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Design of hybrid power plants (solar module-generator set)

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Abstract. Hybrid power plant which utilizes the solar module is the primary source and the generator set is the secondary source for backing up the solar module in battery charging in the village of western Meranti. The total energy needed in this village is 14.21 kWh per day and the use of this energy is from 18:00 to 6:00 o'clock. After the calculation is obtained that the capacity of the battery needed to store energy is 731 Ah with a total of 20 batteries capacity of 1 battery 150 Ah 12 V. In this area the average insolation is 4.87 kWh / m^2 / day, irradiation hours in this village obtained 4.87 hours a day, then the solar module needed 40 modules with 2 circuits, each series is made 2 series and 10 parallel, the required Solar Charge Controller capacity is a minimum of 68.37 A for 2 units and for the inverter because the maximum load power is 2,880 W, the inverter with a capacity of 4,000 W is chosen and for the Genset to be used is a generator with an output of 4,500 W and a battery charger capacity minimum 54.825 A. The use of generator set is only for charging energy to the battery if the energy inside the battery has reached the planned DOD limit and the cost of electricity produced is Rp4.524,00/kWh.

1. Introduction

Western Meranti is one of the villages in Silaen District [1], Until 2019 in this village there was no electricity from PLN that makes the background of this research, this village was at an altitude of 1,140 MDPL with the coordinates of the village 2.458465 north latitude and 99.325925 east longitude, there were 37 houses, 1 school, 2 health facilities and 1 place of worship in this village [1], One of the causes in this village is that there is no PLN electricity network (Perusahaan Listrik Negara). The village is far from the city center and the road to the village is very difficult to reach [2]. Kossi conducts power plant design in Tikalong village using solar module [3], but if use only solar modules, it still has a weakness where the sun does not shine every day so that the production of electrical energy will be disrupted. The purpose of this research is to design hybrid power plant especially in its main components, the use of a hybrid system is expected to be able to serve the electricity needs of the community in accordance with the conditions of the area [4]. The author designs the PLTS system and combines it with the generator set (generator set), where the use of generators is only for charging energy into the battery, so even though in the morning until the afternoon the weather is cloudy which causes the electrical energy generated by the solar module is not enough to serve the load there is still a generator set as a backup energy source that is operated to charge energy into the battery so that people can still feel the benefits of electrical energy at night.

2. Methodology of research

The flows used in this study are starting from environmental condition analysis, electrical energy needs analysis, design of main components and cost analysis. To find out about environmental conditions such

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as the location of the house and the coordinates of the village use data from Google Earth. The potential of solar energy in the village using data sourced from nasa's power larc by entering the coordinates of the village and selecting the time range of data retrieval so that it will be averaged solar energy potential every year in the village, The author uses data that has been published by BPS Toba Regency to get data on the number of houses in the Meranti village that have not been electrified, the number of public facilities and the number of family members in each house, so that the author can determine the electrical energy needs of the community in the village. With the average potential of solar energy every year and the electricity need in the village then carried out the design of components ranging from solar modules, solar charger controllers, batteries, inverters, and generator set so that it gets the size of the components in the PLTH according to the conditions in the village.

3. Results and discussion

3.1. Site selection
Site Selection in this PLTH planning is located in Meranti Barat Village, in Silaen District, Toba Regency, at coordinates 2.458465 north latitude and 99.325925 east longitude [1], this location selection is based on Publication data titled Silaen District in 2019 issued by the Central Statistics Agency Toba Regency which explains that in this village there is absolutely no electricity network from PLN and the distance from this village to the subdistrict center is relatively far, which is 22 km [1], then the reason that makes this village as a location in the execution of this Final Project is the amount the population in this village is small and the housing of this population is centered somewhere. Map of community housing center in Meranti Barat Village can be seen in Figure 1.

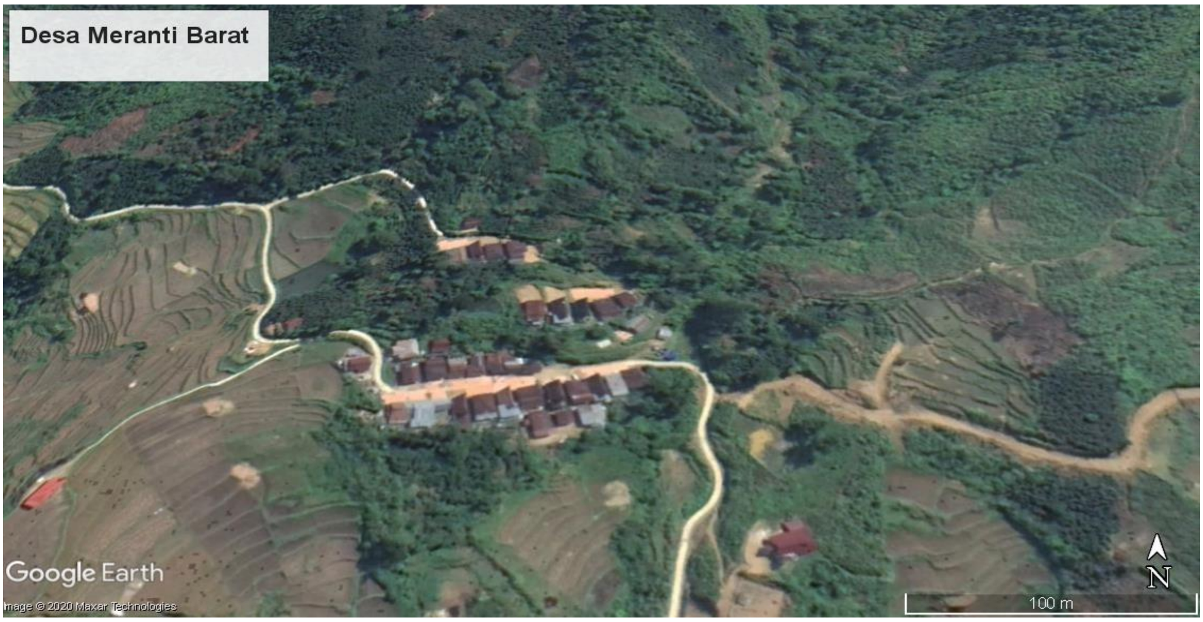

Figure 1. Map of community housing center in Meranti Barat Village [5].

3.2. Analysis of environmental conditions
In analyzing the environmental conditions, the writer takes some data that the writer will use in this design such as average temperature and average daily irradiation, this data can be obtained from the Climatology Station in the district, and can also be obtained from NASA's website by *accessing power.larc.nasa* [6]. This site is a site owned by NASA that knows the value of potential alternative energy on earth by inputting site coordinates, then the required parameters will be obtained, such as data about the value (Incoming Solar Radiation) insolation or commonly referred to as the amount of radiation reaching the earth's surface in a day and the average temperature [7].

Table 1. The temperature and irradiance of Meranti Barat Village [7].

Years	Month	Temperature ^{O}C	Insolation $kWh/m^2/day$
	January	25.38	4.79
	February	25.85	5.50
	March	26.44	5.71
	April	26.97	5.25
	May	26.32	4.64
	June	26.12	4.88
2019	July	25.91	4.80
	August	26.17	5.05
	September	26.33	5.15
	October	25.38	4.43
	November	25.46	4.20
	December	25.20	4.06
	Average	25.96	4.87

From Table 1 it can be seen that the average insolation in West Meranti Village is 4.87 $kWh/m^2/day$ meaning the amount of solar radiation reaching West Meranti Village is 4.87 $kWh/m^2/day$ or 4,870 $Wh/m^2/day$. The radiation received by our earth is 1,367 W / m^2 but the radiation reaching the surface is only about 1,000 W/m^2 [8]. PSH (Peak Sun Hour) is 4.87 hours.

3.3. Calculation of electrical energy requirements

Table 2. Electricity energy needs in Meranti Barat Village [1].

Electrical equipment	Lamp (House)	Lamp (Church)	Lamp (Poskedes)	Lamp (Posyandu)	Lamp (School)	Lampu (Street)	Etc (House)
Total (Point)	4	3	3	3	6	3	
Power(W)	5	10	5	5	5	5	55
Duration of Use (hour/day)	12 (Time 18-06)	12 (Time 18-06)	12 (Time 18-06)	12 (Time 18-06)	12 (Time 18-06)	12 (Time 18-06)	2 (Time 19-21)
Number of buildings	37	1	1	1	1		37
Energy(Wh)	8880	360	180	180	360	180	4070
TotalEnergy (Wh)				14210			

In Table 2, it found that the electrical energy requirements in this village are 14,210 Wh or 14.21 kWh.

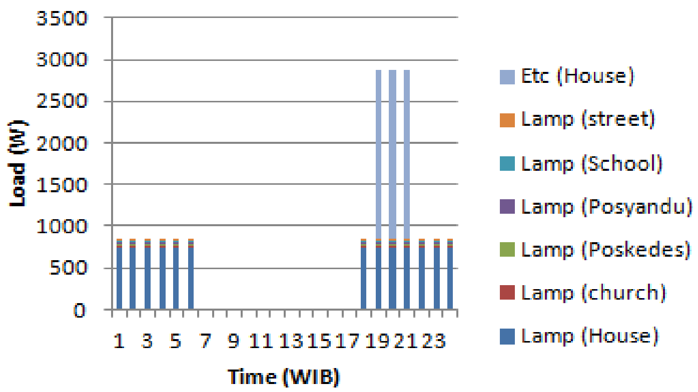

Figure 2. Load power at every hour in Meranti Barat village.

Figure 2 shows peak load occurred at 19.00 WIB - 21.00 WIB at 2880 W. At 18.00 WIB, 22.00 - 06.00 WIB the burden occurred at 845 W.

3.4. Component design in PLTH

3.4.1. Size of batteries. Batteries are a very important role in the PLTH system, especially if electricity is only used at night [9]. The capacity of the battery is designed to be able to supply a load (E) of 14.21 kWh which is used because it must consider the efficiency of inverter, the inverter is not able to convert 100 percent of the energy from the battery to be distributed to the load [6]. The efficiency of the inverter is taken 90%, and the efficiency of the battery is affected by the temperature of the battery [8], taken efficiency from the battery 90 %. In this PLTH using a generator to backup battery charging, the number of days of autonomy (N) is set at 1.5 days. this is made to anticipate if one day there is damage to the generator. DOD (Depth of Discharge) from the battery is taken 75% with DOD 75% so that it can last for 2,000 Cycles. Depth of Discharge is inversely proportional to the lifetime of the battery [10], so the energy that the battery must supply according to equation (1) is 35.08 kWh.

$$E_{batt} = \frac{\mathrm{N} \times \mathrm{E}}{\eta_{\mathrm{inv}} \times \eta_{\mathrm{batt}} \times DOD} \quad (1)$$

Batteries are arranged so that the battery bank voltage ($V_{B\ batt}$) becomes 48 V so that the current flowing is small so as to reduce the diameter of the cable [3]. So the capacity of the planned battery bank according to equation (2) is 730.8 Ah or 731 Ah.

$$\mathrm{C}_{\mathrm{B\ batt}} = \frac{E_{batt}}{V_{B\ batt}} \quad (2)$$

The selected battery capacity (C_{Batt}) is 150 Ah with a voltage (V_{Batt}) of 12 V, according to equation (3) a total of 20 batteries are arranged in 4 series and 5 parallel.

$$N_{battery\ (series)} = \frac{V_{B\ batt}}{V_{Batt}} \quad and \quad N_{battery\ (parallel)} = \frac{C_{B\ batt}}{C_{Batt}} \quad (3)$$

3.4.2. The need for solar modules. The effect of increasing the temperature of the solar module can reduce the output of the module, the temperature coefficient of the module($Coef_T$) is taken at 5%/°C [9]. In Table 1 it is known that in 2019 the maximum temperature is 26.97 °C and ΔT is 1.97 °C, the power loss from the module ($P_{T\ up}$) due to temperature rise according to equation (4) if the P_{MPP} of the module used 200 WP is 1.97 W.

$$P_{T\ up} = Coef_T \times P_{MPP} \times \Delta T \quad (4)$$

The maximum output power of the module in the equation (5) is 198.03 W, from equation **Error! Reference source not found.** T_{CF} is 99%.

$$P_{maks} = P_{MPP} - P_{T\ up} \quad and \quad \mathrm{T_{CF}} = \frac{\mathrm{P_{maks}}}{\mathrm{P_{MPP}}} \quad (5)$$

The solar module used is monocrystalline with efficiency 16%, the solar module is designed to be able to charge battery energy by 35.08 kWh, the efficiency of SCC was taken at 95%. In Table 1 solar irradiation (H) at that location is 4.87 kWh/m^2/days, with that irradiation the area of the solar module needed according to equation **(**6) is 47.84 m^2.

$$\mathrm{A_{PV}} = \frac{\mathrm{E_{batt}}}{\mathrm{H} \times \eta_{\mathrm{PV}} \times \eta_{\mathrm{scc}} \times \mathrm{T_{CF}}} \quad (6)$$

GHI (Global Horizontal Irradiance) is 1,000 W/m^2 [8], so the output of the module if the solar module area is 47.87 m2 according to equation (7) is 7854.4 WP.

$$P_{total} = A_{pv} \times \eta_{pv} \times GHI \quad (7)$$

Using a solar module with P_{MPP} 200 WP then as in equation (8) 39 or 40 solar modules are needed.

$$\text{The number of solar modules} = \frac{P_{total}}{P_{MPP}} \quad (8)$$

Determine the circuit of the solar module by taking into account the input and output of the SCC so that there is no damage to SCC [3], the SCC used specifications are a maximum current output of 120 A and an input voltage of 64 V-116 V, to match the existing SCC capacity, the solar modules are arranged in 2 series and 10 parallel in 2 array, so the total solar modules needed are 40 modules. The solar module that is used is the Gh200M-36 GH solar module with the specifications of V_{mp} 36.6 V and Imp 5.47 A so that according to equation (9) the total V_{mp} of each array is 73.2 V and I_{mp} array is obtained 54.7 A.

$$V_{mp\ array} = V_{mp\ modul} \times N_{series\ modul} \text{ and } I_{mp\ array} = I_{mp\ modul} \times N_{paralell\ modul} \quad (9)$$

In equation (10)**Error! Reference source not found.** the maximum total power of a solar module circuit is 4,004.04 WP.

$$P_{mpp\ array} = V_{mp\ array} \times I_{mp\ array} \quad (10)$$

The solar module is planned as many as 2 array, so the total power of the two array is 8,008.08 WP because PSH is 4.87 Hours so module circuit can produce electrical energy of 8,008.08 WP × 4.87 Hours = 38,999.34 Wh then if the energy needed is 35,060 Wh and the power produced by the solar module circuit is 38,999.34 Wh, the battery will be fully charged one day.

3.4.3. Size of the SCC. In designing SCC, it must be noted that the maximum input voltage and current of the SCC must be higher than the maximum voltage and current of the solar module circuit [3]. Since every change in temperature of the solar module will cause a change in voltage and output current, a safety factor of 1.25 must be given [6], so the required SCC capacity based on equation (11) is 68.37 A because there are 2 series of solar modules then SCC taken 2 units.

$$C_{SCC} = \frac{P_{MP} \times \text{safety Factor}}{v_{mp}} \quad (11)$$

3.4.4. Size of inverter. The maximum load is 2,880 W as shown in Figure 2. The safety factor take 1.25 and required inverter size as in equation (12) is 3,600 W. The selected inverter is a pure sine wave type inverter so that the equipment used can work normally [11]. V input 48 VDC and V output 220 VAC, the capacity of the inverter is adjusted to the capacity of the inverter that is on the market, namely the 4,000 W inverter.

$$P_{inv} = \text{P load maks} \times \text{ safety Factor} \quad (12)$$

3.4.5. Size of generator set. This generator is used only to charge the battery. The battery capacity is 731 Ah and the voltage of the battery is 48 V, if the battery is used with 75% DOD then the remaining capacity in the battery is only 731 Ah -75% × 731 Ah = 182.75 Ah then the generator needs to charge the current to the battery by 731 Ah -182.75 Ah = 548.25 Ah with battery energy that needs to be charged for 542.25 Ah × 48V = 26,316 Wh, then 548.25 Ah the capacity of the battery that needs to be charged by the generator set. if using a C/10 charging rate, the required charging current is 548.25 Ah / 10 hours = 54.825 A. The output power of the required battery charger is 48 V × 1.2 × 54.825 A = 3,157.92 W. Where 1.2 is the ratio of the battery voltage to the voltage of the battery charger, the charging voltage of the battery charger is generally around 120% of the nominal battery voltage [8]. The charger battery used has an efficiency of 90%, then the total input power needed is 3,157.92 W / 0.9 = 3,508.8 W. the selected generator set is 4,500 W.

3.4.6. Size of battery charger. The battery charger required to charge energy into the battery from the generator set based on calculations in section 4.4.5 is 54.825 A with an V input 220 V AC V output 48 V DC. PLTH component installation scheme can be seen in Figure 3.

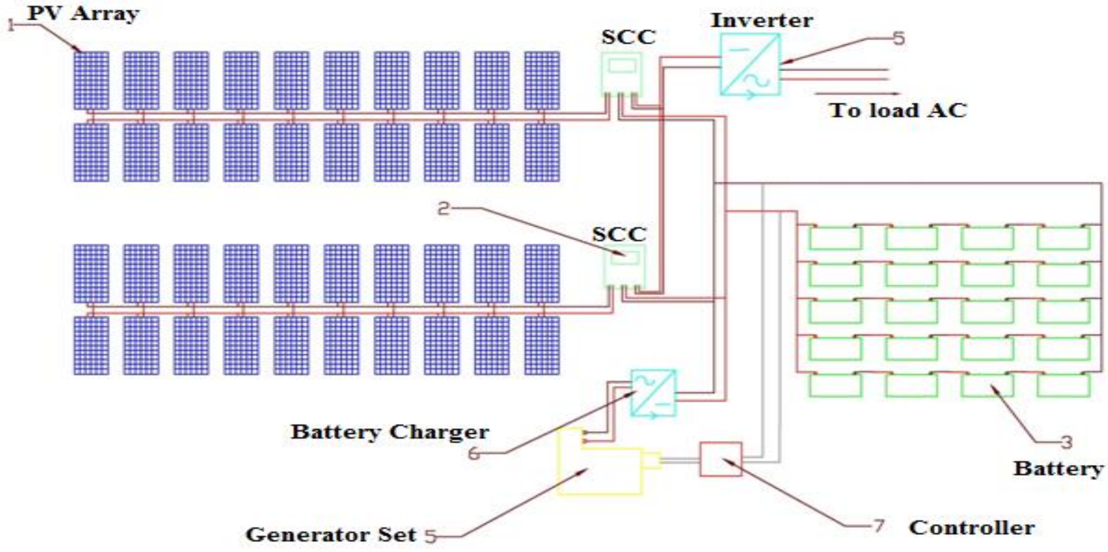

Figure 3. PLTH component installation scheme.

3.5. *Economic analysis*

In the economic analysis of PLTH in used life cycle cost analysis (LCC), the LCC analysis includes the cost of purchasing components (C), installation costs (I_C), operational and maintanance costs ($O\&M_C$), replacement costs (R_C). The cost of purchasing these PLTH components is the purchase of solar modules (PV_C), SCC (SCC_C), inverters (Inv_C), batteries (Bc), generators set (G_C) and battery chargers (BC_C), batteries can last for 5-10 years according to the operation and type of battery used [10]. Because using the estimated future used 2 parameters that affect the value of money from time to time, namely the inflation rate and discount rate [10]. The cost of 40 solar modules is Rp54.000.000,00 for the cost of 20 batteries Rp32.000.000,00, the Inv_C Rp14.300.000,00 and the cost of 2 SCC is Rp10.000.000,00. For Rp10.960.000,00 generator costs and Rp9.960.000,00 battery charger costs, the age of the PLTH is determined to be 20 years (n). Battery replacement every 5 years. for installation costs (I_C) 10% of the cost of components. The generator operates 10 hours per week so that the O & Mc is set for the generator Rp8.092.000,00 / year and the $O\&M_C$ PLTS is Rp2.624.400,00 / year, with an inflation rate in June 2020 (i) 2.19 % and a discount rate (d) 3.5% [12]. then the cost of electrical energy can be estimated. Because the life of the battery is considered to be 5 years, during the lifetime of the PLTH there are 3 times the replacement of the battery. Battery replacement present worth (R_{pw}) Where n is the year of battery replacement is defined based on [8].

$$R_{PW1} = \left(\frac{1+\mathrm{i}}{1+\mathrm{d}}\right)^{5} \times \mathrm{Bc} \;\&\; R_{PW2} = \left(\frac{1+\mathrm{i}}{1+\mathrm{d}}\right)^{10} \times \mathrm{Bc} \;\&\; R_{PW3} = \left(\frac{1+\mathrm{i}}{1+\mathrm{d}}\right)^{15} \times \mathrm{Bc} \quad (13)$$

Current costs of annual O&M from PLTS and Genset are spent over the life of the PLTH 20 years taking into account the inflation rate and discount rate as follows [8].

$$O\&M_{PW} = (O\&M_{\mathrm{PLTS}} + O\&M_{\mathrm{Genset}}) \times \left(\frac{1+\mathrm{i}}{1+\mathrm{d}}\right) \times \left(\frac{1-\left(\frac{1+\mathrm{i}}{1+\mathrm{d}}\right)^{\mathrm{n}}}{1-\left(\frac{1+\mathrm{i}}{1+\mathrm{d}}\right)}\right) \quad (14)$$

Life cycle costs (LCC) can be determined by adding the cost of purchasing solar modules, inverters, batteries, SCC, generators, battery chargers, installation costs, component replacement costs and operating and maintenance costs [8].

$$LCC = PV_c + INV_c + B_c + SCC_c + G_c + BC_c + I_c + R_{PW} + O\&M_{PW} \quad (15)$$

$$ALCC = LCC/(\frac{1-\left(\frac{1+i}{1+d}\right)^n}{1-\left(\frac{1+i}{1+d}\right)}) \quad CoE = \frac{ALCC}{365 \times E_L} \quad (16)$$

After the value of the Annual life cycle costs ALCC has been obtained, it can be determined the cost of the unit of electrical energy produced by PLTH (CoE), namely by dividing the value of the ALCC by the electricity produced by PLTH annually [8]. Table 33 shows the results of economic analysis on the planned PLTH [8].

Table 3. Results of economic analysis on the planned PLTH.

Components	Total Price (Rp)
Solar Module	Rp 54.000.000,00
SCC	Rp 10.000.000,00
Inverter	Rp14.300.000,00
Generator set	Rp 10.960.000,00
Battery Charger	Rp 9.960.000,00
Battery	Rp 32.000.000,00
First battery replacement	Rp30.025.498,00
Second battery replacement	Rp28.172.830,00
Third battery replacement	Rp26.434.477,00
$O\&M_{PW}$	Rp188.002.781,00
Life Cycle Cost	Rp416.977.586,00
Annualized Life Cycle Cost	Rp23.467.423,00
Electrical Cost	Rp4.524,00/kWh

4. Conclusion

Utilization of solar energy as electrical energy for the people of Meranti Barat Village is expected that the community can be more free to do activities at night and the village is bright. Based on the data obtained, irradiation in the West Meranti village averaged 4.87 kWh / m^2 / day and irradiation time 4. 87 hours. With this hybrid system it is expected to serve the energy needs of West Meranti Village of 14.21 kWh/day, the optimal system design is 40 solar modules with 2 series of 2 series and 10 parallel series of modules, 20 batteries per 150 Ah 12 V batteries assembled 4 series and 5 parallel with DC bus voltage of 48 V and 68.37 A SCC of 2 units, 4,000 W inverter with DC input 48 V and DC Output 220 V, Genset 4,500 W and Battery Charger 54.825 A with AC input 220 V and output DC 48 V. after analyzing the cost of PLTH by considering the age of PLTH 20 years with an inflation rate of 2.19% and a discount rate of 3.5%. the life cycle cost of the PLTH is Rp416.977.586,00, the cost of electricity produced is Rp4.524,00 / kWh.

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