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Original Research Paper

Efficiency of Auxiliary Power Consumption in Substations Using Renewable Energy Potentials in East Kalimantan Province

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Abstract: PT PLN (Persero) as the Indonesian state electricity supply company must carry out an energy transition in terms of generation, transmission and distribution. Substations in Indonesia's electric power transmission sector have not yet incorporated the idea of green energy into their operation, event hough there is a great potential for renewable energy in substations, such as the usage of solar and wind energy. The primary power source for the auxiliary substation is energy from the grid, with diesel power serving as a backup. However, the energy mix in the Kalimantan grid is still dominated by energy from coal (based on the Annual Operation Evaluation Report PLN UIP3B 2023). This research investigates the technical and economic viability of utilizing renewable energy in auxiliary substations to mitigate the company's escalating financial burden. Technically, the study aims to determine the optimal PV panel capacity required for auxiliary power needs. Economically, it evaluates the total investment and operational costs, Internal Rate of Return (IRR), Return on Investment (ROI), payback periods, and Levelized Cost of Energy (LCOE). Unique to this study is the direct measurement of kWh consumption data from 23 substations in East and North Kalimantan, a method not previously employed. The findings provide recommendations on the appropriate PV capacity for installation in substations and present an economic analysis.

Keywords: Hybrid Energy System, Levelized Cost of Energy, Solar Power, Substation Efficiency, Techno-Economy Analysis.

1. Introduction

Paris Agreement plays a crucial role in addressing the impacts of climate change by limiting the temperature increase to 1.5°C by 2060. As a country that has ratified the Paris Agreement, Indonesia is committed to reducing greenhouse gas emissions by 29% through domestic efforts and up to 41% with international support by 2030. In 2025 and 2028, the electricity sector is targeted to have an EBT mix of 23% and 28%, respectively, which will then become a reference for the Electricity Supply Business Plan (ESBP) [1].

As of August 2020, Indonesia's renewable energy potential was 417.8 GW, six times higher than its current power generation capacity of 69.6 GW [2]. According to Presidential Regulation No. 22/2017 on the National Energy Plan, the potential capacity of solar power plants in Indonesia is 207,898 MW (megawatts). In Indonesia, the average solar energy received on horizontal surfaces ranges from 4.73 to 5.77 kWh per square meter per day, with an average of 11.8 to 12.4 hours of daylight per day. However, the share of solar capacity in Indonesia's energy production is still very low, at only 3 MW in 2002, 90 MW in 2018, and a further 152 MW in 2019 [3]. This highlights the need to accelerate the adoption of renewable energy technologies such as solar photovoltaic (PV) to reduce dependence on conventional energy sources that contribute to carbon emissions.

The role of Perusahaan Listrik Negara (PLN), as the largest electricity provider in Indonesia, is key to accelerating the energy transition towards net zero emissions. To address the slow expansion of solar energy in the residential, commercial, and industrial sectors, the Indonesian government, under the Ministry of Energy and Mineral Resources (MEMR), has implemented several regulations that provide a legal structure and metering agreements for PV system users in the country. In 2013, PLN implemented a regulation known as PLN Regulation 0733.K/DIR/2013, which allows the installation and operation of photovoltaic (PV) systems alongside the national grid. However, within the electricity transmission system, substations have yet to incorporate the concept of 'green' into their operations. Although there is significant potential in substations, such as the use of rooftop solar PV.

Substations require low-voltage power for their auxiliary loads, which include lighting, HVAC, transformer cooling fans, and battery charging. Most of these require a guaranteed, uninterrupted supply [4]. Self-discharging transformers, or substation auxiliaries, typically draw power from the grid to supply additional loads at substations. Based on the Annual Operation Evaluation (AOE) of the Electric Power System at PT PLN (Persero) Unit Induk P3B Kalimantan, it is reported that the energy mix in the Kalimantan grid is still dominated by coal at 70–80%. The total energy consumption of self-consumption transformers at substations is constantly increasing, from 3,092,350 kWh in 2021 to 3,285,410 kWh in 2023. This data shows that the use of power transformers as the main source to meet additional loads at the substation will incur relatively high costs, which will ultimately become a burden on the company.

The purpose of this study is to provide a technical and economic analysis of the potential use of renewable energy in substations to supply additional loads through PS transformers or substation auxiliaries, so that it is cost-effective and can reduce the burden on the company in the future. The levelized cost of electricity from solar PV technology on the grid is lower than that of coal technology [5]. This study focuses exclusively on a hybrid system consisting of solar panels (PV), an inverter, and a grid. From an economic point of view, kWh consumption data will be used, which will be multiplied by the cost of production (COP) to obtain the company's expenditure per year for the auxiliary substation, so that data in the form of IRR, ROI payback periods, and LCOE will be obtained from the simulation results.

2. Literature Review

In recent years, the drive towards sustainable and self-sufficient power systems has stimulated the integration of renewable energy sources into substation auxiliary services. Substations, while fundamental to the transmission and distribution of electricity, require a reliable supply of auxiliary power to operate control systems, lighting, HVAC, and communication infrastructure. Conventional reliance on the grid or diesel generators for these auxiliary loads is increasingly being challenged by cleaner and more resilient alternatives, primarily in the form of photovoltaic (PV) systems and hybrid configurations with battery energy storage systems (BESS).

Costa explored the development of a Hybrid Battery Energy Storage System (HBESS) specifically for high-voltage substations, highlighting how hybrid configurations can ensure uninterrupted auxiliary power even in the case of grid failure [6]. This concept is further supported by Silva Júnior et al., who characterized the operation of a BESS combined with a PV system, confirming that such arrangements can serve as reliable primary sources for auxiliary loads under regular and emergency conditions [7].

The feasibility of PV-based auxiliary systems has been tested in various settings. Dib et al. implemented an auxiliary service system at a transmission substation using solar PV, illustrating successful operation in a real-world environment [8]. Similarly, Letebele and Van Coller emphasized grid-independent hybrid renewable systems as strategic solutions for transmission switching substations, particularly in remote or grid-constrained areas [4].

Utility-driven initiatives further affirm the growing interest in PV-based substation autonomy. For instance, the São Francisco Hydroelectric Company (CHESF) called for R&D projects to investigate PV mini-generation coupled with BESS to autonomously supply 230/500 kV substations, targeting locations with restricted internal sources or challenging grid access [7].

Sizing and optimization are also central to effective implementation. One study proposed optimal capacity sizing of PV-BESS microgrids to ensure adequate coverage of auxiliary services during contingency events, enhancing both energy security and cost efficiency [9]. Meanwhile, the integration of rooftop PV onto substation infrastructure—such as control buildings and switching bays has been explored by researchers proposing new structural designs and bracket systems optimized for temporary or mobile substations [10] [11].

Urban and regional case studies contribute valuable insights into PV adoption feasibility. Rizvi et al. (2024) assessed the practicality of floating solar PV (FSPV) systems connected to urban substations in Chhattisgarh, India, highlighting economic viability and space efficiency [12]. Other studies, such as those conducted in Lithuania and tropical climates (e.g., Southeast Asia), examined the technical and economic potential of rooftop PV systems in dense or humid environments, concluding that such installations can offer a favorable return on investment and operational resilience [13] [14].

Economic drivers remain a critical factor in deployment decisions. Research on rooftop solar PV adoption economics has shown that policy incentives, upfront costs, and long-term savings all play crucial roles in influencing utility-scale and distributed system investments [15].

Collectively, these studies demonstrate that the integration of PV and BESS into substation auxiliary systems is not only technically feasible but also increasingly economically attractive. However, successful deployment depends on careful sizing, reliable energy storage, robust control systems, and alignment with local climate and grid conditions. In regions like East Kalimantan, Indonesia where solar radiation is high and grid expansion is ongoing, such systems hold immense promise for improving substation efficiency, reducing emissions, and enhancing energy resilience in line with national green energy objectives.

3. Methodology

This research will discuss how to present the existing green energy sources in 23 substations spread over the provinces of East Kalimantan and North Kalimantan (Figure 2). The study will focus on two aspects: technical and economic. Based on (Figure 1) the author applies several steps to the research stages as follows:

3.1. Assessment of Renewable Energy Potential

In this stage, an assessment of renewable energy potential in the East Kalimantan and North Kalimantan regions is carried out. The renewable energy potential in the substation is solar energy and wind energy. The solar energy potential based on ESMAP (Energy Sector Management Assistance Program) has an average global horizontal irradiation (GHI) of 4.4 kWh/m² in this region [16]. For wind energy, however, the potential in East Kalimantan and North Kalimantan is relatively small, with an average wind speed of 2.01 m/s at a height of 10 meters [17]. Based on this, the renewable energy used in this study is solar energy by utilizing the substation roof.

3.2. Collecting Data from Conventional Substation

At this stage of the research, the authors collected primary data on the energy consumption of auxiliary substations per half hour in 23 substations in East and North Kalimantan. The list of substations and coordinate points in this study is shown in Table 1. These electrical energy consumption data are multiplied by the average production cost price to obtain the amount of cost incurred by the company for kWh of the auxiliary substation. In addition, the coordinate data of the substation is used to see the potential of solar energy at each point. Therefore, one of the advantages of this research is that it examines technical and economic studies with primary data measurements from real auxiliary substation loads.

Several studies have carried out similar research in this area. According to Mohamed Dib et al., the combination of PV systems with existing systems in transmission substations can improve the quality of the energy supplied and reduce losses, but they have not provided further technical-economic studies before generalizing this solution [8].

As stated by Washington de Araujo Silva Junior et al., auxiliary systems (SAux) in transmission substations require a continuous power supply. In the event of an external power supply becoming unavailable, the system is reliant on diesel emergency generators (DEG), which have slow response times and are susceptible to failure. The experimental results demonstrate that the battery energy storage system in a photovoltaic configuration is capable of operating autonomously and maintaining a stable voltage and frequency without experiencing outages. The system is capable of withstanding sudden changes in active power and recharging the BESS with excess energy from the PV system. This solution ensures a reliable and continuous energy supply for auxiliary systems in the substation. Nevertheless, further studies are necessary to determine the optimal size and technical and economic viability of this solution [7].

Al Ashwal suggests that additional research is necessary to enhance the design of photovoltaic (PV) systems and assess their effectiveness in various operational scenarios. Future research should prioritize conducting a thorough technical economic study and developing techniques for effectively integrating photovoltaic (PV) plants into a broader power grid [18].

As proposed by Bogdan Filip and Marian Dragomir, this study recommends further investigation to assess the efficacy of solar plants in diverse operational and geographical contexts [19].

As posited by Mpai Letebele and John Van Coller, future studies ought to prioritize a more comprehensive technical and economic analysis alongside the development of more efficacious energy management strategies. This will enhance the reliability and efficiency of auxiliary systems in transmission substations [4].

Consequently, the research will investigate the techno economic analysis of photovoltaic use in 23 East Kalimantan substations, utilizing geographic data and varying load data for each substation.

3.3. Use of PVsyst Software for Design PV System

In this research, the PV System application is used to perform the engineering design to determine the amount of PV that can be installed based on the load requirements at 23 substations. In general, the steps used in the PV-Syst simulation used in this study are as follows:

- Create a new project based on the location point.

Table 1. List Of Substation and Coordinate Location

Number	Substation	Coordinate Location
1	Maloy	0.9240714292072126, 117.849383714792
2	Sangatta	0.4721112155937056, 117.57055829262899
3	Telukpandan	0.16344728965001734, 117.43527484690232
4	Muara Badak	-0.31026437358867215, 117.29168543675256
5	New Samarinda	-0.4068215823989753, 117.1663428716843
6	Sambutan	-0.5251231713622516, 117.21419402530292
7	Kota Bangun	-0.2710961612463912, 116.59555389098061
8	Bukit Biru	-0.4558801771471668, 116.97849439594592
9	Embalut	-0.38186850147653895, 117.05121780582225
10	Tengkawang	-0.5025235583121095, 117.11349086968738
11	Harapan Baru	-0.5473087315642758, 117.10670067459687
12	Bukuan	-0.5832135473056099, 117.1932927205716
13	Karang Joang	-1.1487511554770797, 116.87785841446522
14	Manggarsari	-1.238087244158529, 116.94927336586046
15	New Balikpapan	-1.2258610566286643, 116.8904381579581
16	Industri	-1.2618428063952936, 116.84131112360255
17	Kariangau	-1.1654650291917648, 116.79208682724385
18	Petung	-1.3408153464332517, 116.67184527421396
19	Longikis	-1.516298671050907, 116.32304734534814
20	Kuaro	-1.803434711228812, 116.09377590011634
21	Grogot	-1.8985684107644853, 116.1660171365407
22	Komam	-1.8274758357930712, 115.86953853464982
23	Tanjung Selor	2.810425134405983, 117.36760801997129

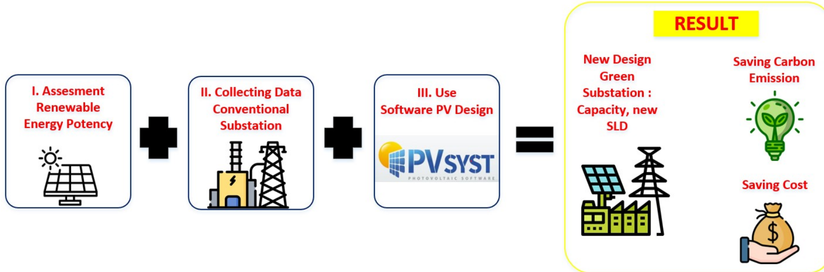


Figure 1. Research Method

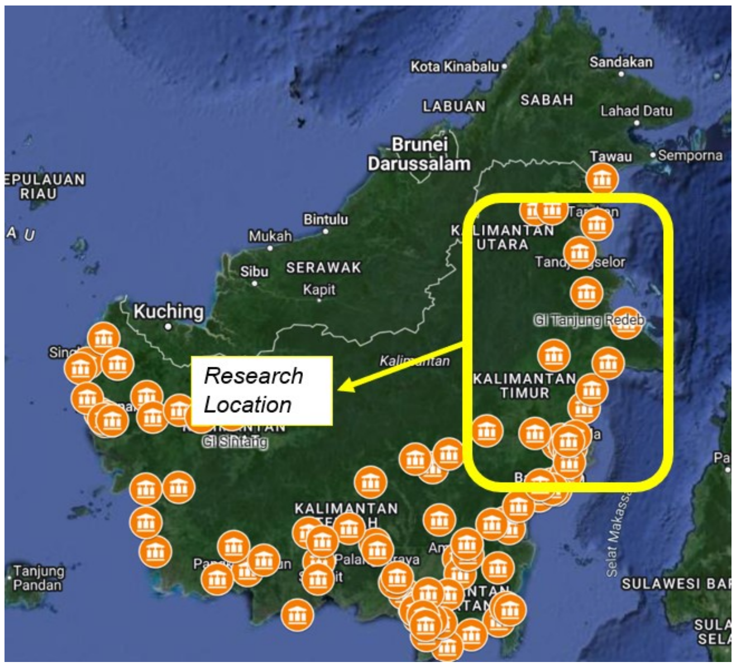


Figure 2. Research Location

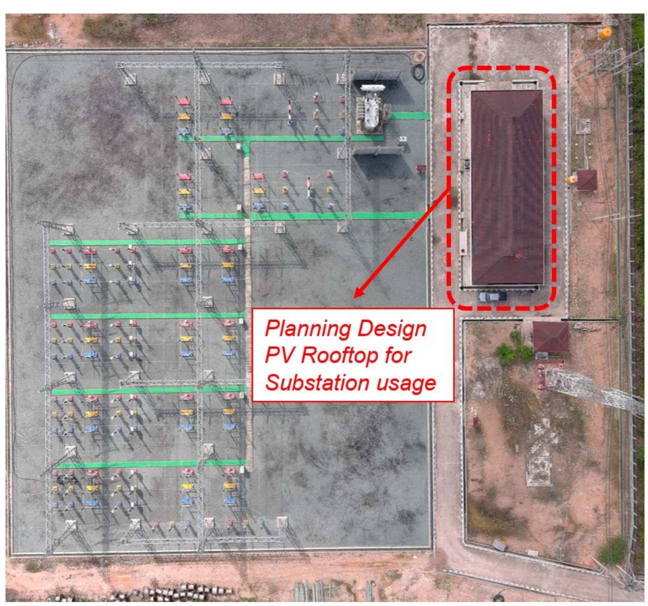
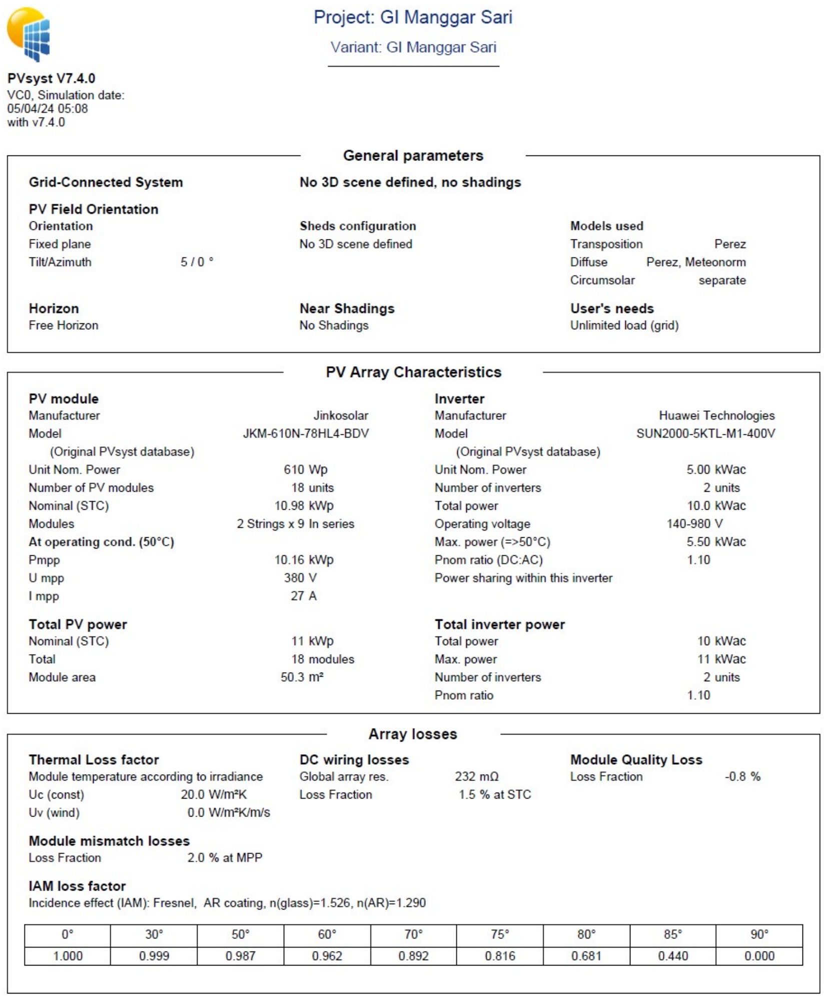


Figure 3. Planning Design PV Rooftop for Substation Usage



Project: GI Manggar Sari

Variant: GI Manggar Sari

PVsyst V7.4.0
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General parameters

Grid-Connected System — **No 3D scene defined, no shadings**

PV Field Orientation					
Orientation		**Sheds configuration**		**Models used**	
Fixed plane		No 3D scene defined		Transposition	Perez
Tilt/Azimuth	5 / 0 °			Diffuse	Perez, Meteonorm
				Circumsolar	separate
Horizon		**Near Shadings**		**User's needs**	
Free Horizon		No Shadings		Unlimited load (grid)	

PV Array Characteristics

PV module		**Inverter**	
Manufacturer	Jinkosolar	Manufacturer	Huawei Technologies
Model	JKM-610N-78HL4-BDV	Model	SUN2000-5KTL-M1-400V
(Original PVsyst database)		(Original PVsyst database)	
Unit Nom. Power	610 Wp	Unit Nom. Power	5.00 kWac
Number of PV modules	18 units	Number of inverters	2 units
Nominal (STC)	10.98 kWp	Total power	10.0 kWac
Modules	2 Strings x 9 In series	Operating voltage	140-980 V
At operating cond. (50°C)		Max. power (=>50°C)	5.50 kWac
Pmpp	10.16 kWp	Pnom ratio (DC:AC)	1.10
U mpp	380 V	Power sharing within this inverter	
I mpp	27 A		
Total PV power		**Total inverter power**	
Nominal (STC)	11 kWp	Total power	10 kWac
Total	18 modules	Max. power	11 kWac
Module area	50.3 m²	Number of inverters	2 units
		Pnom ratio	1.10

Array losses

Thermal Loss factor		**DC wiring losses**		**Module Quality Loss**	
Module temperature according to irradiance		Global array res.	232 mΩ	Loss Fraction	-0.8 %
Uc (const)	20.0 W/m²K	Loss Fraction	1.5 % at STC		
Uv (wind)	0.0 W/m²K/m/s				

Module mismatch losses
Loss Fraction 2.0 % at MPP

IAM loss factor
Incidence effect (IAM): Fresnel, AR coating, n(glass)=1.526, n(AR)=1.290

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.999	0.987	0.962	0.892	0.816	0.681	0.440	0.000

Figure 4. General Parameter PVsyst

- Input the location based on Table 1 to obtain the meteo file. These data are environmental data in the form of global horizontal irradiance (GHI), temperature, and others in the PV System application database.
- Determine the orientation of the solar panel to be installed. In this research, it was determined that the plane tilt is 5° and the azimuth is 0°.
- Enter the technical design parameters of the rooftop PV system to be installed. At this stage, the first thing to be done is to determine the capacity based on the installed substation auxiliary load data. The author uses a capacity of 1.5 times the maximum load of each substation. The basis of this determination is to meet the load requirements by providing a 50% reserve. The PV system designed in this study is a rooftop PV system using the roof of the substation building (Figure 3). Once the capacity has been determined, the type of panel and inverter to be used in the study will be determined.
- Determine the economic parameters. The economic parameters that will be included in the PV system application include module price, module support, inverter, wiring, combiner box, monitoring display system, metering system, installation service price, project lifetime, inflation rate, and electricity tariff (IDR 1,500/kWh).
- Carry out a techno-economic simulation. This stage is the last stage of the PVsyst application, where the output results of calculations using the PVsyst application will be explained in the result section of this paper.

3.4. Saving Cost Analysis

This stage will determine whether or not the installation of a PV rooftop at the substation is feasible based on economic aspects. The economic parameters that will be the basis are the levelized cost of electricity (LCOE), payback period (in units of years), internal rate of return (IRR), and return on investment from the installation of PV rooftops in 23 substations.

4. Finding and Discussion

According to the research that has been carried out, some points that can be the basis of recommendations for the installation of PV for the needs of auxiliary substations are as follows:

4.1. A Stable Substation Load Profile During the Day Is Suitable for Rooftop PV Installation

Operationally, the substation is in operation 24 hours a day. The main load supplied by the auxiliary substation is in the form of air conditioning (AC) for temperature maintenance of equipment such as relays and bay control units (BCU), lighting (lighting), and supply of auxiliary motor drives. Substation auxiliary needs vary, but at least in the East Kalimantan region, based on the years 2022–2023, a minimum of 72,000 kilowatt hours (kWh) per year per substation is required. Using the minimum average calculation, from a total of 23 substations, the auxiliary demand at the substation amounted to 1.8 megawatt hours (MWh) per year. In addition, the load profile at the substation is quite high. This indicates that the auxiliary consumption pattern of the substation is fairly constant throughout the day. Based on the sample at the Muara Badak substation, the load factor in December was 0.90. A constant load, especially during the day, can reduce the impact of electrical instability due to the rise and fall of electrical loads.

4.2. Results of the Technical Design Analysis

In this study, technical recommendations were obtained for the technical PV rooftop capacity that can be installed in 23 substations. The highest capacity is installed in the Embalut substation. This is because the Embalut substation has the highest load compared to the other substations (40 kWh at peak load). The total rooftop PV capacity required in the 23 substations is 642 kWp. This PV capacity is defined in the general parameters of the PV System program (Figure 4) and the output design of the single line diagram output from the PV System program (Figure 6).

The configuration design required in this study can be drawn in the PVsyst application. For example, based on (Figure 4), (Figure 5) and (Figure 6), the rooftop PV configuration design at the Manggar Sari Substation uses 18 Jinkosolar brand PV panels with a capacity of 610 Wp connected into 2 strings, where each string is assembled in a series of 9 pieces. The two strings are connected to each Huawei inverter, which has a capacity of 5.0 kW. The total area required is 50 m², with the average substation roof having a minimum area of 300 m². Based on the design, the total PV DC power is 11.0 kW, while the total PV AC power is 10.0 kW AC, with a Pnom ratio of 1.098.

The results in Table 2 show the total PV studied using the PV System application. In addition, it can be seen that the energy that can be generated per year that can be used for the auxiliary needs of the substation is 986.10 MWh per year. The total usage of the North Kalimantan auxiliary substation in 2023, based on primary data measurements, is 3,285 MWh. Based on the table above, it can be concluded that PV rooftop installation can reduce auxiliary substation consumption by 30.01% per year. This means that the use of rooftop PV at the substation can reduce the company’s burden by IDR 1.479 billion per year for the substation environment in Kalimantan.

4.3. On-Grid PV System That Supports Curtailment

In general, the curtailment of rooftop PV can be explained. If the auxiliary load is small while the PV supply is excessive, the excess PV cannot be absorbed by the load, or, in other words, it is wasted. However, this will not happen because, with the on-grid PV configuration, the excess PV supply is sent to the grid. As it is known, the substation is a load center through a 20 kV feeder.

4.4. Economic Analysis Results: Payback Period, IRR, and ROI

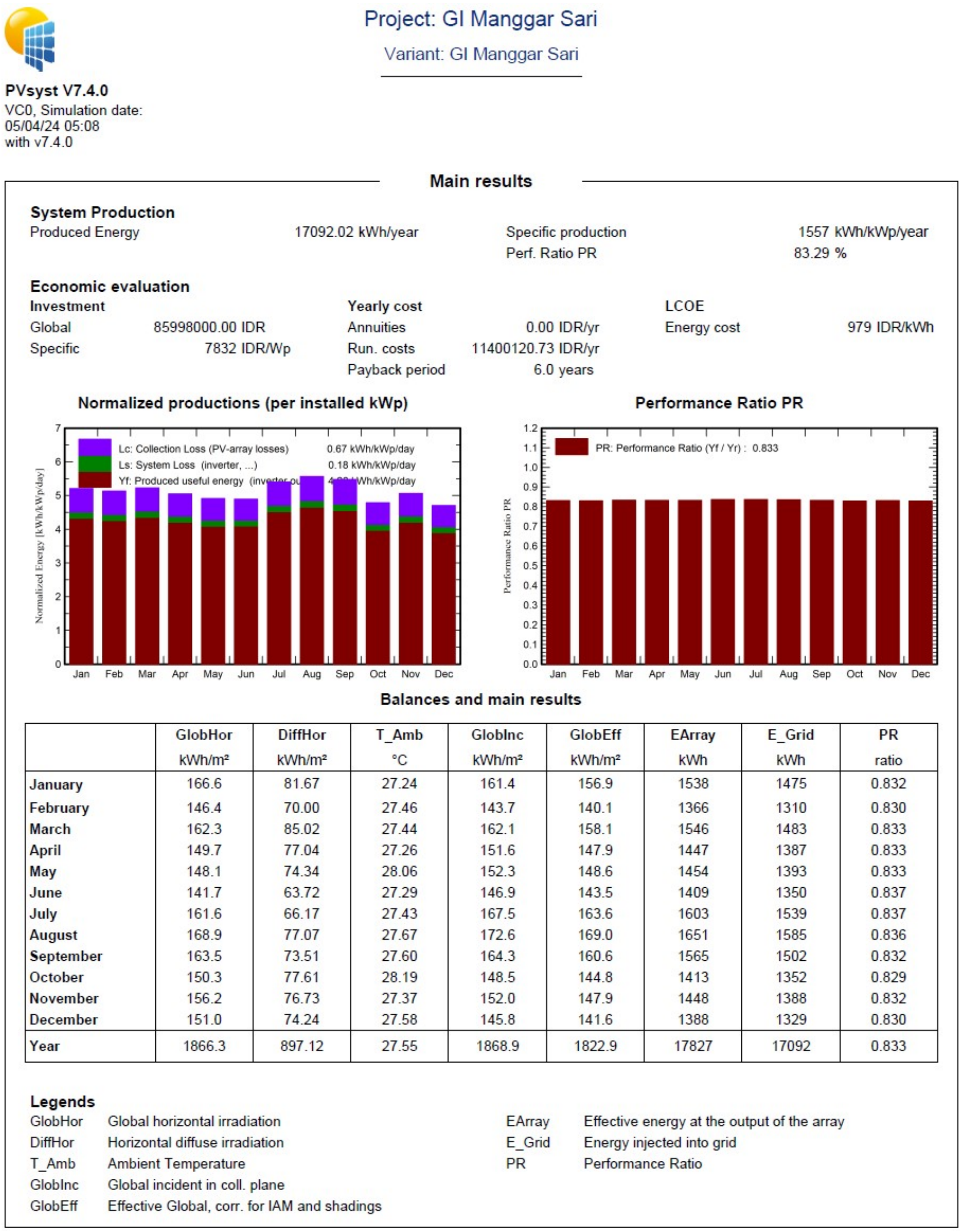
This study is based on the Levelized Cost of Electricity (LCOE) price of PV technology, which is lower than coal technology [5]. Based on the results of the study, it is evident that the LCOE price of rooftop PV is lower compared to the LCOE price of coal technology.

Table 2. Result of Technical Analysis

Number	Substation	Capacity PV (kWp)	Energy (MWh/Year)	LCOE IDR/kWh
1	Maloy	21.96	34.7	790.92
2	Sangatta	27.45	42.4	774.95
3	Telukpandan	38.4	58.9	762.73
4	Muara Badak	27.45	41.5	790.78
5	New Samarinda	27.45	41.6	790.08
6	Sambutan	10.98	16.6	1,006.20
7	Kota Bangun	21.96	33.6	817.81
8	Bukit Biru	21.96	33.3	825.97
9	Embalut	60.4	91.5	767.64
10	Tengkawang	76.9	117	734.52
11	Harapan Baru	27.45	41.8	78.52
12	Bukuan	16.47	25.1	879.23
13	Karang Joang	32.9	51	748.81
14	Manggarsari	10.98	17.1	978.82
15	New Balikpapan	32.9	51.2	745.95
16	Industri	27.45	42.6	770.53
17	Kariangau	21.96	34	807.89
18	Petung	21.96	34	807.42
19	Longikis	21.96	34	808.89
20	Kuaro	27.45	42.3	770.08
21	Grogot	21.96	33.8	812.38
22	Komam	21.96	33.9	810.37
23	Tanjung Selor	21.96	34.2	803.21
	TOTAL	**642**	**986.1**	**808.29**

Table 3. Result of Economic Analysis

Number	Substation	Capacity PV (kWp)	Payback (years)	Period (%)	IRR (%)
1	Maloy	21.96	4.7	23.66	215.6
2	Sangatta	27.45	4.7	23.78	218.2
3	Telukpandan	38.4	4.6	24.17	223.6
4	Muara Badak	27.45	4.8	23.1	209.2
5	New Samarinda	27.45	4.8	23.1	209.6
6	Sambutan	10.98	6.3	17.71	134.5
7	Kota Bangun	21.96	5	22.53	200.6
8	Bukit Biru	21.96	5	22.22	196.3
9	Embalut	60.4	4.6	24.19	223.5
10	Tengkawang	76.9	4.4	25.26	238.7
11	Harapan Baru	27.45	4.8	23.32	212.1
12	Bukuan	16.47	5.4	20.92	178
13	Karang Joang	32.9	4.6	24.53	229
14	Manggarsari	10.98	6	18.47	146.6
15	New Balikpapan	32.9	4.5	24.66	230.7
16	Industri	27.45	4.7	23.97	220.8
17	Kariangau	21.96	4.9	22.94	206
18	Petung	21.96	4.9	22.96	206.3
19	Longikis	21.96	4.9	22.9	205.5
20	Kuaro	27.45	4.7	23.69	217
21	Grogot	21.96	4.9	22.75	203.6
22	Komam	21.96	4.9	22.83	204.7
23	Tanjung Selor	21.96	4.8	23.13	208.6
	TOTAL	**642**	642	4.9	22.9



PVsyst V7.4.0
VC0, Simulation date:
05/04/24 05:08
with v7.4.0

Project: GI Manggar Sari
Variant: GI Manggar Sari

Main results

System Production

Produced Energy 17092.02 kWh/year — Specific production 1557 kWh/kWp/year — Perf. Ratio PR 83.29 %

Economic evaluation

Investment		Yearly cost		LCOE	
Global	85998000.00 IDR	Annuities	0.00 IDR/yr	Energy cost	979 IDR/kWh
Specific	7832 IDR/Wp	Run. costs	11400120.73 IDR/yr		
		Payback period	6.0 years		

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	166.6	81.67	27.24	161.4	156.9	1538	1475	0.832
February	146.4	70.00	27.46	143.7	140.1	1366	1310	0.830
March	162.3	85.02	27.44	162.1	158.1	1546	1483	0.833
April	149.7	77.04	27.26	151.6	147.9	1447	1387	0.833
May	148.1	74.34	28.06	152.3	148.6	1454	1393	0.833
June	141.7	63.72	27.29	146.9	143.5	1409	1350	0.837
July	161.6	66.17	27.43	167.5	163.6	1603	1539	0.837
August	168.9	77.07	27.67	172.6	169.0	1651	1585	0.836
September	163.5	73.51	27.60	164.3	160.6	1565	1502	0.832
October	150.3	77.61	28.19	148.5	144.8	1413	1352	0.829
November	156.2	76.73	27.37	152.0	147.9	1448	1388	0.832
December	151.0	74.24	27.58	145.8	141.6	1388	1329	0.830
Year	1866.3	897.12	27.55	1868.9	1822.9	17827	17092	0.833

Legends

GlobHor Global horizontal irradiation
DiffHor Horizontal diffuse irradiation
T_Amb Ambient Temperature
GlobInc Global incident in coll. plane
GlobEff Effective Global, corr. for IAM and shadings
EArray Effective energy at the output of the array
E_Grid Energy injected into grid
PR Performance Ratio

Figure 5. Main Result PVsyst

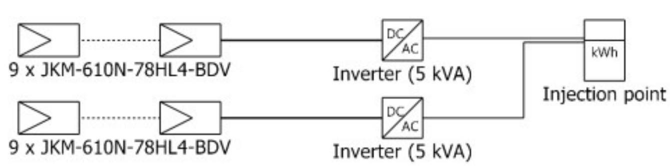


Figure 6. Single Line Diagram Configuration PV in Manggarsari Substation

Based on Table 3, the average value of the payback period for PV installation in 23 substations is 4.9 years. This means that with the investment and operating parameters entered into the application, the investment made will be recovered after 4.9 years and will be profitable for the company in the following year. The parameters included in the calculation of the economic analysis are a project life of 25 years, an inflation rate of 2.65%, a discount rate of 5%, an electricity sale price of IDR 1,500/kWh, and the investment and operating values of the PV systems to be installed. The operating value in this case includes the preliminary parameters of the inverter or the lifetime of the inverter. The assumption of 7 years means that the inverter will be replaced after 7 years of use, while the PV panels will not be replaced during the life of the project.

Table 3 also shows the return-on-investment ROI (%) and the internal rate of return IRR (%). The average value of the IRR is 22.9%, and the ROI is 206%. This value indicates the effectiveness of an investment over the life of the project.

Some points that can be recommended based on this research in the future to improve this research are as follows:

1) This research recommends a simulation using an application:
   The research—the technical and economic analysis of PV rooftop installation for substation auxiliary needs—can be strengthened with a prototype or real experiment in the field by taking a case in one of the substations. This can strengthen the argumentation of this research.
2) This research can be implemented on a larger scale:
   In its implementation, this research can be widely implemented on a scale of more than one province, national, and even international scales to support the acceleration of the energy transition. This is because the aid has a typical design.
3) Use of primary irradiance data:
   The use of primary irradiation data can determine the amount of energy that can be produced by rooftop PV throughout the year. Using primary irradiation measurements rather than the existing database in the PVsyst application can make the study more accurate.
4) Optimization study using Battery Energy Storage System (BESS):
   The use of BESS can overcome the intermittency effect of rooftop PV, although BESS currently has a high economic value based on the levelized cost of electricity (LCOE) [5].

Finally, the author understands that there are still shortcomings in this study. Suggestions and constructive criticism are welcome through the author's email.

5. Conclusion

Based on this research, it can be concluded that solar energy represents the most suitable renewable energy source for implementation in substation environments. Utilizing rooftop photovoltaic (PV) systems significantly enhances the efficiency of auxiliary kilowatt-hour (kWh) consumption in substations. Through the use of PVsyst software, comprehensive technical and economic analyses have been performed, demonstrating considerable potential for renewable energy adoption. Simulations conducted across 23 substations in East Kalimantan have revealed that adopting rooftop PV systems could achieve annual energy savings of approximately 986 MWh, accounting for about 30.01% of the total auxiliary consumption of 3,285 MWh recorded in 2023. Economically, following an average Break Even Point (BEP) period of 4.9 years, substations can achieve annual financial savings of IDR 1.47 billion, assuming an average electricity production cost of IDR 1,500 per kWh.

These findings underscore the importance of renewable energy, particularly solar power, in facilitating a sustainable energy transition and reducing reliance on fossil-based electricity. From a policy perspective, the results offer valuable insights and implications for Indonesian energy policies aimed at emission reductions and increased renewable energy penetration. To further validate and enhance the applicability of these results, future studies should include field experiments to verify simulation data and further research into hybrid system optimization, such as integrating Battery Energy Storage Systems (BESS), to improve reliability and ensure a stable electricity supply within substations.

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