

Enhancing Power Distribution Efficiency in Central Kalimantan through Renewable Energy Integration and Grid Optimization

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Abstract — In areas with uneven development, many residents live far from the city center. The medium-voltage grid in Kuala Jelai, Sukamara Regency, Central Kalimantan, operates as an isolated system, resulting in poor voltage quality and high distribution losses. Annual fuel and lubricant costs exceed IDR 8 billion, with maintenance reaching IDR 2 billion. Despite this, the area has significant untapped solar energy potential. This study evaluates the impact of solar energy integration on reducing distribution losses and identifies the most cost-effective distribution options to support the government's de-dieselization program. Time domain and load flow analyses are used to assess system reliability and measure hourly energy losses across diesel, solar, and hybrid scenarios. Results show that distribution losses in the combined solar-grid network are estimated at 7.21% per month, compared to 9.05% in the diesel system. With an average electricity tariff of Rp959/kWh, the integrated system is projected to generate 1,976,832 kWh annually valued at approximately Rp1.89 billion and save about Rp34.9 million per year through a 1.84% reduction in losses.

Keywords: distribution loss reduction, grid optimization, load flow analysis, power distribution efficiency, renewable energy integration.



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INTRODUCTION

Electricity is a fundamental necessity for modern society, supporting a wide range of activities from household needs to industrial scale. Access to reliable and efficient electricity is a key indicator of regional development. In 2020, Indonesia's national electricity consumption reached approximately 1,084 kWh per capita, reflecting a 4.3% increase compared to the previous year [1]. As reported by PT PLN (Persero), the average rate of distribution power loss

in Indonesia reaches 8.57%, with higher figures generally occurring in remote and isolated regions outside Java due to suboptimal network conditions [2]. Along with economic and population growth, the demand for electricity in Indonesia continues to increase. However, ensuring a stable electricity supply remains a key challenge in several regions, particularly in isolated or remote areas. Distribution networks often face technical obstacles such as extensive transmission distances, challenging geographical conditions, and the use of outdated infrastructure. These conditions lead to high distribution loss, often exceeding 10%, which pose a significant barrier in electrification efforts across the archipelago [3]. In 2020, Indonesia recorded an increase in electricity generator capacity by 8.8% compared to the previous year, reaching a total capacity of approximately 70 GW. While this represents a notable growth, challenges in efficiently distributing energy remain significant. In isolated regions such as Central Kalimantan, the increase in generator capacity does not guarantee an improvement in electricity quality due to limitations in existing distribution network infrastructure. Therefore, innovative approaches that better integrate generators and distribution are needed to enhance efficiency and reduce distribution losses to below 10%. Central Kalimantan, with an area of approximately 153,564 km², faces significant challenges in distributing electricity evenly. Many remote areas in this province remain heavily reliant on diesel power plants as their primary electricity source. However, distribution loss in the Kuala Jelai area of Sukamara Regency, Central Kalimantan, is recorded to be higher than average, reaching around 12%, caused by the long distribution network, challenging geographical conditions, and limited infrastructure. Reliance on diesel power plants also exacerbates the situation due to its high operational costs, with fuel and lubricant consumption costs reaching approximately Rp 8,875,655,261 and maintenance operational costs amounting to Rp 2,502,904,077. In addition, the carbon emissions produced have become a substantial environmental issue. Efforts to replace diesel power plants with renewable energy sources such as solar power plants are increasingly considered as a strategic solution to reduce distribution loss and improve the reliability of electricity supply [4]. This study will discuss how the replacement of these plants can be a solution to improve shrinkage in the interconnection area in Central Borneo especially. Research [4] shows that the implementation of smart grids in Indonesia has great potential to increase efficiency in the electricity distribution system and to support broader integration of renewable energy. Although Indonesia has set a target for renewable energy to contribute 17% by 2025, effective energy management in the electricity sector has not been fully implemented. Another study [5] indicates that utilizing new renewable energy as an alternative electricity supply in Sumbawa Regency over the next 25 years holds considerable potential. Based on simulations using HOMER 3.14 software, the solar radiation energy potential reaches 5.59 kWh/day per solar panel, while the average wind speed received by the wind turbines is 5 m/s.

Solar power plants have great potential to become a more environmentally friendly alternative compared to diesel power plants, particularly in remote areas. By integrating solar power plants with the grid through substations, electricity distribution is expected to become more reliable and efficient [6]. This integration can help reduce distribution loss in isolated regions to below 10%, while also lowering operational costs and contributing to the national target of reducing carbon emissions by up to 29% by 2030, in line with Indonesia's commitment under the Paris Agreement [7]. Many types of research are dedicated to increasing the output and efficiency of a solar panel by eliminating factors affecting efficiency [8]. Integrating solar power plant with substation can also simplify energy management in Central Kalimantan. Substations serve as the main connectors in an integrated grid system, allowing the energy generated from the solar power plant to be distributed evenly across various isolated areas. PV configuration to be installed is determined by the area available for on-grid PV installation [9]. This system not only enhances distribution efficiency but also accelerates the electrification of remote regions that were previously difficult to reach [10]. Since the energy yield from PV is not optimal, it is important to transmit the generated energy with as little loss as possible [11].

PV system plays an important function as a medium of absorption of solar energy source. The working parameters of the PV characteristics can be found by modeling the panel specifications [12]. Distribution loss, often a major challenge in electricity networks serving remote areas, can be mitigated through technology-based solutions [13]. With optimized energy management through the integration of solar power plants and substations, distribution loss that previously exceeded 10% is expected to be reduced to below 10%, significantly enhancing operational efficiency. Energy loss on the line is the difference between the electricity released to the grid by the producer, measurable by the meter at its output, and that used, measured by the total meter reading at the input of all consumers [14]. While previous studies have highlighted the strong potential of solar power plants and smart grid systems in improving electricity distribution efficiency in isolated regions and supporting renewable energy integration, practical challenges in implementation, particularly in Central Kalimantan, remain largely unresolved. Many studies, such as those by [4] and [5], focus on theoretical efficiencies and technical simulations, but few discuss the concrete integration of solar power plants, substations, and distribution networks within the unique geographical and infrastructural conditions of Central Kalimantan. The optimal design starts with the analysis of the existing load profile and the capability of the generation system. Then, the optimization procedure is applied by considering the minimum generation cost and the maximum number of customers that can be served [15]. Moreover, there is a lack of comprehensive studies on the technical and economic impacts of replacing diesel with solar power plants in reducing distribution loss in isolated areas [16]. This emphasizes the importance of conducting more in-depth and focused research on the practical application of solar power plant integration with substations, especially in the Central Kalimantan region. This research should include a thorough analysis of the efficiency of electrical energy distribution in the grid, the reduction of carbon emissions generated by the hybrid power generation system, and the social and economic impacts felt by local communities.

This study acknowledges several limitations that may influence the accuracy and scalability of the proposed solar PV system. Weather variability, particularly in regions with inconsistent cloud cover or seasonal monsoons such as parts of Central Kalimantan. Infrastructure readiness remains a challenge, as many remote or rural areas lack the grid infrastructure or maintenance networks necessary for seamless deployment and long-term operation [17]. System integration risks especially when combining solar with existing diesel or grid networks include synchronization issues, voltage fluctuations, and control system incompatibilities. Thus, this research aims to present a practical integration model of various types of generators, including solar power plants, to overcome the problem of power losses in isolated power grids located far from urban centers. This integration is expected to improve the reliability of electricity supply, optimize the utilization of renewable energy sources, as well as support sustainable development that provides direct benefits to the communities around the research site.

METHOD

A research flow chart is necessary to ensure that all stages of the research can be carried out in a systematic and well-organized manner. This diagram serves as a clear and easy-to-understand visual representation of the research process, where each step and procedure that must be carried out is described in detail and coherently. In the flow chart, the workflow is described using box symbols that represent various activities or decisions, as well as connecting lines or arrows that indicate the direction and order of implementation of each step. With a research flow chart, researchers can carry out the research process in stages, following each stage coherently without skipping any important parts.

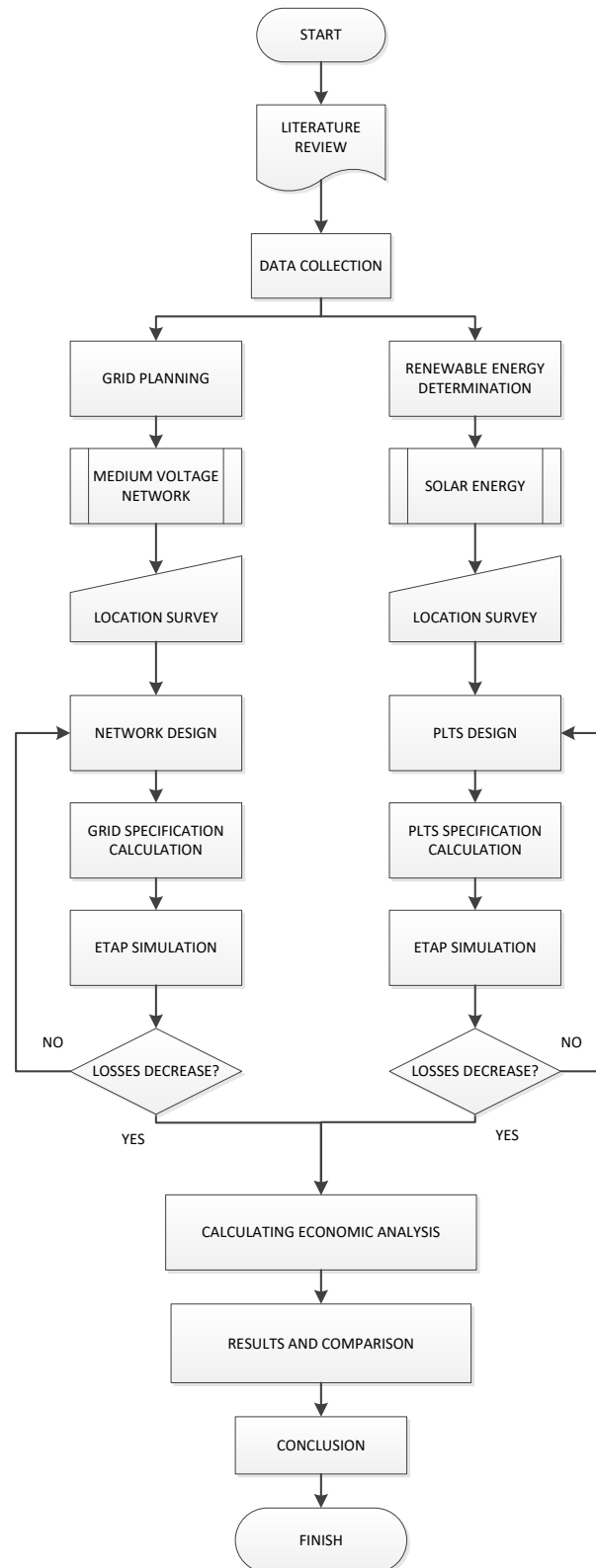


Figure 1. Methodological Flowchart

As shown in Figure 1 the design of the energy system follows three main approaches: grid development design, solar power plant design, and a hybrid solar power plant on-grid design, which are then compared with the existing condition using diesel power plant. Each approach begins with a literature review and data collection, followed by a site survey to gather specific information, such as the distribution network layout for the grid, and solar irradiation levels for

the solar power plant. For the hybrid design, distribution system optimization is carried out in isolated areas of Central Kalimantan using the potential of renewable energy and grid system to reduce distribution loss. The next steps are specification calculation, system design, and economic analysis. Technical simulations using tools such as ETAP are carried out to ensure voltage profiles and energy potential, with additional evaluation of voltage drop for system optimization. This process concludes with a discussion of the findings and conclusions, integrating technical and economic analyses to help determine the most optimal energy solution.

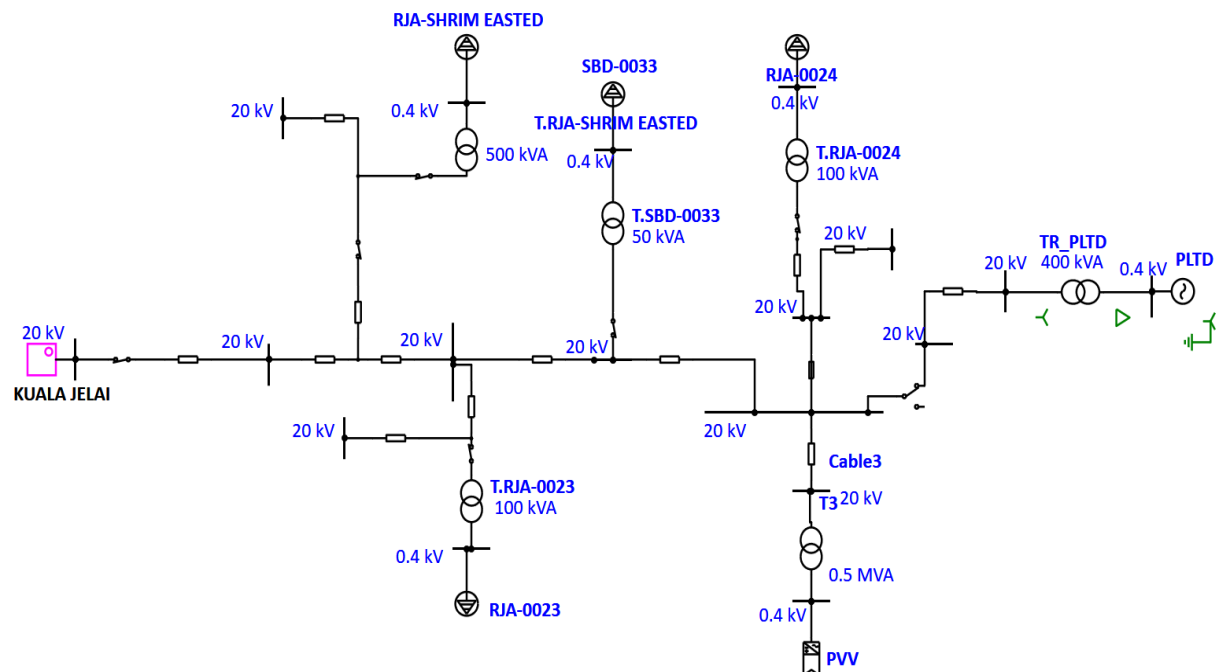


Figure 2. Single Line Diagram of ULD Kuala Jelai

Several key parameters used in this research to determine the most optimal and efficient simulation results include System Base Load, System Peak Load, Energy Generated, Reduction in Distribution Loss Percentage, and Economic Analysis. The five parameters can be analyzed using Time Domain and Load Flow analysis using Newton-Raphson methodologies. These methods vary load and generation levels within the power system and calculate steady-state power flow conditions over time. The purpose is to understand how the system responds to changes in inputs or operating conditions. For example, they can be used to analyze fluctuations in voltage or current following disturbances in the electrical network. Time domain analysis is essential in understanding system behavior under unstable conditions, such as short circuits or sudden load changes. Meanwhile, load flow analysis is a numerical method used to determine the steady-state conditions of an electrical power system. This method calculates voltage, current, power, and power factor at various points throughout the network. Figure 2 shows the load flow analysis assists in system planning, ensuring stability, and determining equipment capacity. For instance, it calculates power flows in transmission lines or the voltage level at a bus within a substation. This analysis is essential in designing reliable systems, ensuring stability, and determining equipment capacity. The load profile is shown in figure 3.

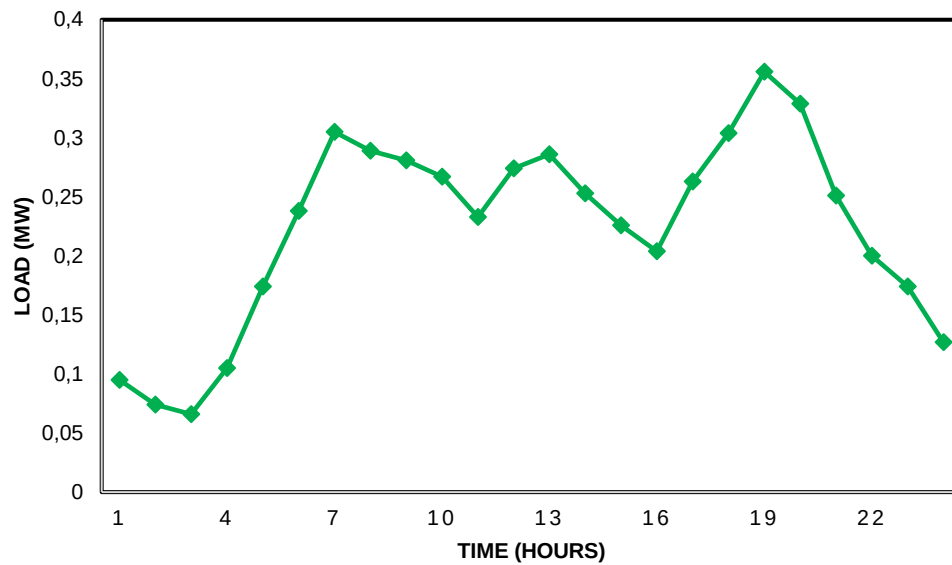


Figure 3. Load Profile of Kuala Jelai

The methodology in this research consists of the following steps. First data collection of renewable energy potential (solar irradiation), technical data of the existing distribution network, electricity demand in Kuala Jelai as shown in Figure 3, and economic data such as investment, operational, and maintenance costs. The power distribution system is designed by deactivating the diesel power plant and replacing it with a solar power plant as the primary energy source. The substation grid is integrated to stabilize energy supply. The solar power plant design is based on optimal capacity obtained from solar irradiation data. The design includes calculations for inverter capacity, solar panels, battery storage, and control systems to ensure overall system efficiency and reliability. Technical parameters such as energy efficiency, system component capacity, and load energy requirements are calculated to support the overall system design. Simulations are conducted by modeling the solar power plant as the main energy source and the substation grid serving as a backup to ensure system stability. ETAP software tools are used to evaluate the performance of the proposed model, including energy savings, and reduction in distribution losses. The diesel power plant is excluded from the simulation to reflect a full renewable energy transition scenario. Simulation results are analyzed to assess the technical and economic feasibility of the proposed system. Evaluation includes comparisons of key parameters such as operational costs, and distribution loss. Conclusions are drawn to recommend the most optimal and efficient implementation strategy.

A. Solar Power Plant Scheme

In this solar power plant scheme, electricity supply from the diesel power plant is replaced by solar energy. Necessary data input includes solar radiation, base load, and peak load. In this study, the formulas used to calculate the electrical energy generated from solar power are presented in equations (1), (2), and (3). Equation (1) calculates the power output of the solar power plant, Equation (2) calculates the amount of electrical power generated, and Equation (3) estimates the total electrical energy that can be generated.

$$P_{PV} = f_{PV} \times Y_{PV} \times \frac{G}{G_{STC}} \quad (1)$$

$$P_{electric} = \eta_{system} \times P_{PV} \quad (2)$$

$$E_{electric} = P_{electric} \times t \quad (3)$$

Where PPV represents the power output (kW) generated from solar energy, fPV is the derating factor (%), YPV is the maximum output power (kWp) of the solar power plant under standard test conditions, G is the solar irradiance at a given time (W/m^2), and GSTC refers to solar irradiance under standard test conditions (1000 W/m^2) [18]. Pelectric is the electrical energy generated (kW), η_{system} is the system efficiency (%), Eelectric is the electrical energy generated (kWh), and it represents time (h). HOMER software is used in this study to design and calculate the energy generated by solar power, providing a prediction on the electrical energy output based on equipment with specific technical specifications.

B. Grid System and Renewable Energy Integration

A grid system, or electrical power grid, is an infrastructure network that connects power generators, transmission lines, distribution networks, and energy consumers. This system enables efficient distribution of energy from generators to end users [19]. The main components of a grid system include, Power Generator, Transmission Lines, Substations, and Distribution Lines.

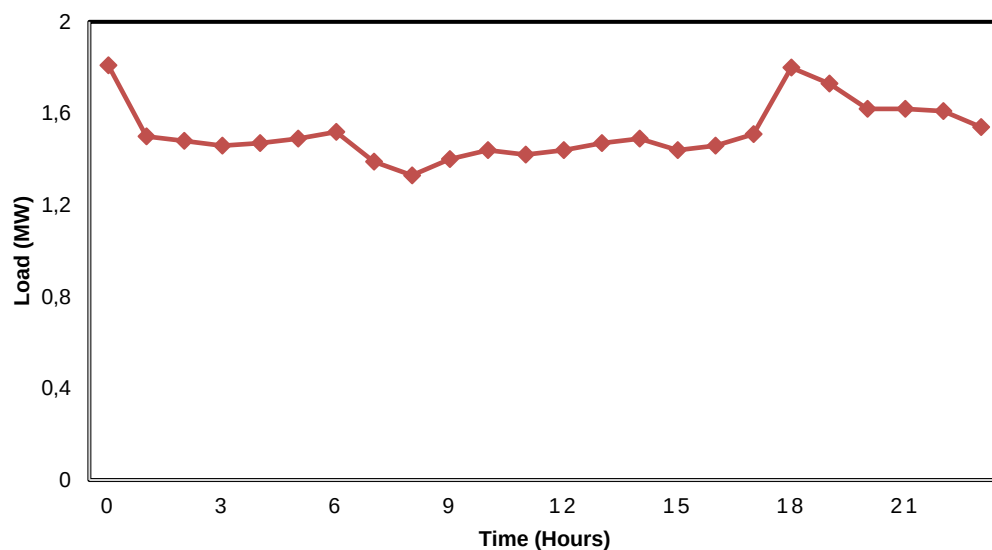


Figure 4. Load Profile of SKM04 Coastal Route – Kuala Jelai

Integrating renewable energy into the grid aims to improve distribution efficiency, reduce reliance on conventional energy sources, and minimize distribution losses. Figure 4 shows the load profile for Coastal Route – Kuala Jelai that will be analyze. Then, key strategies for renewable energy integration include Solar Power, Smart Grid Technology, Energy Storage Systems, and Reduction of Distribution Loss. A hybrid system is a system that integrates renewable energy sources, such as solar and wind power, with conventional grid systems to provide a more stable and efficient electricity supply. This system allows renewable energy to compensate and supply power when conventional generators cannot meet demand or experience disruptions. Key advantages of hybrid systems include improved energy reliability, reduced operational costs, and lower carbon emissions, all contributing to environmental sustainability. In remote areas like Central Kalimantan, hybrid systems are particularly beneficial as they reduce reliance on non-renewable sources such as fossil fuel-based power plants and utilize locally available renewable resources such as solar panels.

C. Distribution Loss

Distribution loss refers to the power lost during transmission from power generator centers through transmission and distribution lines to end users. This loss primarily results from

resistive impedances in cables and distribution equipment, which generate heat and dissipate energy. Distribution loss also occurs due to changes in voltage and current as electricity flows through the distribution system. Distribution loss is classified into two types: technical loss and commercial (non-technical) loss. Technical loss occurs due to conductor resistance and inductive effects within the distribution network while commercial loss involves unauthorized electricity consumption or revenue loss caused by metering errors [19]. This leads to economic loss for electricity providers due to reduced revenue, lower system efficiency, and increased energy production costs. Efforts to reduce distribution loss include using high-quality cables and distribution equipment to minimize resistance and technical loss, as well as implementing technologies that improve distribution efficiency, such as efficient transformers and smart grid monitoring systems.

$$P_{loss} = I^2 \times R \quad (4)$$

Where,

P_{loss} : Power loss (Watt)
 I : Electric current (A)
 R : Resistance (Ohm)

R (Ohm) is the conductor resistance within the distribution system and I (Ampere) represents the load current flowing through the system including key components of the formula (4). Conductor resistance (R) is the root cause of technical losses in the system. Factors such as the type, length, and cross-sectional area of the conductor all affect the magnitude of this resistance.

$$R = \rho \frac{L}{A} \quad (5)$$

Where,

ρ : Resistivity
 L : Conductor length
 A : Cross sectional area

From equation (5), power loss can be calculated using the formula.

$$P_{loss} = P_{in} - P_{out} \quad (6)$$

Based on the power loss formula (6), loss percentage can be calculated as follows:

$$Loss \% = \frac{P_{out} - P_{in}}{P_{out}} \times 100 \% \quad (7)$$

Where,

P_{in} : Input input to the distribution system (power received by consumers)
 P_{out} : Output power to the distribution system (power generated by the system)

Where P_{out} is the energy produced by the system (kW) and P_{in} is the energy received by end users (kW). To reduce distribution loss, P_{out} should be minimized to be as close as possible or equal to P_{in} . One way to achieve this is by improving the system voltage and shortening the length of the distribution line, thereby bringing the energy source closer to the load center.

$$P_{loss} = \min (P_{out}, L) \quad (8)$$

Where P_{out} and L are interrelated; thus, a reduction in L leads to a corresponding decrease in P_{out} thereby minimizing energy loss during the distribution process.

D. Net Present Cost (NPC)

Net Present Cost (NPC) is the current value of all costs associated with a project, investment, or system over its lifetime. It is a financial metric to compare the total cost of various alternatives and to select the option with the lowest life cycle cost. NPC focuses on cash outflows (costs) and aims to minimize the overall cost, calculated using the following equation:

$$NPC = \sum_{t=1}^t \frac{C_t}{(1-r)^t} - C_0 \quad (9)$$

Where,

C_t : Annual cash flow in t period

C_0 : Investment value at year 0 (IDR)

r : Interest rate (%)

E. Operational Cost

Operational cost refers to the total annual cost required to operate the system, consisting of Operation and Maintenance costs (O&M Cost, IDR/year) and Fuel Costs (Fuel Cost, IDR/year). It can be calculated using the following equation:

$$\text{Operating Cost} = \text{O\&M Cost} + \text{Fuel Cost} \quad (10)$$

RESULT AND DISCUSSION

A. Simulation Result

The medium voltage distribution system in the Kuala Jelai area of Sukamara, Central Kalimantan Province currently gets its electricity supply mainly from a diesel power plant located about 5 kilometers from the load center or the center of electricity consumers. However, to support efforts to reduce dependence on fossil fuels and increase the use of renewable energy, a solar power plant (PLTS) is currently planned in the area. The planned solar farm can be seen more clearly in Figure 5, which illustrates the layout and location of the solar farm system. In addition, the daily energy production profile of the proposed system has also been compiled and displayed in Figure 6, which shows the estimated electrical energy output of the solar power plant at each hour during its operational period. With this solar plant, it is expected that the electricity supply will be more stable, efficient, and environmentally friendly, especially during peak energy usage hours during the day. Community perceptions of solar PV installations are generally positive, especially in remote areas where electricity access was previously limited or unreliable. Residents often express appreciation for the improved quality of life brought by stable lighting, cooling, and the ability to power communication devices and small businesses. Solar projects have also created local employment opportunities during the construction, installation, and maintenance phases, which often involve training programs that enhance the skills of local youth and technicians. Socio-economic impacts include increased productivity, longer operating hours for small businesses, and reduced household energy costs by replacing diesel generators. In addition, community-based solar projects tend to foster a stronger sense of ownership and sustainability, as local cooperatives or village institutions are often involved in the management and supervision of the system.



Figure 5. Voltage Source Location Map

In Central Kalimantan, practical implementation of solar PV systems has proven particularly suitable due to the region's vast land availability, high solar irradiation levels averaging above 4.9 kWh/m²/day, and the scattered, off-grid nature of many rural communities. Unique geographical characteristics, such as limited grid connectivity and dense forested terrain, make traditional transmission line expansion costly and impractical creating a strong case for decentralized solar energy.

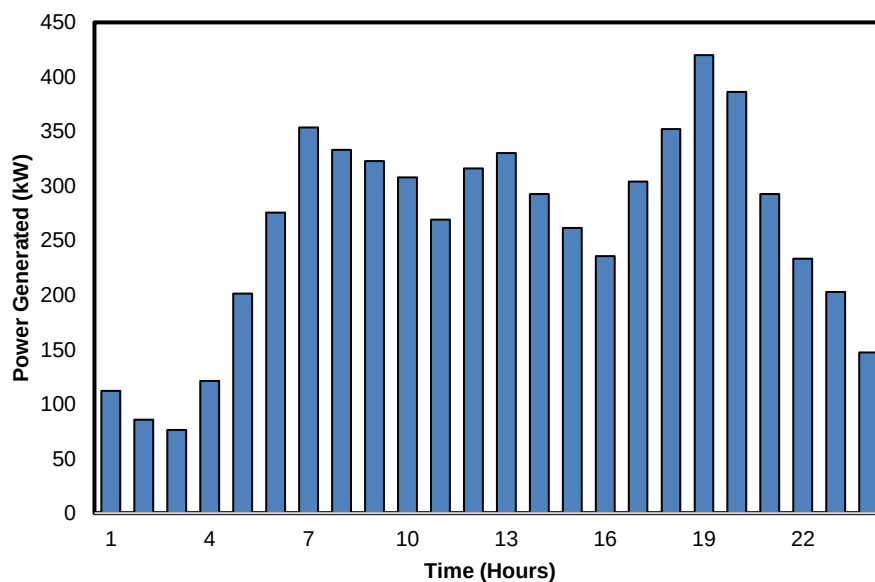


Figure 6. Energy Generated by Diesel Power Plant

On average, the diesel power plant generates approximately 5,556 kW of energy per day over a 24-hour period, with average daily fuel consumption of 2,909 liters or approximately IDR 19,781,200 per day. The Kuala Jelai area in Sukamara Regency, Central Kalimantan, is a coastal and sparsely populated region with 1,512 residential electricity customers. The abundance of available land offers significant potential for developing medium to large-scale solar power plants. Compared to diesel power plants, solar power plant installations provide

the advantage of quiet operation, allowing them to be located closer to load centers. The specifications for solar power plant requirements are shown in Table 1. Hourly power and energy profiles for this study are based on simulation data obtained from globalsolaratlas.info as illustrated in figure 6. Solar energy output is directly influenced by the availability of sunlight; consequently, solar power generation is intermittent and subject to local weather conditions.

Table 1. Solar Power Plant Specifications

Information	Value and Unit
Power Plant Capacity	500 kWp
Capacity Per Unit	500 Wp
Number of Units	1000
Inverter Capacity	500 kW (AC)
Inverter Capacity Per Unit	100 kW (AC)
Number of Inverters	5

Figure 7 indicates that the solar power plant is capable of generating power output ranging from 2.8 kW to 302.9 kW. Solar power plant can only supply electricity between 06:00 and 18:00, with generation levels determined by the intensity of solar irradiation at the site.

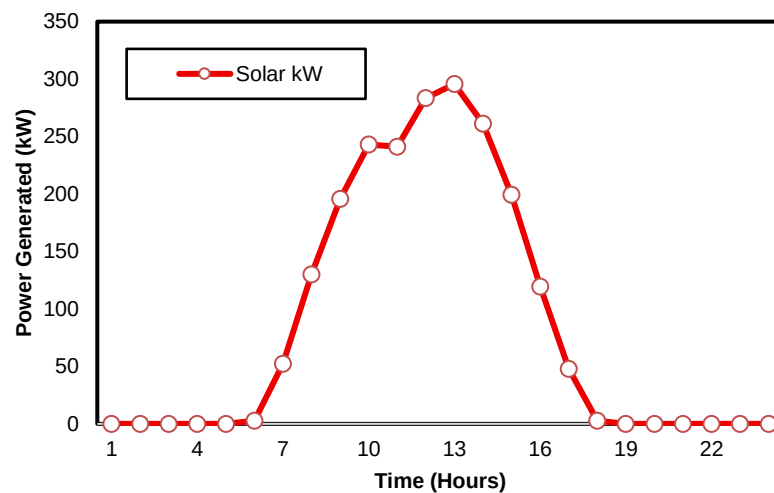


Figure 7. Energy Generated by Planned Kuala Jelai Solar Power Plant

As illustrated in Figure 8, between 10:00 and 13:00, the energy output from the solar power plant closely aligns with that of the diesel power plant, making this period optimal for solar energy utilization. To address the intermittency of solar power and reduce emissions from diesel generation as part of the de-dieselization program, integration with the main grid, supplied from the substation, is essential [20]. However, the development of a Medium-Voltage Network to extend grid access to remote areas requires significant investment. Figure 9 demonstrates that the Main Substation can provide a greater energy supply than either the diesel or solar power plant, and it offers enhanced energy security due to its capacity for 24-hour operation. The projected power curve for the medium-voltage grid is illustrated in Figure 10. This figure illustrates the respective power curves for each energy source as well as the system load. The curves indicate that solar power plant is capable of supplying the system, particularly between 10:00 and 13:00, although its output tends to fluctuate. Meanwhile, diesel power generation can be substituted by the grid system to support the de-dieselization program. During peak load periods, from 18:00 to 22:00, the grid plays a critical role in meeting electricity demand. Grid supply is reduced as renewable energy input starts to increase and is minimized when renewable energy sources operate at maximum capacity [21].

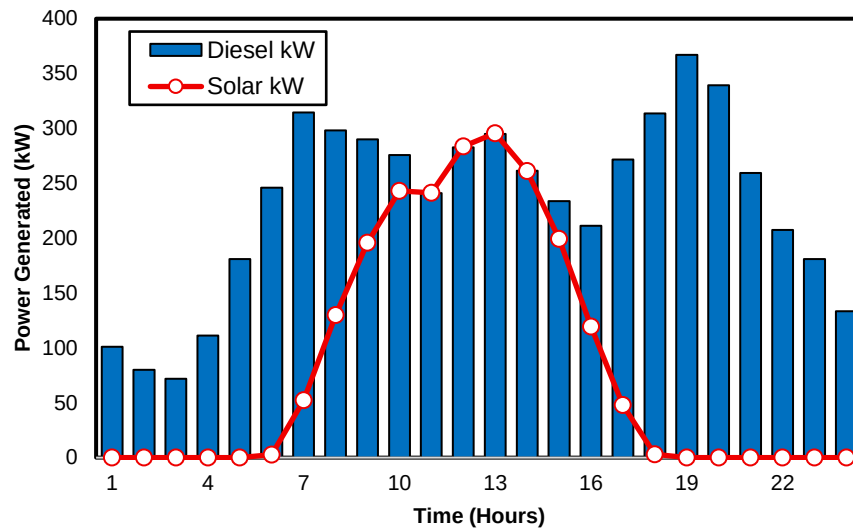


Figure 8. Energy Generated by Diesel vs Solar Power Plant

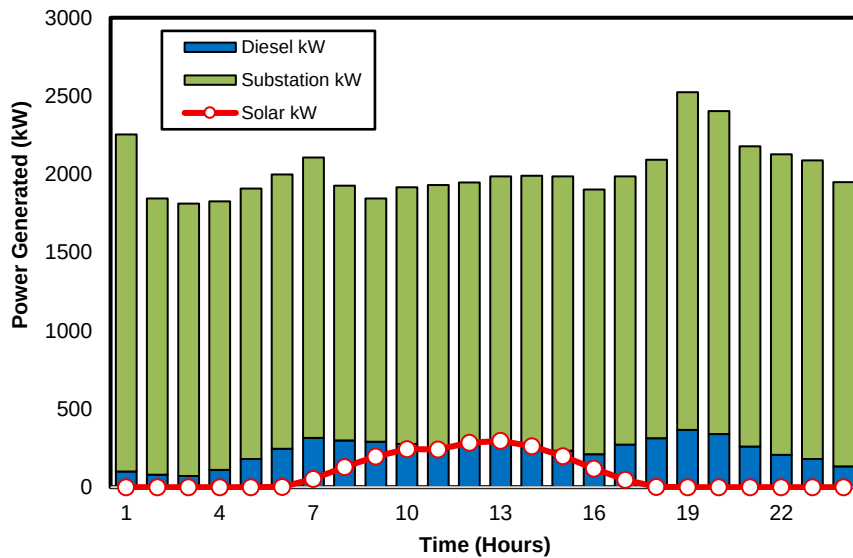


Figure 9. Energy Generated by the Substation, Diesel, and Solar

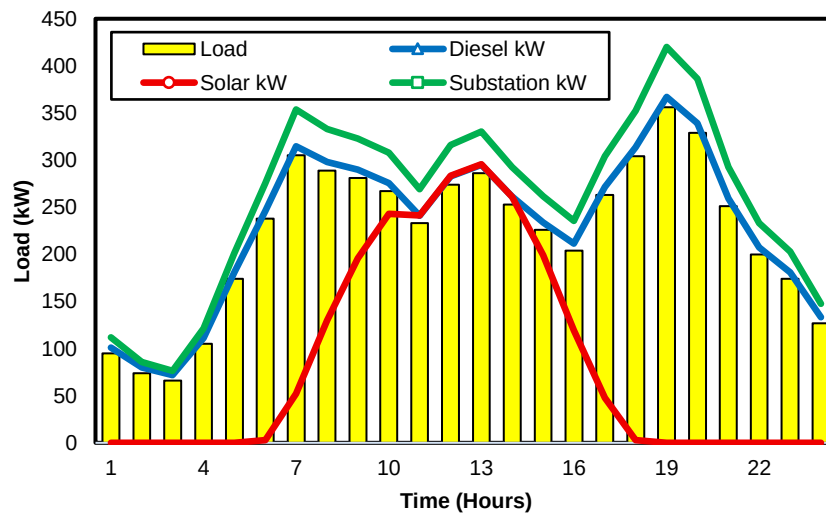


Figure 10. Energy Load Curve and Energi Generated by Diesel, Solar and Substation

Figure 11 presents the energy supply curves from each source, showing that, on a daily basis, solar energy and the grid system can supply 2,075.07 kWh (33.29%) and 4,158.64 kWh (66.71%), respectively. The power curves used in this study were obtained from primary data collected directly on an hourly basis at the study site, covering various important parameters such as solar irradiation, substation capacity, as well as the electrical load occurring on the system. These power curves are instrumental in describing and characterizing the operational conditions and performance of the power generation system under analysis. In addition, the curves also serve as an effective predictive tool to model and understand the general characteristics of renewable energy sources, particularly solar energy, available in the Kuala Jelai region.

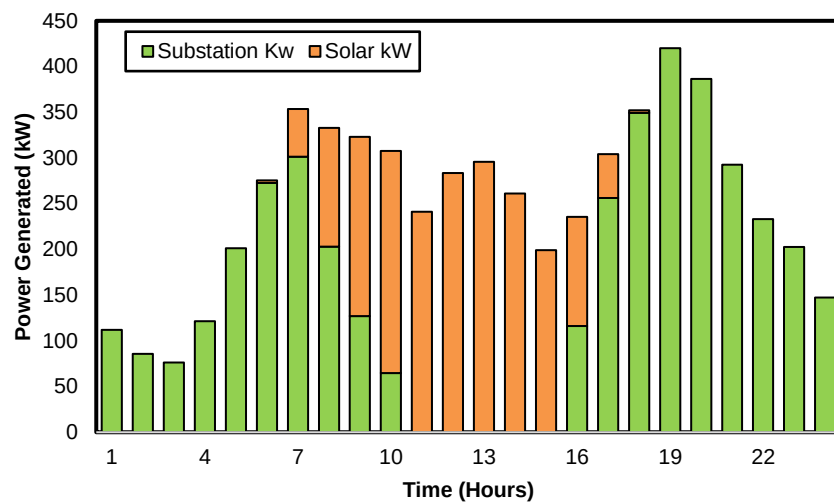


Figure 11. Composition of Energy Source by Substation and Solar Energi

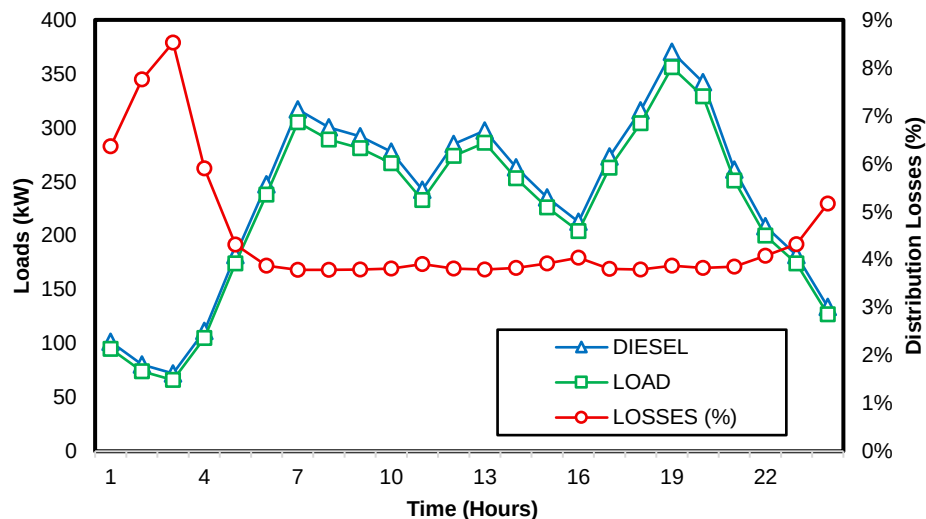


Figure 12. Power Loss Curve of the Diesel Power Plant System

Based on Figure 11, it can be seen that solar energy is able to provide sufficient electricity supply during daytime hours, where the sunlight intensity is at an optimal level. However, the energy output from these solar plants tends to decrease at certain times of the day, such as during cloudy weather conditions or during the late afternoon hours. To overcome these fluctuations and ensure continuity of electricity supply, the system is designed to be complementary to the electricity supply from the main grid, so that when the solar energy

output decreases, the electricity load needs can still be met stably through the electricity supply from the grid. Results from the Time Domain and Load Flow analysis indicate that the daily generated power is 5,604.5 kWh, with system energy losses amounting to 250.5 kWh or 4.5%, as presented in Figure 12. In the PV-Grid system, daily generated power reaches 6,107.7 kWh, with system energy losses of 733.16 kWh or 12.10%, as shown in Figure 13. This higher loss in the PV-Grid system is attributed to the substation being situated at a considerable distance from the Kuala Jelai load center, significantly impacting system losses. However, when focusing specifically on the solar power plant system, particularly between 10:00 and 13:00, energy losses are 35.54 kWh out of 261.5 kWh generated, or approximately 3.29%.

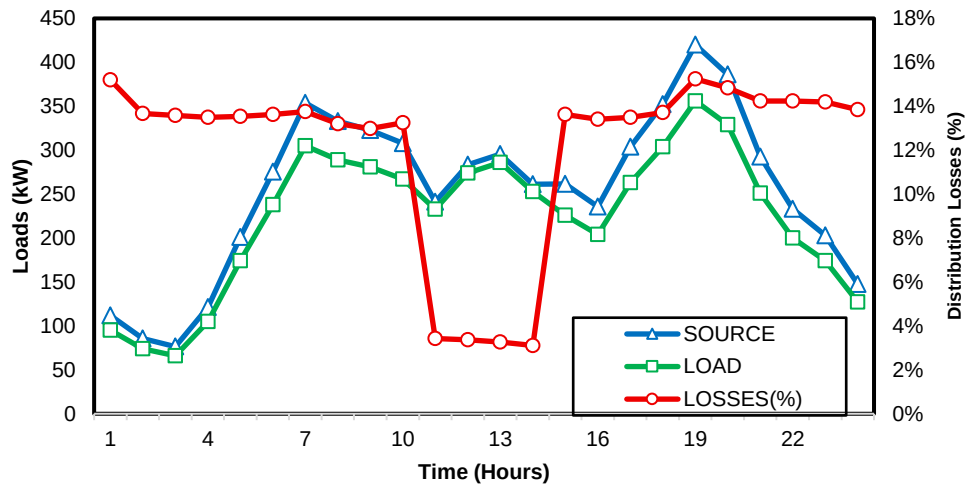


Figure 13. Power Loss Curve of the PV – Grid System

Table 2. System Comparison with Static Load

STUDY ID	SUB STATION	SUBSTAION-SOLAR POWER	DIESEL POWER
Data Revision	Base	Base	Base
Configuration	Normal	Normal	Normal
Diversity Factor	Normal Loading	Normal Loading	Normal Loading
Load (MW)	1.11	1.11	0.29
Generation (MW)	1.24	1.20	0.32
Loss (MW)	0.13	0.09	0.03
LF	0.80	0.80	0.80
LLF	0.69	0.69	0.69
Time (Hours)	720	720	720
Load (kWh)	637.63	638.20	164.73
Loss (kWh)	65.38	46.01	14.91
Loss (%)	10.25%	7.21%	9.05%

Analysis of load calculations using static methods in network simulations enabled a comparison of the three network configurations, as laid out in Table 2. The results indicate that network losses are lowest for the integrated solar power plant – grid network, at 7,21% or equivalent to 46.019 kWh out of of 638.208 kWh monthly. This compares favourably with the diesel power plant network which shows losses of 9,05% or equivalent to 14.910 kWh out of 164.736 kWh monthly. Given an average electricity tariff of IDR 959 per kWh in the Sukamara region, the financial loss due to distribution losses amounts to IDR 44,132,221 per month for

the solar power plant – grid network and IDR 14,298,690 per month for the diesel power plant network. The total annual energy generated by the integrated system is estimated at 1,976,832 kWh, valued at approximately IDR 1,895,781,888. With a reduction in distribution losses of 1.84%, the annual cost savings are estimated at IDR 34,882,386. Assume the NPC calculation of the 500 kWp solar power plant and 500 kWp diesel generator in the table 3.

Table 3. Net Present Cost (NPC) comparison between solar plant and diesel

Cost Component	500 kWp Solar PV	500 kW Diesel Generator
Initial Investment (CAPEX)	IDR 10,000,000,000	IDR 0 (existing asset)
Fuel Cost / Year	IDR 0	IDR 8,800,000,000
O&M Cost / Year	IDR 100,000,000	IDR 2,500,000,000
Inverter / Engine (Discounted)	IDR 837,600,000	Included in O&M
NPC of Fuel + O&M (20 yrs)	~IDR 1,100,000,000 (Present Value)	~IDR 129,611,000,000 (Present Value)
Total NPC (20 years)	IDR 11,637,600,000	IDR 129,611,000,000

This comparison clearly shows that although a 500 kWp solar PV system requires a high initial investment of IDR 10 billion, its long-term operating costs are much lower compared to a 500 kW diesel generator. Over a 20-year period, the solar farm incurs a total Net Present Cost (NPC) of approximately IDR 11.64 billion, including inverter replacement and discounted O&M costs. In contrast, the diesel generator, despite having no initial capital cost (existing assets), generates an NPC of approximately IDR 129.61 billion due to continuous high fuel and maintenance costs. This shows that adopting solar power can generate potential cost savings over two decades, while offering additional environmental benefits. The 500 kW diesel generator produces 2,587,360 kWh annually, and the fuel consumption is 0.28 liters per kWh, the total annual diesel usage is 724,460.8 liters/year. Using the IPCC standard emission factor of 2.68 kg CO₂ per liter of diesel, the annual carbon emission is the annual diesel usage multiplied by 2.68 kg CO₂ is 1.942 tons CO₂/year. Since the solar PV system produces no carbon emissions during operation, switching from diesel to diesel will eliminate these emissions. Over a 20-year period, the total carbon reduction is 1,942 tons CO₂ times 20 years which is 38,840 tons CO₂.

CONCLUSION

This study concludes that the isolated region of Kuala Jelai in Sukamara Regency, Central Kalimantan, has strong potential for solar energy due to its vast undeveloped land and abundant sunlight. Simulations show that solar power can generate around 2,075.07 kWh per day, or 62,250 kWh per month. This supplements the existing grid supply of 4,158.64 kWh daily and the diesel plant's 5,556 kWh, which incurs high fuel costs averaging IDR 19.78 million per day. Integrating solar with the grid reduces distribution losses to 7.21%, compared to 9.05% in the diesel-only system. The combined system generates 1,976,832 kWh annually, valued at IDR 1.89 billion, and saves IDR 34.88 million per year by cutting losses by 1.84%.

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