

Feasibility Study of a Hybrid Power Plant (Solar and Diesel Power Plant) on Kerayaan Island, South Kalimantan

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Abstract. This study investigates the feasibility of implementing a hybrid power generation system combining solar power (PLTS) and diesel generators (PLTD) on Kerayaan Island as a solution to provide 24-hour electricity, reduce fuel consumption, and lower greenhouse gas (GHG) emissions. By incorporating battery storage, this hybrid system significantly decreases fuel usage, reduces annual operational costs, and achieves a lifetime reduction in GHG emissions by 11,867.4 tonnes of CO₂. Financial analysis confirms the project's viability, with a Net Present Value (NPV) of Rp 11,392,864,224, an Internal Rate of Return (IRR) of 30.52%, a Payback Period of 3.8 years, and a Return on Investment (ROI) of 231.8%. From a network modeling perspective, this system has minimal losses, amounting to 0.0005 MW. Overall, the project demonstrates strong feasibility from technical, economic, and environmental perspectives, highlighting its potential as a profitable and sustainable investment.

Keywords: *hybrid power generation; solar power; diesel power; investment feasibility*

1 Introduction

Energy plays a vital role in sustaining life and supporting all activities of living beings. It is crucial in driving socio-economic development and improving human welfare. The exploration of sustainable energy sources is imperative to mitigate global warming caused by the extensive use of fossil fuels. Fossil fuel consumption significantly increases carbon emissions, contributing to global climate change [1], [2], [3].

Electrical energy is one of the most impactful energy types, and its demand continues to rise alongside population growth. According to the General Plan for Electricity Supply (RUPTL) 2021–2030, the Indonesian government aims to meet electricity demands while adhering to the principles of sustainability, efficiency, and accessibility. National electricity demand is projected to grow at an average rate of 4.9% per year [4], [5], [6].

Based on PLN's 2021–2030 Electricity Supply Business Plan (RUPTL), electricity generation in Indonesia remains heavily reliant on fossil fuel-based power plants, despite an increased commitment to renewable energy (RE). The RUPTL targets approximately 51.6% of new generation capacity from RE sources, with the remainder from fossil fuel-based plants, such as coal-fired power plants (PLTU) and gas turbine power plants (PLTG). However, despite these ambitious targets, the realisation of Indonesia's renewable energy potential remains low. For instance, solar energy, which has an estimated potential of 207,898 MW, is currently utilised at only 0.1% of its total capacity [4]. This underscores the urgent need for accelerated investment, supportive policies, and infrastructure development to increase the contribution of renewable energy in the national energy mix.

Diesel power plants are often installed in regions without coal or natural gas supplies, especially in remote areas with small electricity demands. However, electricity sourced from diesel power presents significant challenges, including high greenhouse gas (GHG) emissions and expensive electricity costs. Diesel power plants frequently experience operational issues, maintenance challenges, and costly fuel transportation, all of which contribute to higher electricity prices. Nevertheless, diesel generators offer low standby losses and can be located near load centres, making them viable in certain situations [7], [8], [9], [10].

Unlike fossil fuels, which are expensive and environmentally harmful, renewable energy serves as a sustainable alternative with abundant resources [10], [11]. The use of renewable energy sources, such as solar, wind, and hydropower, is essential in designing electricity systems that align with environmental protection, sustainability, and economic growth. Renewable energy effectively mitigates the negative impacts of conventional energy usage and provides significant economic benefits [3], [12]. Solar energy, in particular, offers an inexhaustible and environmentally friendly source of electricity on a large scale [2], [13].

Solar energy is especially abundant in tropical countries, where sunlight is available almost year-round. Electricity generated from solar panels is cost-effective, mitigating the rising costs of conventional electricity [12]. Moreover, solar panels can produce substantial amounts of electricity without relying on fossil fuels, making them an environmentally friendly option [11].

South Kalimantan has several areas facing limited electricity access due to challenging geographical conditions. According to the 2021–2030 RUPTL, the region holds significant potential for solar power development due to its high solar radiation intensity throughout the year. Developing a hybrid solar-diesel power plant equipped with battery-based energy storage systems offers a practical

solution to enhance electrification in isolated areas while ensuring sustainable electricity supply [6], [12], [14] .

Kerayaan Island, located in Kotabaru Regency, South Kalimantan, has considerable renewable energy potential, particularly from solar radiation. Based on Global Horizontal Irradiation (GHI) data from Meeonorm, the island receives an average annual solar irradiance of 1,987.3 kWh/m²/year, or approximately 5.44 kWh/m²/day. This consistent solar energy potential, with relatively stable monthly variations, underscores the viability of solar power generation on the island. Currently, the island's electricity system relies entirely on diesel power plants (PLTD), with limited electricity availability [14], [15] .

The use of electrical energy derived from diesel generators is relatively expensive due to the need to transport fuel from mainland Kalimantan via sea and land routes [8] . Consequently, alternative electricity generation methods must be implemented to address issues related to electricity availability and the rising costs of fossil fuels. The alternative energy sources should reduce dependence on fossil fuels, which have adverse effects on the environment and public health [14]

Given this background, this research aims to assess the feasibility of a hybrid power plant (solar and diesel) to ensure a reliable and sustainable electricity supply for Kerayaan Island. The hybrid system integrates a Solar Power Plant (PLTS) with a Diesel Power Plant (PLTD) as a backup source and is equipped with batteries for energy storage.

The inclusion of batteries ensures a 24-hour electricity supply, including during the night or when solar intensity is reduced. The energy storage system stores excess energy generated by the PLTS during the day and distributes it during peak loads or when the PLTS is not operational.

This study is expected to provide a comprehensive solution for the development of a PLTS-PLTD hybrid generator with batteries on Kerayaan Island, capable of delivering reliable, efficient, and sustainable electricity. The results are also anticipated to serve as an initial step in promoting renewable energy development in other isolated areas of South Kalimantan.

2 Literature Review

2.1 *Potential of PLTS in Indonesia*

Solar Power Plants (PLTS) are a type of renewable energy application that utilizes photovoltaic effects to produce electricity. These systems directly convert solar radiation into electrical energy using semiconductors that absorb and

transform sunlight into electricity [16] . Solar energy represents an abundant, clean, and sustainable resource, making it a crucial solution for renewable energy utilization [13], [17] .

Indonesia, as a Southeast Asian country located along the equator, experiences an average of 12 hours of sunlight daily [2], [12] . Based on the global horizontal irradiation map from SolarGIS, Indonesia receives an average solar radiation of 4.80 kWh/m²/day. Figure II.1 illustrates this distribution, showing that the southern and western parts of Indonesia receive higher solar radiation intensities. Higher solar radiation indicates greater potential for PLTS development in these regions [12] .

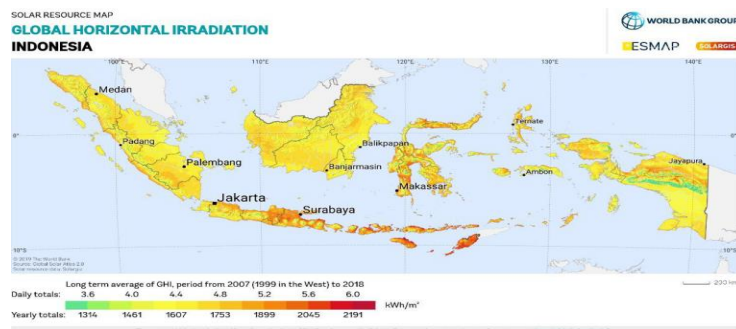


Figure 1 Global Horizontal Irradiation (Globalsolaratlas.info, 2022)

Indonesia has sufficient availability of new renewable energy (EBT) resources to reduce its dependency on fossil fuels. According to Government Regulation Number 79 of 2014 on National Energy Policy, the renewable energy target is set at 23% by 2025 and 31% by 2050. In 2019, Indonesia's renewable energy potential was 441.7 GW, with an installed capacity of only 9.07 GW, representing a mere 2% of the total potential [18] . This energy potential includes tidal/wave energy (11.0 GW), geothermal energy (32.6 GW), bioenergy (60.6 GW), wind energy (60.6 GW), and solar energy (207.08 GW). However, the realized solar power capacity was only 0.090 GWp [10] . Solar energy potential exists across nearly all provinces in Indonesia, but its utilisation remains suboptimal. The solar energy potential in Indonesia is illustrated in Figure 2 below:

South Kalimantan faces significant environmental challenges, including substantial greenhouse gas emissions from the energy, transportation, and waste sectors. According to the National Greenhouse Gas Inventory System (SIGN SMART), the energy sector is the largest contributor to carbon emissions, primarily due to fossil fuel-based power plants and transportation activities [19]. Coal-fired power plants dominate electricity generation in the province, accounting for approximately 77% of the installed capacity, leading to high greenhouse gas emissions. This aligns with the energy sector's contribution to South Kalimantan's Gross Regional Domestic Product (GRDP), which stands at 18% [20].

3 Methods

3.1 Research Location



Figure 3 research location on Kerayaan Island

The research was conducted on Pulau Kerayaan, situated at coordinates $4^{\circ}05'20''\text{S}$, $116^{\circ}12'19''\text{E}$, covering a total land area of 2,500 square meters. This location was strategically chosen due to its significant potential for renewable energy development and its suitability for the implementation of a hybrid energy system.

3.2 Load Projection

3.2.1 Load at Night

The proposed electricity load pattern for nighttime, as depicted in Figure 4, illustrates the distribution of power consumption, reflecting energy needs during this period.

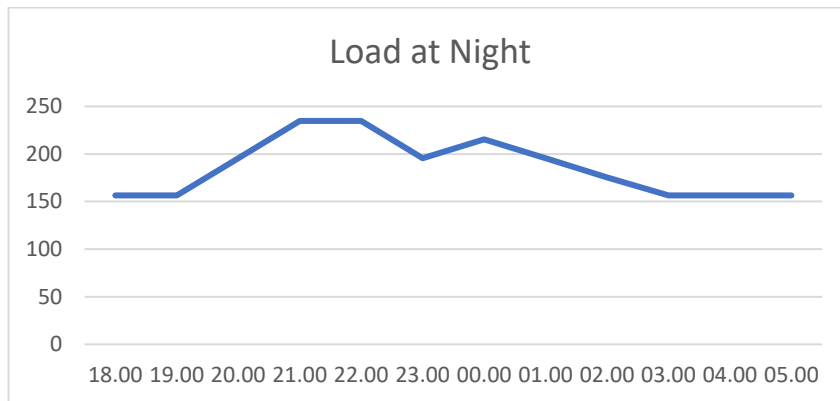


Figure 4 Design of Load Pattern during Nighttime

The figure demonstrates variations in electricity demand from 6:00 PM to 5:00 AM. The load stabilizes at approximately 150 kWh during the early evening (6:00 PM–8:00 PM) and increases significantly, reaching a peak of approximately 234.72 kWh between 9:00 PM and 10:00 PM. Subsequently, the load gradually decreases, stabilizing again at around 150 kWh after 3:00 AM until the early morning. This pattern corresponds to typical nighttime activities, with peak loads likely attributable to energy-intensive activities such as the use of household appliances and lighting, followed by a decline as activities diminish closer to bedtime.

3.2.2 Load During the Day

The electricity load pattern for daytime, shown in Figure 5, illustrates power consumption distribution reflecting energy needs during this period.

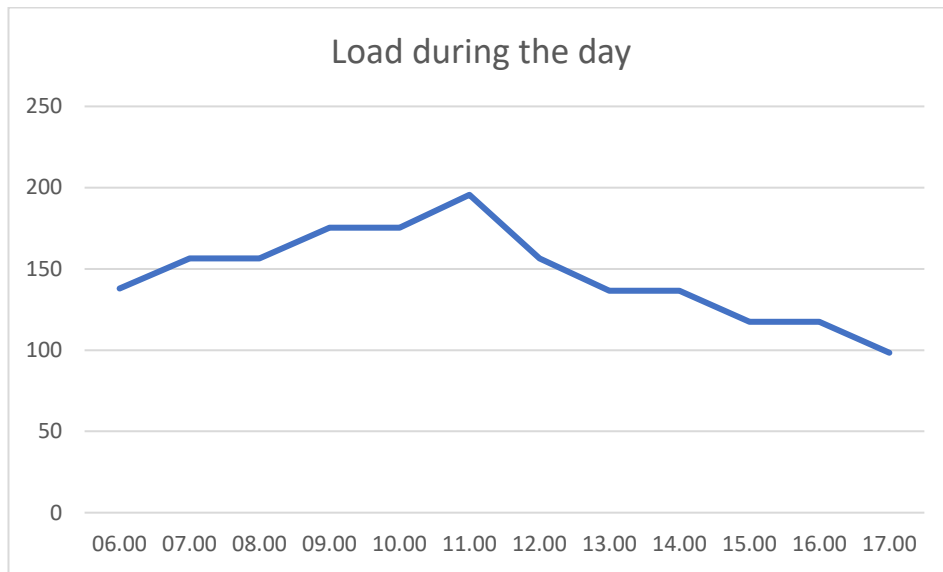


Figure 5 Design of Load Pattern during Daytime

The figure indicates that the load begins to increase in the morning, peaking at around 11:00 AM, likely reflecting heightened activities during working hours. Thereafter, a gradual decline in the load is observed, continuing into the evening, which corresponds to a reduction in operational activities. This pattern reflects a typical daytime energy consumption distribution, dominated by activities during working hours.

3.3 Daily Energy Consumption

Daily load data is derived from the output power of four transformers. The total daily electrical energy consumption is 1,956 kWh.

Table 1 Electrical Load Daily

Type	Power (Kw)	Usage Time (hours)	Energy Consumption (kWh)
1	38	12	456
2	80	12	960
3	26	12	312
4	19	12	228
Total			1,956 kWh

3.4 Solar Radiation Data

Based on the data, the average annual solar radiation reaches 1,987.3 kWh/m²/month, with an average wind speed of 1.4 m/s and an average temperature of 27.4°C.

	Global horizontal irradiation kWh/m ² /mth	Horizontal diffuse irradiation kWh/m ² /mth	Temperature °C	Wind Velocity m/s	Linke turbidity [-]	Relative humidity %
January	166.9	86.6	27.3	1.40	3.631	83.3
February	152.5	79.4	27.4	1.30	3.619	83.3
March	160.3	81.7	27.4	1.20	3.441	83.8
April	157.6	76.0	27.4	1.09	3.276	85.2
May	157.6	68.4	27.9	1.20	3.382	83.5
June	143.7	64.8	26.9	1.19	3.519	85.6
July	165.1	68.6	26.9	1.39	3.571	81.7
August	181.4	71.6	27.2	1.69	3.714	78.3
September	177.7	75.7	27.3	1.79	4.002	78.7
October	185.1	82.2	28.0	1.50	4.202	78.6
November	179.5	76.9	27.6	1.31	3.854	83.0
December	159.9	74.5	27.6	1.40	3.476	82.6
Year	1987.3	906.5	27.4	1.4	3.641	82.3

Figure 6 Global horizontal irradiation year-to-year variability 5.5%

4 Results and Discussion

4.1 Energi yang dihasilkan

The energy output of the Kerayaan Island Solar Power Plant (PLTS) is 676,512 kWh/year.

	GlobHor kWh/m ²	DiffHor kWh/m ²	T_Amb °C	GlobInc kWh/m ²	GlobEff kWh/m ²	EArray kWh	E_User kWh	E_Solar kWh	EUnused kWh	EFrGrid kWh
January	166.9	86.61	27.34	150.6	145.6	51479	60637	49415	0	11222
February	152.5	79.43	27.41	143.4	139.5	49047	54769	46280	0	8488
March	160.3	81.73	27.43	158.1	154.3	53886	60637	49425	661	11211
April	157.6	76.03	27.41	163.4	159.8	55798	58681	51124	1960	7557
May	157.6	68.42	27.89	171.3	167.9	58328	60637	53209	1370	7427
June	143.7	64.76	26.90	158.9	155.8	54639	58681	51745	324	6935
July	165.1	68.60	26.93	182.4	178.9	62671	60637	57461	841	3176
August	181.4	71.64	27.23	193.4	189.9	66001	60637	60397	1463	240
September	177.7	75.65	27.32	179.1	175.4	60952	58681	56419	1160	2261
October	185.1	82.21	28.00	177.0	172.7	60008	60637	56406	293	4231
November	179.5	76.91	27.58	162.4	157.5	55200	58681	51647	0	7034
December	159.9	74.52	27.60	142.3	137.7	48502	60637	45903	0	14734
Year	1987.3	906.52	27.42	1982.3	1934.9	676512	713949	629432	8072	84517

Legends

GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_User	Energy supplied to the user
T_Amb	Ambient Temperature	E_Solar	Energy from the sun
GlobInc	Global incident in coll. plane	EUnused	Unused energy (battery full, no grid injection)
GlobEff	Effective Global, corr. for IAM and shadings	EFrGrid	Energy from the grid

Figure 7 Simulation results from PVSyst

4.2 Performance Ratio

Based on the data presented in Figure 8, the performance ratio (PR) of the solar photovoltaic (PV) power generation system (PLTS) is calculated at 0.794. This indicates that the PLTS system produces 79.4% of the energy expected under ideal or reference conditions.

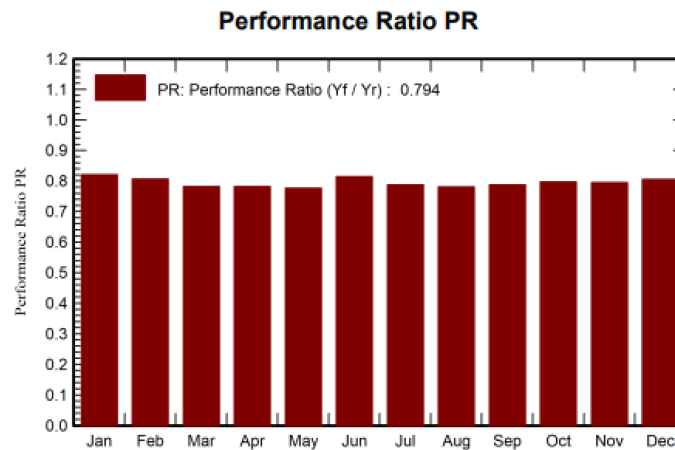


Figure 8 Performance Ratio

4.3 Economic Analysis of the Solar Power Plant Using the PV System

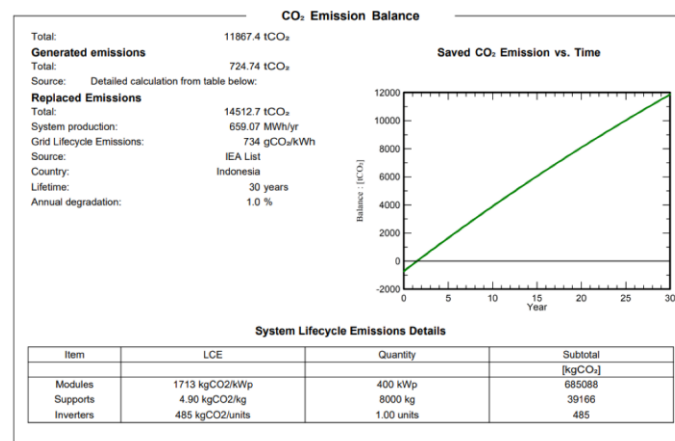
Based on the image below, it can be observed that the Net Present Value (NPV) of this project is Rp. 11,392,864,224, with an Internal Rate of Return (IRR) of 30.52%, a Payback Period of 3.8 years, and a Return on Investment (ROI) of 231.8%. Overall, this project appears financially feasible, offering the potential for profitable investment returns.

Year	Electricity sale	Own funds	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Self-cons. saving	Cumul. profit	% amort.
0	0	4.921.451.150	0	0	0	0	0	0	-4.921.451.150	0.0%
1	0	0	60.896.700	215.588.920	0	0	-60.896.700	1.573.582.996	-3.503.750.779	28.8%
2	0	0	61.938.034	215.588.920	0	0	-61.938.034	1.573.582.996	-2.175.986.556	55.8%
3	0	0	62.997.174	215.588.920	0	0	-62.997.174	1.573.582.996	-932.468.356	81.1%
4	0	0	64.074.426	215.588.920	0	0	-64.074.426	1.573.582.996	232.134.647	104.7%
5	0	0	65.170.098	215.588.920	0	0	-65.170.098	1.573.582.996	1.322.816.632	126.9%
6	0	0	66.284.507	215.588.920	0	0	-66.284.507	1.573.582.996	2.344.256.365	147.6%
7	0	0	67.417.972	215.588.920	0	0	-67.417.972	1.573.582.996	3.300.837.082	167.1%
8	0	0	68.570.819	215.588.920	0	0	-68.570.819	1.573.582.996	4.196.665.135	185.3%
9	0	0	69.743.380	215.588.920	0	0	-69.743.380	1.573.582.996	5.035.587.450	202.3%
10	0	0	70.935.992	215.588.920	0	0	-70.935.992	1.573.582.996	5.821.207.892	218.3%
11	0	0	72.148.998	215.588.920	0	0	-72.148.998	1.573.582.996	6.556.902.600	233.2%
12	0	0	73.382.746	215.588.920	0	0	-73.382.746	1.573.582.996	7.245.834.351	247.2%
13	0	0	74.637.590	215.588.920	0	0	-74.637.590	1.573.582.996	7.890.966.022	260.3%
14	0	0	75.913.893	215.588.920	0	0	-75.913.893	1.573.582.996	8.495.073.203	272.6%
15	0	0	77.212.021	215.588.920	0	0	-77.212.021	1.573.582.996	9.060.756.016	284.1%
16	0	0	78.532.346	215.588.920	0	0	-78.532.346	1.573.582.996	9.590.450.189	294.9%
17	0	0	79.875.250	215.588.920	0	0	-79.875.250	1.573.582.996	10.086.437.428	304.9%
18	0	0	81.241.116	215.588.920	0	0	-81.241.116	1.573.582.996	10.550.855.143	314.4%
19	0	0	82.630.339	215.588.920	0	0	-82.630.339	1.573.582.996	10.985.705.553	323.2%
20	0	0	84.043.318	215.588.920	0	0	-84.043.318	1.573.582.996	11.392.864.224	331.5%
Total	0	4.921.451.150	1.437.646.720	4.311.778.400	0	0	-1.437.646.720	31.471.659.920	11.392.864.224	331.5%

Figure 9 Detailed economic results (IDR)-Simulation results from PVSyst

4.4 Environmental Impact Analysis

As shown in Figure 10, the deployment of solar energy in this project results in a significant reduction in carbon dioxide (CO₂) emissions, amounting to 11,867.4 tons over the system's lifetime. This considerable reduction underscores the project's positive environmental impact and highlights the role of the solar power system in mitigating the carbon footprint compared to conventional energy sources, which are typically associated with higher greenhouse gas emissions.

Figure 10 CO₂ Emission Balance -Simulation results from PVSyst

4.5 Fuel Savings

The integration of the solar power and battery system has successfully reduced the operational hours of the diesel power plant (PLTD) from 13 hours to just 2.25 hours per day. Previously, the total fuel consumption for three PLTD units over 13 hours amounted to 888 liters. After the implementation of the solar and battery systems, fuel consumption decreased to 153.44 liters, resulting in savings of 734.56 liters. This equates to cost savings of IDR 8,212,279.12, based on a fuel price of IDR 11,195 per liter.

4.6 Grid Modeling Using Digsilent Power Factory

4.6.1 Grid Losses

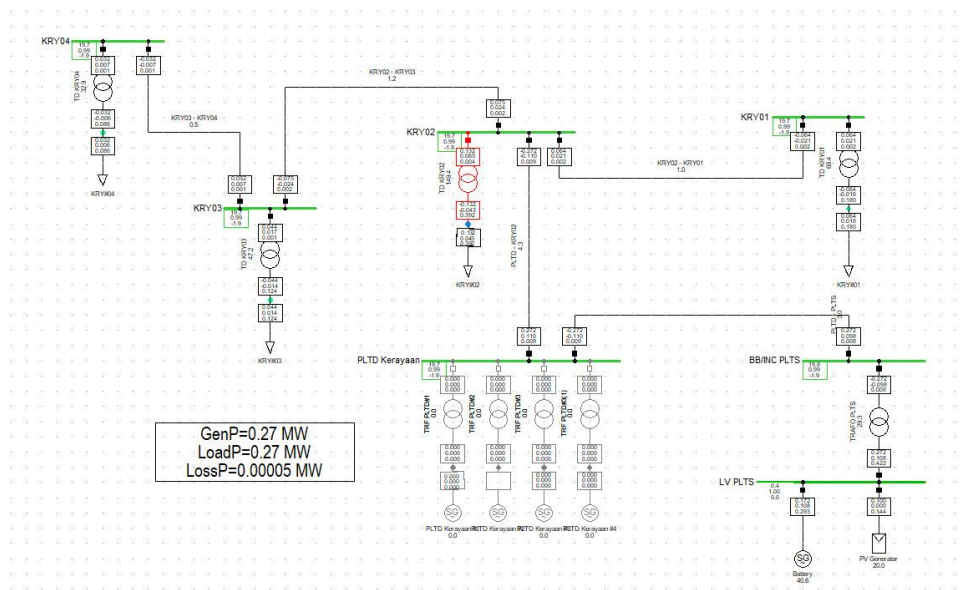


Figure 10 Grid losses -Simulation results from Digsilent Power Factory

The simulation results indicate that power losses in the network amount to 0.00005 MW (50 W). These values are categorized as minimal, falling within acceptable ranges for well-optimized power systems. The low scale of these losses highlights the potential for further enhancements in system operations, particularly through distributed generation and advanced grid management strategies, to achieve near-lossless performance.

4.6.2 Adequacy

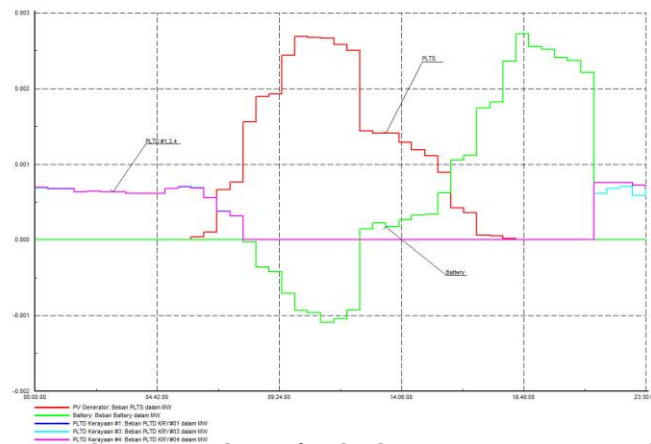


Figure 11 Adequacy Analysis of Hybrid Energy System Power Flow

The simulation results demonstrate that the hybrid energy system can reliably provide a 24-hour power supply for Kerayaan Island. The integration of the solar power plant (PLTS) with the existing diesel power plant (PLTD) has extended the duration of the power supply from the initial 12 hours to a full 24 hours. This hybrid system proves to be an effective solution for addressing the energy needs of isolated areas while improving operational efficiency. Moreover, the adoption of solar energy reduces reliance on fossil fuels, thereby lowering both operational costs and environmental impacts. This approach aligns with sustainable energy development goals and significantly enhances the quality of life for residents in remote regions.

5 Conclusion

The hybrid solar power and battery system achieved significant fuel savings of 734.56 liters, reducing diesel generator operating hours and cutting fuel consumption by 79.11%. The system also effectively reduced greenhouse gas emissions, demonstrating environmental benefits. Financial analysis confirms the project's feasibility. The performance ratio of the solar power system (PLTS) was calculated at 0.794, while power losses in the network were determined to be minimal at 0.00005 MW. These results validate the hybrid system's efficiency, reliability, and suitability for addressing energy demands sustainably.

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