersari Village.

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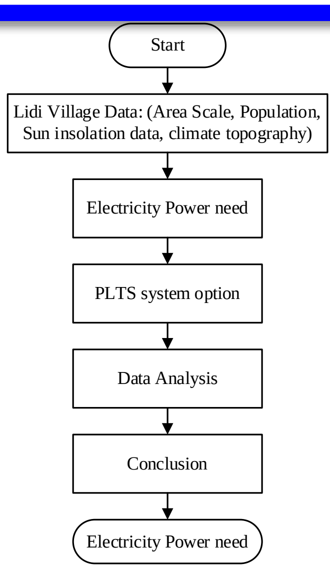

Fig 1. Research Flowchart

3.2. Data Collection

1) Power Requirement

Table 1. Total Electrical Energy Needs In Magersari Village

No.	Village Component	Amount	Electrical Energy Usage (Wh)
1	House	376	259.624
2	Elementary	2	3.863
3	Praying Place	1	1.116
4	Maternity Hut	3	1.668
	Total		266.276

Magersari Village is located on West Java with an area of +4.86 Km with a total of 361 households, while the facilities and infrastructure include 2 elementary school buildings, 1 place of worship, and 3 village maternity hut units. The total amount of electrical energy needed in Magersari Village is 366,276 W or (266.276 kWh) with the following details:

4. Results and Discussion

4.1. Determining The System Of Solar Power Plant

Determining the system design of a solar power plant requires several components and from this system will be distributed to supply electricity needs in Magersari Village which can be seen in Figure 2.

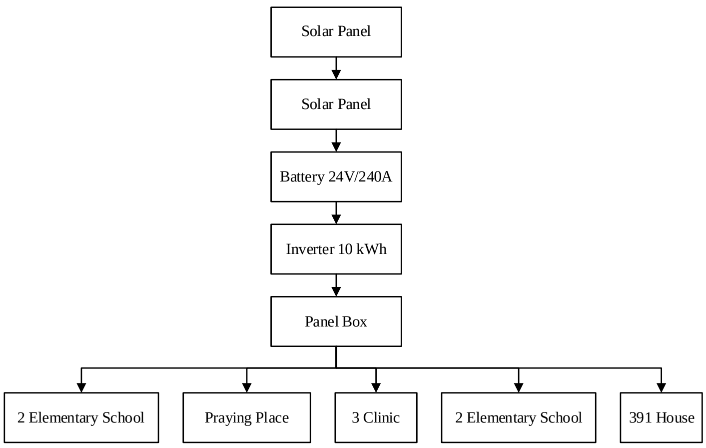

Fig 2. Electrical Distribution System Block Diagram

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From the power source, the 350 Unit Solar Module with a capacity of 200 Wp is divided into 7 networks to 6 units of Panel Box. Panel Box is channeled to Charge Controller. From the Charge Controller which functions to control the charging of electricity to the battery and the release of electricity from the battery to the inverter equipment. The battery to Inverter which converts electric current from DC to AC is forwarded to the Distribution Panel. Furthermore, from the distribution panel then distributed to the consumers.

4.2. Electrical Calculation Results of Solar Power Plant System

The average electrical energy per day is 326,276Wh. The need for electrical energy is summed with the assumption of losses in the system, the assumption of losses for system components[6] is 15%. Then the amount of energy needed (ET) can be calculated based on equation (3):

$$\begin{aligned} E_T &= \text{Electrical energy needs} + (15\% \times \text{Electrical energy needs}) \\ &= 266.276 + (15\% \times 266.276) \\ &= 365.217\text{kWh}/(306{,}217\ \text{kWh}) \end{aligned}$$

4.3. Array Area Calculation Results

The value of η_{out} of is determined based on the efficiency of the inverter, which is 0.9. If the value E_T, G_V, η_{pv}. TCF dan ηout have been obtained, then the PV area value can be calculated based on equation (4):

$$\begin{aligned} \text{PV Area} &= \frac{E_t}{G_{AV}\ x\ \eta_{pv} x\ TCF\ x\ \eta_{out}} \\ &= \frac{306{,}217\ \text{kWh}}{5.11 \frac{\text{kWh}}{\text{m}^2}\ x\ 0.15\ x\ 0.965\ x\ 0.9} \\ &= \frac{306{,}217\ \text{kWh}}{0.665705\ \frac{\text{kWh}}{\text{m}^2}} \\ &= 460\ \text{m}^2 \end{aligned}$$

4.4. Result of Generated Power Calculation

From the calculation of the array area, the power generated by PV can be calculated using equation (5) as follows:

$$\text{P(Watt peak)} = \text{Area array} \times \text{PSI} \times \eta_{pv}$$

With an array area is 460 m^2, Peak Sun Insulation is 1000W/m, and solar panel efficiency is 15%

$$\text{P(Watt peak)} = \text{Area array} \times \text{PSI} \times \eta_{pv}$$

$$\text{P(Watt peak)} = 420\text{m}^2 \times \frac{1000\text{W}}{\text{m}} \times 15\% = 39.000\ \text{Watt peak}$$

$$\text{P(Watt peak)} = \text{Area array} \times \text{PSI} \times \eta_{pv}$$

4.5. Calculation Results of the Number of PV Panels

Calculation of the number of panels using equation (1) as follows:

$$\text{Number of PV Panels} = \frac{\text{P(Watt Peak)}}{P_{MPP}} = \frac{69{,}000}{200} = 345 \approx 350\ \text{Panel}$$

4.6. Calculation Results of Charge Regulator Battery Capacity

The load on the solar power plant system takes energy from the BCR[8][9][1]. The current capacity that flows in the BCR can be determined by knowing the maximum load installed. The

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maximum load that occurs is 70,050 W with the maximum load of the system voltage is 24 Volts, then the current capacity flowing in the BCR can be calculated using equation (6) as follows:

$$I_{max} = \frac{Pmax}{Vs} = \frac{70{,}050}{24} = 2{,}8.7\ A$$

To meet the required current of 2,8.7 A, then:

$$\frac{I_{max}}{linv} = \frac{2{,}918.7}{80} = 36.48$$

The value 80 is taken from the capacity of the BCR on the market, which is 80A/24V

4.7. Battery Capacity Calculation Results

To calculate the required battery capacity is to use equation (7) as follows:

$$AH = \frac{Et}{Vs}$$
$$= \frac{306{,}217}{24}$$
$$= 12{,}256\ Ah$$

The specified autonomy day is three days, so the battery only stores energy and delivers it on the same day. The amount of deep of discharge (DOD) on the battery is 80%[6]. Then the required battery capacity is:

$$Cb = \frac{AH\ \times\ 3}{DOD} = 12{,}759\ \times \frac{3}{0.8} = 47{,}846\ Ah$$

In this research the battery used is Sonnenschein A600 Solar with a capacity of 240 Ah, the total battery required is:

$$Cb = \frac{47{,}846}{240}$$
$$= 199.35 \approx 200\ \text{Batteries}$$

4.8. Inverter Capacity Calculation Results

In the selection of the inverter, the working capacity is sought to approach the power capacity served, this is so that the work efficiency of the inverter is maximized. The inverter type used is Sun Gold Power 10 kW which is adjusted to the power generated by 70,050 WP. Then the capacity of each inverter capacity is 10 kW, with a total of 7 inverters.

4.9. Solar Power Plant Component Cost Analysis

The total initial investment cost for the Solar Power Plant component[10] to be developed in Magersari Village is Rp.2,693,475,000, - (Two Billion Six Hundred Ninety-Three Thousand Four Hundred Seventy-Five Thousand Rupiah). Consists of costs for purchasing PV panels, battery charge regulators, batteries, inverters, PV racks.

Table 2. Table 1. The Amount Of The Initial Investment For The Solar Power Plant To Be Developed In Magersari Village

No.	Component	Amount	Price (Rp)	Total Price (Rp)
1	PV Panel	350	3.600.000	1.260.000
2	Battery Charge Regulator	36	6.180.000	222.480.000
3	Battery	200	4.095.000	814.905.000
4	Inverter	10	34.359.000	343.590.000
5	Rak PV	350	150.000	52.500.000
	Total			2.693.475.000

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4.10. Analysis of Maintenance and Operational Costs

For the calculation of maintenance and operational costs (M), the specified are 1% of the initial investment fee (8 :

$$M = 1\% \times \text{Total Investment Cost}$$
$$= 0{,}01 \times 2.693.475.000$$
$$= \text{Rp.}\, 26.934.750$$

4.11. Life Cycle Cost Analysis

The life cycle cost (LCC) for the solar power plant is determined by the present value of the total cost of the solar power plant system which consists of initial investment costs (C) and long-term costs for maintenance and operations (M_{pw}). (9) as follows:

$$LCC = C + M_{pw}$$
$$= 2.693.475.000 + 226.817.530$$
$$= \text{Rp.}\, 2.920.292.530$$

4.12. Solar Power Plant Energy Cost Analysis

Calculation of the energy cost (cost of energy) of a solar power plant is determined by the life cycle cost (LCC), capital recovery factor (CRF), and annual production kWh. The energy cost (cost of energy) of the solar power plant is calculated by equation (12) as follows:

$$COE = \frac{LCC\ X\ CRF}{AkWh}$$
$$= \frac{2{,}920{,}292{,}530\ x\ 0{,}1187}{111{,}769.205}$$
$$= \frac{346.638.723{,}311}{111{,}769.205}$$
$$= \text{Rp.}\, 3.101{,}38\ /\ \text{kWh}$$

4.13. Discussion

Based on the conclusions drawn, there are several suggestions in designing and testing this tool, including some suggestions that can be taken for the design of this tool. The planning for the solar power plant in Magersari Village is only about how to distribute it, not discussing the fire protection that might happen to the distribution panel. Therefore, it could be better if added protection devices such as fire alarms on the distribution panel. Fire alarms manipulate panels to perform a wide variety of tasks, saving lives and protecting property. Some fireplace dampening structures or fireplace sprinkler structures is rapid, while others are not.

Then in planning the manufacture of solar power plants, it is also necessary to pay attention to the level of energy efficiency produced. This can be achieved by adding a solar tracker that will detect the direction of the sun's rays so that the energy produced will be more efficient. The design of the power plant in Magersari Village also needs to take into account the terrain has taken for assembly, installation, and distribution throughout the village. It is necessary to cooperate with residents in doing some of these things because if they are the people who better understand the area there.

5. Conclusion

From the results of the discussion, it was found that to meet the electricity needs in Magersari Village there were 376 housing units, 1 unit of worship place, 2 units of elementary school, 3 village maternity hut units required electrical energy of 306,217 Wh. To fulfill this need, the following conclusions can be drawn: The maximum power generated by the PV Array is a 70,050 Watt peak (920.5 V and 76.1 A), The required number of PV panels is 350 panels with a panel capacity of 200WP which is connected in series and parallel, The area of the array placement is 3,039.27 m^2.

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Based on the geographical location of Magersari Village which is at a position of 8º South Latitude and 121º East Longitude, the installation of solar panels (arrays) for the Solar Power Plant is oriented towards the north. The capacity of the BCR used is 2,918.7 A as many as 36 units with the capacity of each BCR which is 24 V/80A. The number of batteries used is 199 pieces with a capacity of each battery which is 24V/240Ah. The inverter used is 10 kW as many as 7 pieces with a voltage on the system that is 24V. The total initial investment cost for the solar power plant components to be developed in Magersari Village is Rp.2,693,475,000, - (Two Billion Six Hundred Ninety-Three Thousand Four Hundred Seventy-Five Thousand Rupiah) not including installation costs.

The total cost of maintenance and operations is Rp. 26,934,750,- / Year. (Twenty Six Million Nine Hundred Thirty-Four Thousand Seven Hundred Fifty Rupiah / Year). The life cycle cost (LCC) for the solar power plant to be developed in Magersari Village is Rp. 2,920,292,530, - (Two Billion Nine Hundred Twenty Million Two Hundred Ninety-Two Thousand Five Hundred Thirty Rupiah). Based on the calculation results of LCC, CRF, and kWh of annual production, the energy cost (COE) for the solar power plant to be developed in Magersari Village is Rp. 3,100, - / kWh

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