Design of Tracker based PV System for Health Care Facilities in Remote Islanded

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Abstract: In this paper, the solar based electrical power system for health care facilities in the Mentawai island has been presented with different tracking mechanisms. First, the health center's electrical system was designed for a photovoltaic (PV) system with fixed installations combined with diesel generators as backup systems. The optimal results with the lowest cost of energy (CoE) values are obtained with the PV/Diesel configuration and storage system in operation. Furthermore, the electrical system was tested using three different PV structure installations - fixed structures, single-axis tracking, and dual-axis tracking mechanisms. Among the three tracking configurations, the two-axis tracking system was found to be the most profitable in terms of PV electricity production 3,931 kWh in a year and had the lowest CoE of 0,307 \$/kWh. The payback period for a flat PV system longer than the two-axis tracker PV system. Apart from the increase in power generation, PV systems with two-axis solar tracking will need fewer PV modules to supply the same load, hence requiring less space.

1 INTRODUCTION

Community health centers for remote areas in the Indonesian archipelago need to be considered during the current Covid-19 pandemic. Lack of facilities and electricity resources is an important issue that needs attention. Based on the the Indonesian state-owned power utility firm, PT PLN (Persero) planning document in Electricity Supply Business Plan 2018-2027, there are still some areas in Indonesia that have an electrification ratio below 80%, mainly in the islands area. The availability of electricity resources for the region is a priority, but the quality is less noticeable.

Generally, the supply of electricity in the islands relies on diesel generators. Diesel generators are known consume expensive fuels and are not very environmentally friendly. Therefore, the presence of the assembler from an easily installed and environmentally friendly solar energy source becomes the right choice as an electric power source in rural health clinics for the islands. This is also in line with the Nawacita vision as part of the Indonesia government's policies, which is intended to build a political, economic, and Indonesia cultural sovereign. This policy has nine work programs, one of which is to develop Indonesia from the periphery by strengthening regions and villages.

Several previous studies have been carried out by utilizing solar energy with low operational costs and environmentally friendly. The 6,709 kWh energy per day during clear sky can be produced by using 5@250 Wp PV panel in West Sumatera. In the literature, a study on the design of hybrid PV power plants with battery storage has been carried out for health care clinics in remote areas in the Gema sub-district of Kampar Regency. Several studies on the optimization and feasibility of PV have also been carried out for rural villages in Nigeria , Masirah Island, and rural desert areas in Oman. The optimal design and feasibility analysis carried out using Homer software. The result obtained revealed a hybrid PV/wind/diesel/battery system as the most cost-effective. However, the load of health care center studied used general health clinic facilities and not support Covid-19 patients and used flat solar panel installation.

The feasibility study of the PV system in a public health center in the midst of the covid-19 pandemic must pay attention to some Covid service equipment. The lack of weather data will affect the calculation of economic viability, especially on PV

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systems installed in the tropical area. Economic feasibility studies have also been carried out in previous studies taking into account the cycling cost of each component. The economic feasibility study also functions to determine the optimal NPC (Net Present Cost) of all the system options designed. Details of the PV system design for the Community Health Center (Puskesmas) in the Siberut Island, one of the islands in the Mentawai Islands as a case study will be explained in the following section.

2 DESIGN OF PV POWERED HEALTH CARE FACILITIES

2.1 Health Care Clinic Facilities

In rural communities, the health care facilities are not in a well-developed state. In some cases, rural individuals do not have access to these facilities and are required to travel to distant places or urban areas. Considering the current pandemic condition, health facilities in remote island health centers need to be equipped with Covid patient handling equipment and sufficient availability of electrical energy. The Covid-19 patient handling equipment at least as default data given by Hybrid Optimization of Multiple Energy Resources (HOMER) Powering Health Tool (NREL, 2020):

Covid Isolation Ward
    Exhaust fan (per Covid isolation cubicle)
    Exhaust fan (staff change area)
Basic Care Ward
    Exhaust fan (per Covid isolation cubicle)
    Oxygen Concentrator (50% of beds)
    BiPAP respirator (50% of beds)
    CPAP respirator (50% of beds)
    Infusion pump
    Exhaust fan (staff change area)

The daily electrical demand of health care facilities is as shown in Figure 1. The average power of health care facilities load is 0,24 kW with peak load is 1,49kW. The energy average of 5,68 kWh/day with load factor is 16.

The monthly average load profile with a peak demand in April and November in November is illustrated in Figure 2.

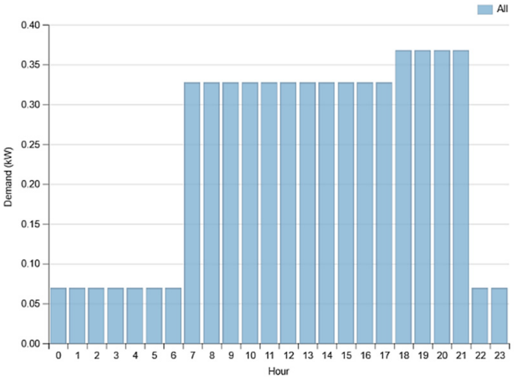

Figure 1: Daily electrical demand of health care Facilities.

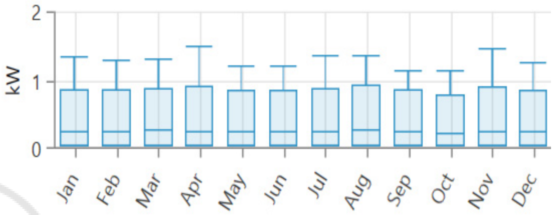

Figure 2: Annual electrical demand of health care Facilities.

2.2 Homer based PV System Design

The HOMER Powering Health Tool uses the proprietary optimization algorithm of the HOMER (Hybrid Optimization Model for Multiple Energy Resources). The tool can be used through link: https://poweringhealth.homerenergy.com/ developed by the National Renewable Energy Laboratory (NREL) (NREL, 2020). The economic feasibility study of the generation installation commonly uses general business feasibility study criteria such as CoE and net present cost (NPC) (Haghighat et al., 2016). These criteria can be used to determine the profitability of a project as an initial consideration PV system installation.

The cost of energy can be calculated by using the following equation (2):

$$CoE = \frac{Invest \times T_{OutF}}{kWh_{Total}} \qquad (1)$$

where:

Invest = initial investment cost ($)
TOutF = Total Out Flow ($)
kWhTotal = Total PV energy generated (kWh)

The net present cost or life-cycle cost of a component to be evaluated is the present value of all the costs of installing and operating the component during the life of the project, minus the present value of all revenue generated during the life of the project. Homer calculates the net present cost of each component in the system and the overall system. The formula for determining NPV is as follows (O. dan C. H. Thum, 2013).

$$NPV = \sum_{t=0}^{m} \frac{CIF_t}{(1+k)^t} - Invest \qquad (2)$$

where:

m = lifespan of the PV system in year
CIF = cash in flow ($)
k = Discount rate

The payback period can be calculated by using the following equation (3):

$$PP = y_i \ (year) + \left(\frac{F_{i-1}}{F_D} \right) * 12 \ (month) \qquad (3)$$

where:

PP = payback period
yi = year at full recovery or net cash flow equal to zero
Fi-1 = unrecovered cost at the beginning of last year
FD = cash flow during the year

The annual maintenance and operational costs for the PV system generally accounted as 1 - 2% of the total initial investment cost (R. G. J.Lee, B. Chang, 2016). The large percentage of annual maintenance and operational expenses in the PV power plant covering costs for solar panel cleaning work, maintenance and inspection costs of equipment and installations will be set at 1% of the initial total investment because Indonesia only has two seasons, i.e., the rainy season and the dry season so that the cost of cleaning and maintaining the solar panel is not as high as the country that has four seasons in one year. Besides, the determination of this percentage is also based on the level of wage labor in Indonesia, which is cheaper than the wage rate of labor in other countries.

3 DESCRIPTION OF TEST SYSTEM STUDY

The feasibility study carries out for health care facilities in Simatalu, West Siberut, Kepulauan Mentawai, West Sumatra, Indonesia. The location coordinate is 1 degree 25.56 minutes South for latitude and 98 degrees 55.47 minutes East for longitude.

The average solar radiation in kWh/m^2/day is as Figure 4 with the highest radiation in February.

The optimum design of a hybrid power system for a small health clinic in Mentawai Island was carried out using a free online Homer Powering Health Tool and detailed analysis with different tracking mechanisms using Homer Pro 3.13.

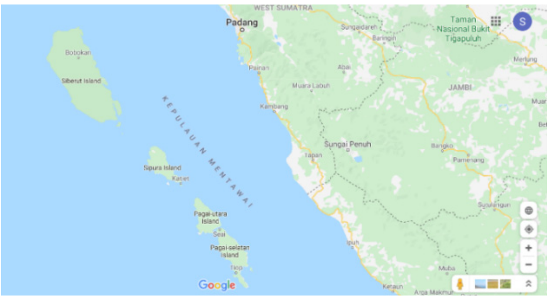

Figure 3: Mentawai Island, West Sumatra, Indonesia.

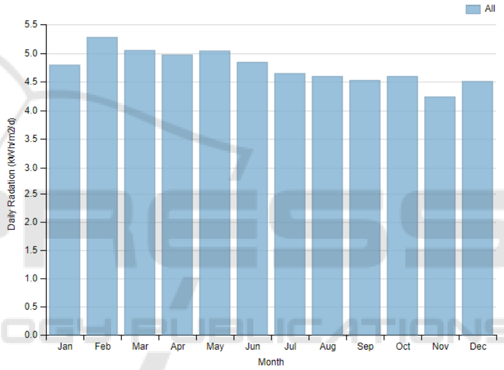

Figure 4: The average solar radiation of Mentawai Island.

4 RESULT AND DISCUSSION

The simulation results containing all of the system configurations that meet the electrical needs of the simulated health clinic are shown in Table 1. Where D stands for Diesel, PV stand for photovoltaic and S stands for Storage system. They are ranked in ascending order with the lowest life-cycle cost at the top.

Table 1: The capacity estimate of hybrid system installation.

Config	PV	Diesel (D)	Storage (S)	Converter
	(kW)	(kW)	(kW·h)	(kW)
1. D/ PV /S	2	2	14	1
2. PV /S	7	—	11	2
3. D / S	—	2	4	0
4. D	—	2	—	—

The simulation results for economic feasibility are shown in Table 2.

Table 2: Economic feasibility result.

Configuration	Initial Capital	TNPC	Operating Cost	COE
	($)	($)	($/yr)	($/kWh)
1. D / PV / S	8,073	11,415	191	0.314
2. PV / S	11,201	13,504	131	0.372
3. D / S	3,449	21,207	1,013	0.583
4. D	2,216	35,236	1,884	0.969

The optimum system design configuration with minimum cost results, i.e., 0.314 $/kWh, can be extracted from the first row of tables. Solar panels require very little maintenance since there are no moving parts and generally self cleaning, but in mainly dry areas or where panel tilt is minimal, dust and other substances such as bird droppings can build up over time and impact on the amount electricity generated by a module. Therefore, in this study, the fixed cost for operation and maintenance are chosen 1 % of the initial investment. The degradation of the solar panel is also considered in this study, and the PV system energy generated decreases every year.

The schematic of the PV-Diesel and storage system for further detail analysis is, as shown in Figure 5.

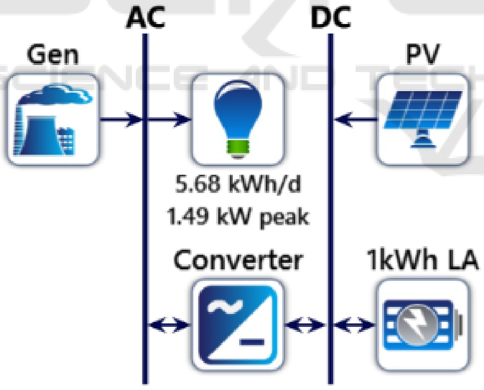

Figure 5: Schematic of the PV-Diesel and storage system.

The 643 solutions were simulated with 473 were feasible, and 170 were infeasible due to the capacity storage constraint. 118 were omitted due to 33 for lacking converter, 15 for having an unnecessary converter, and 64 no source of power generation. The detailed simulation result obtained, as shown in Figure 6 for NPC result per component and the categories optimization result shows in Table III.

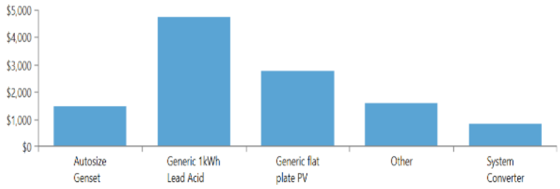

Figure 6: Net present cost per components.

From Table 3, it is found that the optimal size of the PV system is 2.41 kW, diesel generator 1.7 kW, and 14 units of lead-acid battery and a 1.43 kW power converter. The payback period of PV installation for household tariffs can also be calculated using equation (3) based on Table III data. The payback period from Homer Pro simulation is obtained three years and four months.

Table 3: Categorized Optimization Result.

Architecture									Cost			
				PV (kW)	Gen (kW)	1kWh LA	Converter (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)
●	●	●	●	2.41	1.70	14	1.43	CC	$11,415	$0.314	$190.65	$8,073
●		●	●	5.81		13	1.56	CC	$13,504	$0.372	$131.39	$11,201
	●	●	●		1.70	6	0.383	CC	$21,207	$0.583	$1,013	$3,449
●	●		●	3.37	1.70		0.531	CC	$34,599	$0.952	$1,615	$6,300
	●				1.70			CC	$35,236	$0.969	$1,884	$2,216

After the optimal configuration value is obtained, then testing is done using a solar panel with a tracker system. The three different PV structure installations are fixed structures, single-axis tracking, and dual-axis tracking mechanisms. The initial investment cost for a single axis solar track is 10% -15% more, and for a two-axis solar track is 25% more than a fixed installation structure. Tracking settings require periodic maintenance of rotating parts, and moving parts may need to be changed from time to time. Repairs and replacements can occur in the long run with tracker settings. The optimum sizing and its technical and economic parameter results are shown in Table IV.

Table 4: The optimum sizing and its technical and economic parameter results.

Parameter	**without Tracker**	**Tracker (Single Axis)**	**Tracker (Dual Axis)**
PV (kW)	2.41	2.43	2.25
Diesel (kW)	1.7	1.7	1.7
Battery	14	14	13
Converter	1.43	1.47	1.48
PV Production (kWh/yr)	3341	3519	3931
Renewable Fraction	90.9	91.0	89.8
Fuel	56.8	55.7	63
COE ($/kWh)	0.314	0.313	0.307
NPC($)	11415	11363	11148
PV Capital Cost ($)	2767	2784	2579
Initial Capital	8073	8107	7728
Simple payback (yr)	3.4	3.4	3.2

From the simulation results of Table 4, it is obtained that the smallest PV capacity and the number of batteries occurs in cases where a two-axis tracker system is used. The two-axis tracker system has good implications for the investment cost of PV systems to be 2,579 $. The use of a two-axis tracker system has increased electricity production from solar energy sources from 3,341 to 3,931 kWh/yr. Apart from the increase in energy production 0f, PV systems with two-axis solar tracking will need fewer PV modules and batteries to supply the same load, hence requiring less space.

From the economic point of view, a PV system with a two-axis Tracker is more economical because it produces the lowest COE of 0.307 $/kWh as well as the payback period of this system is faster around 0.2 years. The payback period for the flat and single-axis tracker PV system is 3.4 years; however, by using the two-axis tracker PV system to be 3.2 years.

The analysis of environmental influence needs to be considered and needs to be taken into account by knowing the amount of energy that can be generated from the installation of the PV system. The factor of greenhouse gasses (GHG), as mention in Ref, can be known large emissions that can be reduced if using photovoltaic as a source of electrical energy.

5 CONCLUSION

The technical and economic analysis of tracker based solar power system for remoted islanded has been presented. The potential of the energy of the PV system can be generated 3,341 kWh/year. The test result using three different PV structure installations - fixed structures, single-axis tracking, and dual-axis tracking mechanisms, shows that the two-axis tracking system has more profitable in terms of PV electricity production 3,931 kWh in a year and had the lowest COE of 0,307 $/kWh. This system requires less PV module and battery storage, as well as lowest PV system, cost 2,579 $, and less space needed for system installation. The analysis of environmental influence needs to be considered for future research in order to reduce CO_2 emission.

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