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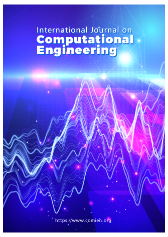

Feasibility Study of Grid Connected Solar PV Design with Battery at Sandai 150/20 kV Substation as a Tayap 4 Feeder Backup When System Blackout Occurs

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***Abstract*— Distribution system of Sandai 150/20 kV substation at Ketapang System located in West Kalimantan, Indonesia still has the potential for blackout due to low of backup energy supply. This research aims to make an analysis of the design of grid connected Solar PV with battery used as a backup for Tayap 4 feeder at Sandai Substation when the system experiences a disturbance and operated as island. The selection of solar PV is needed as an effort to optimize renewable energy in the West Kalimantan region. The research method is by conducting simulations on PVsyst software to understand the energy supplied into the load. Solar PV capacity size, battery size, and battery operation scheme become variable used in this research. Furthermore, in order for the PV plant to serve the Tayap 4 load when there is a grid outage, the minimum PV capacity is 5.5 MWp with a battery of 18,739 kWh at 80% DOD. The results of the financial analysis of the feasibility of the investment meet the investment feasibility criteria with the selling assumption using the upper limit of the local COE of IDR 3,684.**

Keywords— Blackout; photovoltaic; PVsyst software; Sandai.

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I. INTRODUCTION

Reliable electrical energy is one of the basic needs of society as a driver of investment, education and economic development. Power plants are generally built near the energy source, then distributed through the transmission line until it reaches the substation. However, the conservation of electrical energy in large plants is currently fossil fuels resulting in a negative impact on the environment [1]. In addition, the long transmission network also has the potential for interference and can cause blackouts in the transmission system even to the Power Plant. Blackouts will cause the cessation of the supply of electrical energy to remote communities, especially those who are customers in the distribution system[2]

The distribution system in the Sandai sub-district of Ketapang Regency is currently supplied from the Aur Kuning PLTD and Tajuk Kayong PLTD, planned by PT PLN (Persero) to be supplied by the Ketapang PLTU through the Sandai 150/20 kV Substation with 1 (one) Power Transformer with a capacity of 30 MVA. After the operation of GI Sandai then the existing PLTD will be deactivated, so that the Sandai system will only get a single supply from GI Sandai and has no backup. Backup supply of electrical energy in the distribution system is needed especially if there is a blackout condition in the transmission system which causes the power plant to also blackout. When a blackout condition like this occurs, it will take a long time to recover[3]. If the distribution system does not have a backup supply, then in the event of a blackout condition on the transmission system, the reliability of the distribution system will be disrupted and failure to meet the needs of electrical energy 24 hours a day to the community[4].

Government regulations in various countries regarding PV as one of the plants with renewable energy sources that are environmentally friendly encourage the development and research of off-grid solar power plants[5][6]. even to the research of high-level grid-tied PV systems are starting to be developed[7]. The risk of grid instability and vulnerability makes it safer for researchers to use on-grid PV in isolated system conditions, but weak in terms of reliability. The intermittent nature of PLTS also makes the development of

PLTS in the Kalimantan area tend to be in isolated conditions, while there is potential for interconnection of substations that can be utilized for interconnection [8] succeeded in obtaining the results of analysis, design, and experimentation of photovoltaic energy management systems with battery backup the proposed system works correctly, without dangerous transients for inverters or loads and demonstrates the feasibility of PV power management system control strategies with battery backup capable of operating in island systems and grid-connected systems. Analysis of PLTS on Grid as one of the potential energy reserve supplies around the Substation needs to be done because Sandai Sub-district is located in the tropics which has a renewable energy source, namely solar power, which is available throughout the year.

The main reasons for using solar PV technology are as follows: (1) the energy source is abundant and free; (2) the energy source is available anywhere; (3) the operating and maintenance costs of the solar PV system are relatively small; (4) it does not require frequent maintenance and can be done by trained local operators; and (5) it is environmentally friendly, as there are no gas emissions and hazardous waste[9]. This research is the opposite of the general condition, namely PLTS on the grid only as an intermittent generator and when the system experiences a disruption / blackout, the PLTS is conditioned to be separated from the system and does not supply the load (anti-island). This research will be carried out by collecting data on transmission system conditions, distribution system loads that will be supplied by the Sandai Substation and then will be continued with the design of a substation equipped with PLTS. The design will be simulated using PVsyst software to find out how much PLTS design capacity to be able to serve Tayap 4 loads when there is a grid outage and financial analysis of PLTS investment feasibility.

II. MATERIAL AND METHOD

Field research activities is carried out at the Sandai GI construction site plan in Sandai District, Ketapang Regency. Meanwhile, data research activities will be carried out at the PLN office. The geographical location in the Ketapang area with coordinates at -1.1464o S, and 110.6131o E

The research procedure is depicted in the form of the following fishbone diagram:

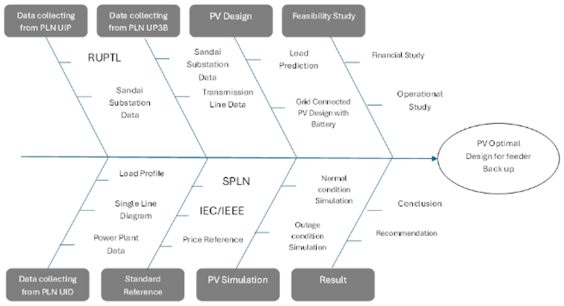


Fig. 1 Research flow with fishbone diagram

The stages and parameters in designing this PLTS can be seen in the flowchart figure as follows:

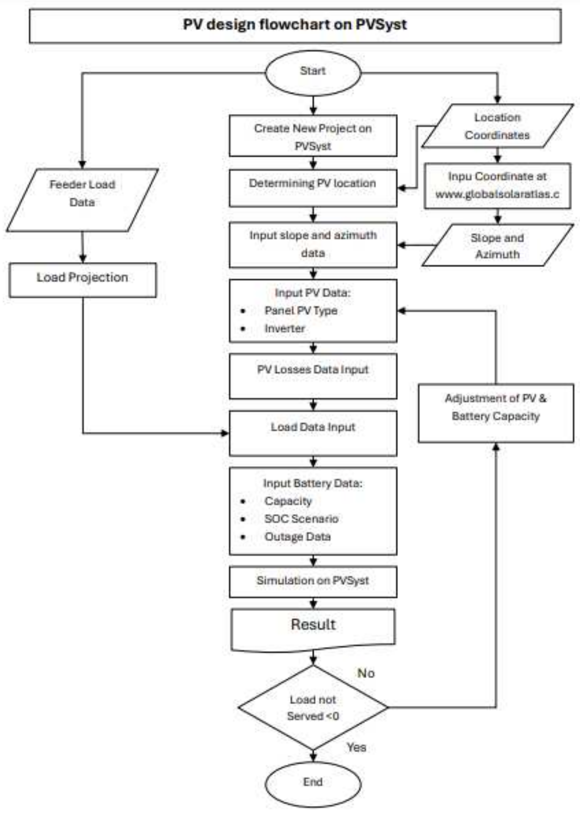


Fig. 2 Flowchart of solar power plant design

A. Location Point Determination

The determination of the location point is closely related to the solar potential that will be generated. The location where the solar power plant will be built is in Sandai with coordinates -1.1464o S, and 110.6131o E. These coordinates are entered into the site parameters in PVsyst.

In PVsyst software there are several sources of meteorological data that can be used. At the Sandai location, a comparison was made with 3 (three) data sources, Meteonorm, NASA and PVGIS. Data from PVGIS shows an annual GHI of 1,827 kWh/year while NASA data is 1,831 kWh/year and meteonorm data is 1,674 kWh/year. This study uses data from PVGIS with consideration, according to the information in the help file in the PVsyst application, PVGIS data is generated from satellite interpolation results from 2005 to 2016 which is the latest data, while NASA data uses interpolated data from 1989 to 2005 and meteonorm interpolated data from 1991 to 2009.

B. Determination of Solar Power Plant Orientation

The orientation direction of the solar power plant is very important so that the energy producedcan be optimized. Determination of the optimal tilt angle uses references from the website https://globalsolaratlas.info by entering the location of Sandai.

The optimum tilt angle obtained from the Global Solar Atlas website is 6^{o} with Azimuth 0^{o} due to its proximity to the Equator. The tilt data was tested on the PVsyst application and it is proven that the angle and azimuth are the best with a GHI value that will be received by the solar power plant of 1,684 kWh/m2 /year. This value is the highest value obtained in the PVsyst application, so it can be concluded that the expected tilt angle and azimuth are the same between global solar atlas data and PVSyst.

C. Data Entry of Solar PV System

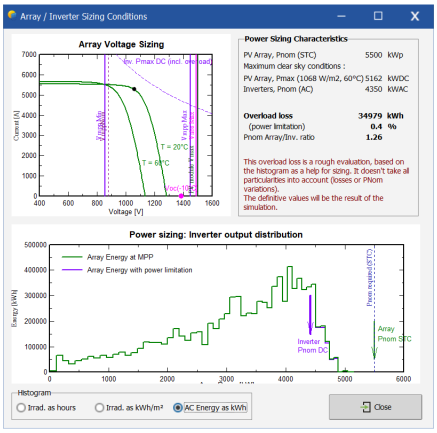
In this menu, there are several things that must be entered as parameters.

1) PV capacity to be installed: Simulations were conducted by trying several variations of installed PV capacity 4 MWp; 5 MWp; 5.5 MWp; 6 MWp; 7 MWp and 8 MWp. The software will automatically estimate the land requirement for PV based on the dimensions and number of modules to be installed.

2) PV module type: This simulation uses mono-crystalline modules with a capacity of 550 Wp. PVsyst software has a fairly complete database of PV types sourced from manufacturers' datasheets in the world. The selection of monocrystalline type in this study considers the advantages possessed when compared to poly-crystalline type.

3) Inverter type: The type of inverter used is the SMA model with a capacity of 150 kW. The inverter database in the software is also quite complete.

The arrangement of modules and the number of inverters that will be needed will be calculated automatically by the software by considering the overload loss limit where the value does not exceed 3%. Or by considering the Pnom Ratio which is the ratio between Pnom (Array) and Pnom (Inverter) commonly known as the DC/AC ratio. An acceptable Pnom ratio has a value of 1.25 to 1.3. Display of the determination of Inverter size criteria in PVSyst software as in Figure 3.



Power Sizing Characteristics

PV Array, Pnom (STC)	5500	kWp
Maximum clear sky conditions :		
PV Array, Pmax (1068 W/m2, 60°C)	5162	kWDC
Inverters, Pnom (AC)	4350	kWAC
Overload loss	**34979**	**kWh**
(power limitation)	**0.4**	**%**
Pnom Array/Inv. ratio	**1.26**	

This overload loss is a rough evaluation, based on the histogram as a help for sizing. It doesn't take all particularities into account (losses or PNom variations).
The definitive values will be the result of the simulation.

Histogram: ○ Irrad. as hours ○ Irrad. as kWh/m² ● AC Energy as kWh

Fig. 3 Inverter Sizing Conditions

4) Solar PV losses: Overall, an overview of losses for a solar power plant with a capacity of 5.5 MWp can be seen in Figure 4.

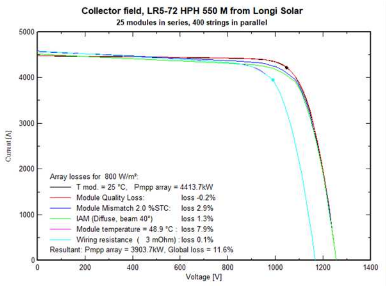
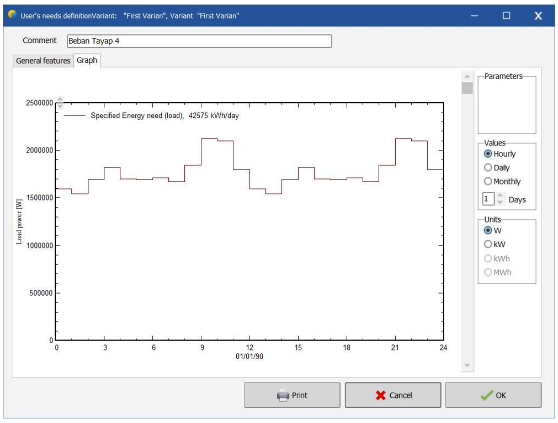


Fig. 4 Losses data of solar power plant

5) Self-Consumption Data: Self-consumption is the load that will be supplied by the Solar PV System. In this study using the load data of the Tayap 4 feeder as in Figure 5. It can be seen that the peak load occurs during the day and at night. Load data for 1 year is entered into the template file available in the PVsyst software.

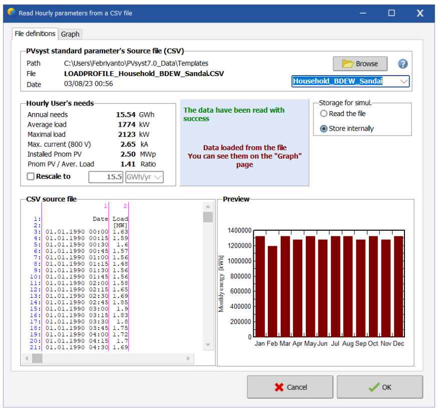


Comment: Beban Tayap 4

Values: ● Hourly ○ Daily ○ Monthly, 1 Days

Units: ● W ○ kW ○ kWh ○ MWh

Fig. 5 Daily Profile of Repeater Load



PVsyst standard parameter's Source file (CSV)

Path: C:\Users\Febriyanto\PVsyst7.0_Data\Templates
File: **LOADPROFILE_Household_BDEW_Sandai.CSV**
Date: 03/08/23 00:56
Household_BDEW_Sandai

Hourly User's needs

Annual needs	**15.54**	GWh
Average load	**1774**	kW
Maximal load	**2123**	kW
Max. current (800 V)	**2.65**	kA
Installed Pnom PV	**2.50**	MWp
Pnom PV / Aver. Load	**1.41**	Ratio

☐ **Rescale to** 15.5 GWh/yr

The data have been read with success

Data loaded from the file
You can see them on the "Graph" page

Storage for simul.: ○ Read the file ● Store internally

CSV source file

```
                   1     2
              Date  Load
                    [MW]
01.01.1990 00:00 1.63
01.01.1990 00:15 1.59
01.01.1990 00:30  1.6
01.01.1990 00:45 1.57
01.01.1990 01:00 1.56
01.01.1990 01:15 1.48
01.01.1990 01:30 1.56
01.01.1990 01:45 1.56
01.01.1990 02:00 1.58
01.01.1990 02:15 1.65
01.01.1990 02:30 1.69
01.01.1990 02:45 1.85
01.01.1990 03:00  1.9
01.01.1990 03:15 1.83
01.01.1990 03:30  1.8
01.01.1990 03:45 1.75
01.01.1990 04:00 1.72
01.01.1990 04:15  1.7
01.01.1990 04:30 1.69
```

Fig. 6 Parameters from CSV File throughout the year

It can be seen that the annual energy demand in Tayap 4 is 15.54 GWh with a peak load of 2.1 MW and an average load of 1.7 MW.

1) Storage/Battery: The Solar PV system that will be used in this simulation is connected to Weak Grid Islanding, where the Solar PV will be a backup supplying Tayap 4 if there is an outage and the substation cannot supply the load. The power flow control performed by PVsyst software is as follows:

a. When the solar energy is sufficient to supply the load, the rest will be used for battery charging, and if there is any excess energy left, it will be sent to the grid.
b. When solar energy is insufficient to supply the load or for example at night, the load can be supplied from the grid and battery, but still maintain backup power if at any time there is a grid disturbance/outage. Restrictions are made by setting a battery DOD limit for load supply of 60% and a minimum DOD limit of 20% to maintain the condition of the battery, so that there is still 40% reserve when the Solar PV operates Island/there is a grid outage.
c. When there is a grid fault/outage (Figure 7), the switch immediately operates (open) and Tayap 4 will be supplied from solar energy and batteries.

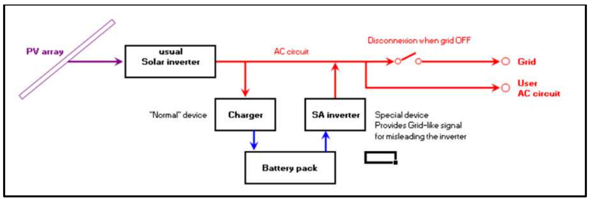


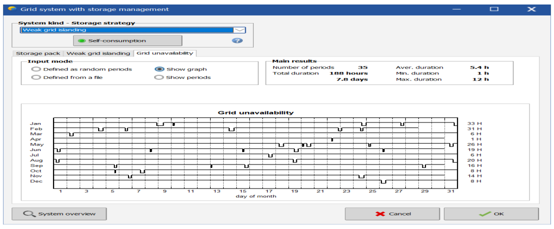
Fig. 7 Backup scheme during interruption with battery from Solar PV

The data that needs to be inputted on this menu are:

a. System type/storage strategy with Weak Grid Islanding option
b. The type of battery used in this simulation is the Lead Acid type with a voltage of 2 V and a capacity of 915 Ah. The number of batteries needed in this study is 12,800 pieces with the configuration as in Figure 8. Figure 8. The battery capacity is 29,280 Ah with a utilizable stored energy of 18,739 kWh at 80% DOD.

The energy is capable of supplying the load for 7.5 hours at peak load.

a. Weak Grid Islanding data is data on battery operation scenarios to supply loads when the system experiences a total blackout. The maximum charging limit is limited to 95%, the minimum battery DOD limit is 60% for daily load supply and the minimum DOD limit is 20% to maintain battery quality. When the battery SOC is 95%-60% and the solar source is no longer available, the first priority to supply the load is from the battery discharge until it reaches the 60% DOD limit. When the battery SOC is 60% the first priority for supply is from the grid, but if there is a grid outage then the supply will use energy from the battery until it reaches the 20% SOC limit.
b. Grid unavailability data or outage scenarios for 1 year, can be seen in the following display Figure 8.


Grid system with storage management

System kind - Storage strategy: Weak grid islanding

Input mode
○ Defined as random periods
○ Defined from a file
● Show graph
○ Show periods

Main results
Number of periods 35
Total duration 188 hours
7.8 days
Aver. duration 5.4 h
Min. duration 1 h
Max. duration 12 h

Fig. 8 Simulation of Disturbance Graph for 1 year

It is assumed that there are 35 interruptions in 1 year with the longest duration of 12 hours and the shortest duration of 1 hour. The total outage duration is 188 hours for 1 year. Through this data, we will see the performance of the Solar PV system and see the potential unavailability of power for the loads supplied, especially the Tayap 4 feeder.

III. RESULT AND DISCUSSION

B. *Sandai Electricity Development Plan*

Based on the results of interviews and data collection, it is known that the 2021-2030 RUPTL is depicted in the electricity development map in Figure 9. The Sandai area will be built a substation with a capacity of 1x30 MW and a transmission network that will be connected to the Equatorial System through a 150 kV transmission to Tayan substation and also connected to the Ketapang system through a 150 kV transmission to Sukadana substation. The first stage of transmission line construction is for the Sukadana-Sandai section and then the Sandai-Tayan section. In the first phase of development, the Sandai substation will be supplied from existing power plants in the Ketapang system, namely the 2x10 MW Ketapang coal power plant and 2x6 MW Ketapang IPP coal power plant and several diesel power plantss. Seeing these conditions, the electricity system in Sandai can still be said to be less powerful. Through this research, it will be analyzed if the Sandai substation is built on-grid Solar PV with batteries as energy backup storage.

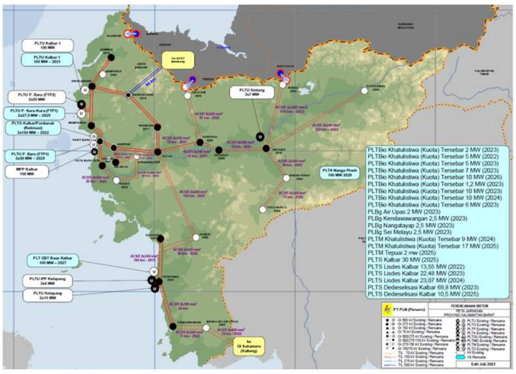


Fig. 9 West Kalimantan electricity development map

C. *Load Projection*

The first step in designing a solar power plant is to calculate the power requirements that will be supplied. The single line diagram of the Solar PV development plan in Sandai.

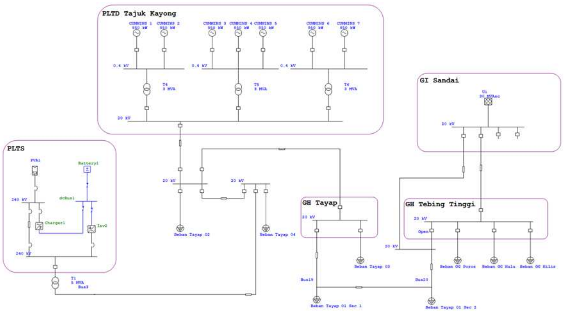


Fig. 10 Single line diagram of Sandai solar power plant construction plan

When Sandai Substation is operated, diesel power plants Tajuk Kayong, which is a rental diesel power plants, will be deactivated. From the diagram, the Solar PV is planned to be connected to the System through a voltage of 20 kV. The Solar PV will operate island when there is an outage at the substation. The load that will be supplied by the Solar PV is only on the Tayap 4 feeder, the following is the load profile of the Tayap 4 feeder.

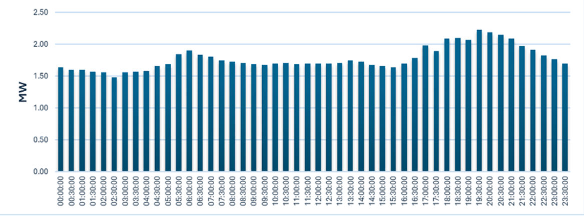


Fig. 11 Daily Load Profile of Tayap 4 Feeder

TABLE I

COMPARISON OF PVSYST SIMULATION RESULT OUTPUT

No	PV Capacity MWp	GlobHor kWh/m^2	DiffHor kWh/m^2	T_Amb °C	GlobInc kWh/m^2	GlocEff kWh/m^2	EArray MWh	E_User MWh	E_Grid MWh	EFrGrid MWh	E_Miss MWh
1.	4	1,827.0	877.5	25.8	1,832.7	1,749.4	5,762.0	15,540.0	2.0	10,054.9	31.6
2.	5	1,827.0	877.5	25.8	1,832.7	1,749.4	7.224.1	15,540.0	4.1	8,766.9	24.8
3.	5.5	1,827.0	877.5	25.8	1,832.7	1,749.4	7,956.6	15,540.0	20.4	8,140.9	23.6
4.	6	1,827.0	877.5	25.8	1,832.7	1,749.4	8,673.4	15,540.0	139.3	7,638.6	22.6
5.	7	1,827.0	877.5	25.8	1,832.7	1,749.4	10,144.9	15,540.0	847.4	7,010.0	22.1
6.	8	1,827.0	877.5	25.8	1,832.7	1,749.4	11,545.0	15,540.0	1,808.3	6,678.7	21.7

Description:

GlobHor	: Global Horizontal Irradiation
DiffHor	: Diffuse Horizontal Irradiation
GlobInc	: Incident global irradiation
GlobEff	: Global "effective", net of optical losses (shadings, IAM, soiling).
EArray	: Effective energy at the array output
E_User	: Energy required by the load
E_Grid	: PV energy delivered to the grid
EFrGrid	: Energy supplied to the load from the grid
E_Miss	: Energy demand of loads that are not served due to grid outages and or battery limitations.

TABLE II

UNSERVED LOAD DATA AND BATTERY SOC AT THE BEGINNING OF THE DISTURBANCE

No	PV Capacity (MWp)	Load not Served Tgl 7-9 Jan	SOC at Outage start time (%)
1	4	8,562.3	42.5
2	5	7,725.4	53.3
3	5.5	7,236.1	57.6
4	6	7,783.8	54.4
5	7	7,222.3	55.7
6	8	7,135.4	56.9

The load profile will be used to simulate in PVsyst when there is a substation outage, so that the Solar PV and battery systems will supply the load.

D. *Simulation with PV capacity variations*

Simulations were conducted for several types of solar power plant capacity while maintaining the battery capacity and DOD scheme. The following table is the energy comparison between each capacity variation.

From Table 1 Comparison of PVsyst simulation result outputIt can be concluded that the capacity capable of maintaining supply to the load if the grid is disrupted starts from a capacity of 4 MWp with an E_miss value of 31.6 MWh. However, the ability to supply to the grid is quite small at only 2 MWh per year. Solar power plants with a capacity above 6 MWp can send energy to the grid in a large enough capacity, but E_miss is still found. This is due to the limited capacity of the installed battery. Table 2 illustrates the conditions on January 7 to 9, where it is assumed that there was a grid outage on January 8 for 12 hours starting at 10:00 pm until 10:00 am the next day. Outages during this time are rare, but this study aims to test how the system will work if the outage occurs. It can be seen that when a disturbance occurs at 10:00, the battery will send energy to the load up to the 20% DOD limit, but because the grid disturbance has not been resolved, there is missing energy or the load is not served until the grid is back on. In Solar PV with a capacity of 5 MWp, the value of unserved load of 7216.82 kWh is smaller when compared to other capacities. This is because at the beginning of the grid outage, the battery SOC condition at a capacity of 5 MWp is higher than the others. SOC conditions are influenced by operating patterns as shown in the graph Figure 12 but in total one year E_miss of 5.5 MWp capacity is still higher than the larger capacity.

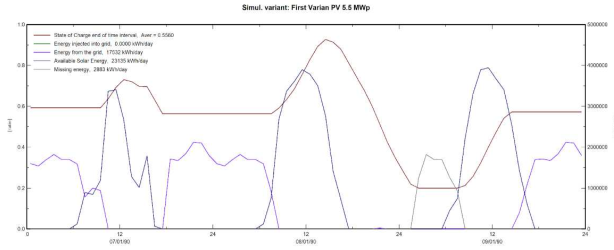


Fig. 12 Instantaneous Energy Profile Graph during substation Outage with 5.5 MWp Solar PV

E. *Simulation with battery capacity variation*

This simulation will compare if the battery capacity is increased by 12% from 18,739 kWh to 21,082 kWh with 80% DOD. From Table 5 It can be seen that there is a decrease in unserved load (E_miss) and also the PV energy sent to the Grid (E_Grid). The energy generated from PV is mostly used for battery charging. Examples of graphs for 5.5 MWp PV capacities can be seen in Figure 13.

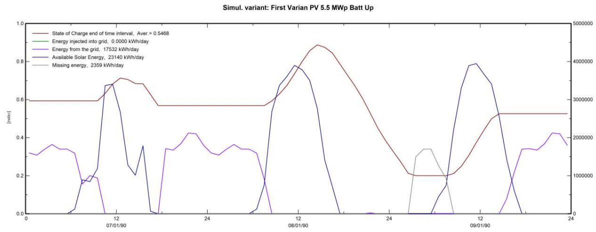


Fig. 13 Simulation graph with 5.5 MWp PV variation

F. *Simulation with various battery DOD schemes*

In the picture , it can be seen that when a blackout occurs from 10.00 pm to 10.00 pm, the battery starts to supply the load of Stage 4 until the battery SOC condition is at 20%. Insufficient battery capacity resulted in unserved loads totaling 7,725 kWh. Whereas in the 5.5 MWp Solar PV design as shown in Figure 14 then the unserved load becomes smaller at 7,236.1 kWh.

TABLE III

PVSYST SIMULATION RESULTS WITH BATTERY CAPACITY VARIATION

No	PV Capacity MWp	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlocEff kWh/m²	EArray MWh	E_User MWh	E_Grid MWh	EFrGrid MWh	E_Miss MWh
1.	4	1,827.0	877.5	25.8	1,832.7	1,749.4	5,771.6	15,540.0	2.0	10,046.0	25.9
2.	5	1,827.0	877.5	25.8	1,832.7	1,749.4	7.224.1	15,540.0	4.1	8,763.0	20.4
3.	5.5	1,827.0	877.5	25.8	1,832.7	1,749.4	7,958.6	15,540.0	6.0	8,121.1	21.9
4.	6	1,827.0	877.5	25.8	1,832.7	1,749.4	8,677.3	15,540.0	48.7	7,544.5	19.8
5.	7	1,827.0	877.5	25.8	1,832.7	1,749.4	10,130.0	15,540.0	572.4	6,774.3	19.3
6.	8	1,827.0	877.5	25.8	1,832.7	1,749.4	11,537.0	15,540.0	1,448.4	6,351.8	18.9

TABLE IV

PVSYST SIMULATION RESULTS WITH DOD SCHEME VARIATIONS

No	PV Capacity MWp	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlocEff kWh/m²	EArray MWh	E_User MWh	E_Grid MWh	EFrGrid MWh	E_Miss MWh
1.	4	1,827.0	877.5	25.8	1,832.7	1,749.4	5,760.0	15,540.0	2.0	10,067.1	24.3
2.	5	1,827.0	877.5	25.8	1,832.7	1,749.4	7.219.3	15,540.0	30.1	8,811.3	19.5
3.	5.5	1,827.0	877.5	25.8	1,832.7	1,749.4	7,956.3	15,540.0	241.8	8,354.8	18.8
4.	6	1,827.0	877.5	25.8	1,832.7	1,749.4	8,675.1	15,540.0	590.8	8,045.5	20.4
5.	7	1,827.0	877.5	25.8	1,832.7	1,749.4	10,137.1	15,540.0	1,543.2	7,641.9	19.9
6.	8	1,827.0	877.5	25.8	1,832.7	1,749.4	11,544.0	15,540.0	2,630.7	7,411.8	19.5

TABLE V

SIMULATION RESULTS WITH VARIOUS BATTERY CAPACITIES AND DOD SCHEMES

No	PV Capacity MWp	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlocEff kWh/m²	EArray MWh	E_User MWh	E_Grid MWh	EFrGrid MWh	E_Miss MWh
1.	4	1,827.0	877.5	25.8	1,832.7	1,749.4	5,770.8	15,540.0	2.0	10,057.2	20.3
2.	5	1,827.0	877.5	25.8	1,832.7	1,749.4	7.220.4	15,540.0	8.3	8,782.7	18.7
3.	5.5	1,827.0	877.5	25.8	1,832.7	1,749.4	7,965.5	15,540.0	112.0	8,231.6	17.9
4.	6	1,827.0	877.5	25.8	1,832.7	1,749.4	8,962.5	15,540.0	428.5	7,884.5	17.7
5.	7	1,827.0	877.5	25.8	1,832.7	1,749.4	10,122.1	15,540.0	1,310.2	7,450.6	17.1
6.	8	1,827.0	877.5	25.8	1,832.7	1,749.4	11,527.0	15,540.0	2,358.3	7,185.2	16.7

TABLE VI

COE CALCULATION

No	PV Capacity	Energy	Investment cost	O & M Cost	i	n	CRF	LCC	COE
	MWp	MWh	Rp	Rp	%	tahun		Rp	Rp
1	4	5,762.00	160,555,252,968.11	920,544,000.00	5.75%	20.00	0.0854	261,406,724,175.69	3,875.44
2	5	7,224.10	166,784,584,068.11	1,115,544,000.00	5.75%	20.00	0.0854	288,999,549,997.81	3,417.36
3	5.5	7,956.60	169,998,614,700.07	1,213,044,000.00	5.75%	20.00	0.0854	302,895,327,990.84	3,251.94
4	6	8,673.40	173,113,252,500.07	1,310,544,000.00	5.75%	20.00	0.0854	316,691,713,151.90	3,119.07
5	7	10,144.90	179,342,583,600.07	1,505,544,000.00	5.75%	20.00	0.0854	344,284,538,974.02	2,898.99
6	8	11.545.00	185,571,914,700.07	1,700,544,000.00	5.75%	20.00	0.0854	371,877,364,796.14	2,751.59

The value of unserved load can also be reduced by changing the battery SOC scheme, which is to increase the amount of reserves for blackout conditions above 60.

c. In this simulation, changes were made to the DOD scheme. In the initial condition the scheme used is:

a. Maximum charge : 95%
b. Minimun discharge normal usage : 60%
c. Minimum discharge grid is not available : 20%

Changed to a new scheme:

a. Maximum charge : 95%
b. Minimun discharge normal usage : 70%
c. Minimum discharge grid is not available : 20%

When compared to the initial conditions Table 1, the simulation results in Table 4 there is a decrease in E_miss and EfrGrid, but the energy delivered to the grid has increased

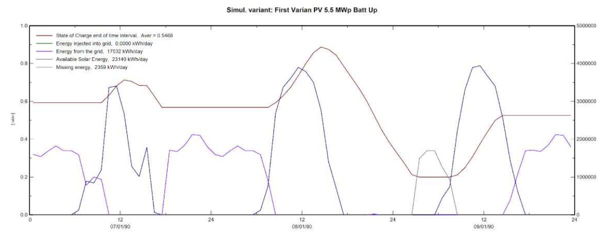


Fig. 14 Instantaneous Energy Profile Graph during substation Outage with 5.5 MWp Solar PV

G. *Simulation with various battery capacity and DOD schemes*

Further simulations with variations in battery capacity and DOD. This is done by combining an increase in battery capacity by 12% and also changing the DOD scheme can be seen in Table 5. There is a decrease in E_miss compared to the previous two simulations, and an increase in PV energy delivered to the grid.

TABLE VII

INVESTMENT FEASIBILITY CALCULATION FROM

No	PV Capacity MWp	B/C Ratio	NPV x1000 Rp	PBP	IRR	BEP
1	4	1.45	77,162,287	11.81	5.07%	11
2	5	1.73	131,705,185	9.43	8.01%	9
3	5.5	1.90	162,153,832	8.45	9.67%	8
4	6	1.98	185,596,728	8.03	10.57%	8
5	7	2.22	240,545,013	7.06	12.93%	7
6	8	2.42	292,414,079	6.41	14.95%	6

H. *Financial Analysis of the Feasibility of Solar Power Plant Investment*

The initial investment cost of the solar power plant (Cost) to be built includes costs such as: EPC costs which include PV panels, batteries, inverters and buildings as well as non-EPC including land acquisition, engineering services and licensing. To determine the initial investment cost, several studies and market surveys are needed to determine the price of certain components. The results of the COE calculation of each capacity can be seen in the following table.

Can be seen in Table 6 COE calculation that the greater the capacity, the lower the COE value, but in Solar PV with a capacity of 4 MWP, the COE value of Rp 3,875.44 is above the System BPP value of Rp 3,684. Solar PV capacity of 5 MWp with an investment of 166.7 billion obtained a COE of Rp 3,417.36 while Solar PV with a capacity of 5.5 MWp with an investment of 169.9 billion obtained a COE of Rp 3,251.94. With an increase in investment of 3.2 billion, there was a decrease in COE of Rp 165.42.

Investment feasibility analysis that the price set by the government is currently the upper tariff limit for PV systems without batteries, so in this study the average BPP of the local system is used as the upper limit for setting the selling price of energy from the Sandai Solar PV system with a value of Rp 3,684. Using this value, the B/C Ratio, NPV, PBP and IRR calculations were obtained as follows.

Table 7 Investment Feasibility Calculation it can be seen that: The B/C Ratio value for all types of capacity is above 1 so it can be said to be included in the feasible criteria. The NPV value for all capacity types is positive. The payback period will be faster as the capacity increases, because the energy generated is also greater. The IRR value with a PV capacity of 4 MWp is still below the BI discount factor value of 5.75%, but for a capacity of 5 MWp and above it is above the BI discount factor value.

IV. CONCLUSIONS

The results of the analysis of the construction of Solar PV on Grid with batteries at the Sandai substation location with the aim of being a backup supply source for the Tayap 4 extension can be concluded as follows: The circuit design successfully combines the design of a conventional 150/20 kV Sandai Substation and a solar power plant. This result is through the determination of the location point coordinates -1.1464o S, and 110.6131o E, with an optimum tilt angle of 6o with Azimuth 0o because it is close to the equator, the estimated GHI that will be received by Solar PV is 1,684 kWh/m2 /year, determining the type of mono-crystalline PV module, determining the type of inverter SMA model with a capacity of 150 kW. After analyzing the ability of an on-grid Solar PV circuit equipped with a battery to back-up the system when a disturbance occurs, besides being influenced by the capacity of PV and batteries, it is also influenced by the battery operating scheme.

Based on the results of the PVsyst software simulation, the Solar PV built can serve Tayap 4 loads when there is a grid outage, if the minimum Solar PV capacity is 5.5 MWp with a minimum battery capacity of 18,739 kWh at 80%DOD as in Error! Reference source not found. with the value of unserved energy is quite small compared to others as well as considering the amount of investment value. As for the reliability in financial analysis, assuming the selling price uses the upper limit of the local BPP of Rp 3,684, -then the design of the on-grid solar power plant development design with batteries meets the criteria for investment feasibility. This economic evaluation includes the initial investment costs of Solar PV (Cost) such as: EPC costs which include PV panels, batteries, inverters and buildings and non-EPC including land acquisition, engineering services and licensing.

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