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Implementation of Solar Power Plant as a Backup Power Source in Apartment Buildings

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Abstract—Indonesia has an average solar energy potential of 4.8 kWh/m²/day with a monthly variation of around 9%, providing opportunities for renewable energy utilization through Solar Power Plants to reduce dependence on fossil fuels and lower carbon emissions. This study is applied to The Lana Apartment, projected to have high electricity consumption. The main supply comes from PLN with a capacity of 2000 kVA, while backup power is provided by a generator with a capacity of 1250 kVA. To reduce reliance on the generator, this study aims to design and analyze Solar Power Plants as an environmentally friendly backup power system for the apartment. The Solar Power Plants design was created using HOMER software to model energy production potential, calculate power requirements, and evaluate system performance using the performance ratio. Simulation results show that the designed Solar Power Plants have a capacity of 2997.28 kWp, an inverter capacity of 3500 kW, and a battery capacity of 50160 Ah. This system can generate approximately 4,165,251.97 kWh per year with a performance ratio of 79.32%, indicating good operational efficiency in line with optimal Solar Power Plants standards. The implementation of these Solar Power Plants is expected to provide a more environmentally friendly backup power alternative and potentially reduce operational electricity costs in the apartment building.

Keywords: Backup Power System, HOMER Software, Renewable Energy, Solar Power Plant, Performance Ratio.

INTRODUCTION

Indonesia has substantial potential for solar energy development, with daily irradiation averaging between 4.5 and 4.8 kWh/m². This abundant solar resource positions solar power as one of the most promising renewable energy sources in the country. Supporting this potential, studies highlight the importance of Solar Power Plants (SPP) to reduce dependency on electricity from the national grid in areas such as Ecopark Ancol, where solar power can effectively supplement conventional power sources [1]. Analysis suggests that Indonesia has

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the capacity to meet its future energy needs through the strategic development of solar energy infrastructure. There are extensive opportunities to install solar power systems on rooftops, reservoirs, and across vast agricultural lands, maximizing space for energy production. According to estimates, Indonesia's electricity demand could reach up to 9000 Tera-Watt-hours per year by 2050, nearly 30 times the current consumption. The development of solar infrastructure would be critical to meeting this anticipated demand [2]. In regions prone to power interruptions, Solar Power Plants are increasingly valued as reliable backup power sources. For instance, PT. Sumedang Televisi Utama has implemented SPP to address frequent disruptions in PLN's electricity supply. Studies underscore the role of SPP in improving energy reliability and resilience in such areas, highlighting its potential for stabilizing power access in communities [3]. Photovoltaic systems in Indonesia hold great promise in reducing carbon emissions. With a target installed photovoltaic capacity of 985.5 MW by 2028, Indonesia aims to significantly contribute to carbon dioxide reduction efforts, with potential annual emissions reductions reaching 1.341 million tons. This target underscores the environmental benefits of scaling up solar energy infrastructure in the country [4]. A GIS-based spatial mapping study in West Kalimantan identified 34% of the region as suitable for SPP development, factoring in the presence of conservation zones. Despite the high irradiation levels throughout the region, site selection remains crucial due to environmental preservation considerations. The optimized development of SPP in suitable locations aligns with Indonesia's renewable energy targets and supports sustainable growth [5]. They [6] discuss that renewable energy sources, including solar, wind, geothermal, and ocean currents, are abundant and naturally replenished, thanks to the continuous cycles in nature. Unlike fossil fuels, which are finite and diminish over time, renewable resources regenerate through natural processes, allowing them to be harnessed sustainably without the risk of depletion. This characteristic enables renewable energy to serve as a stable and environmentally friendly alternative for long-term energy generation, as it reduces reliance on finite resources and minimizes environmental impact [7]. [8] emphasize that renewable resources such as sunlight, wind, and biomass are naturally replenished, meaning their use does not exhaust these resources. Their renewability allows for a sustainable approach to energy production, as these sources can continuously support human energy needs without degradation. This self-replenishing quality positions renewables as a key solution to meet increasing energy demands worldwide while preserving environmental balance. By reducing reliance on non-renewable sources, renewable energy promotes both ecological and economic stability, creating a foundation for a sustainable energy future [9] further highlights that renewable energy sources like solar and wind power are nearly inexhaustible in the foreseeable future, enabling intergenerational use without fear of scarcity. The renewability of these resources stands in contrast to the finite nature of fossil fuels, which require millions of years to form and are consumed at much faster rates. Thus, renewable energy sources are not only abundant but are essential for supporting a sustainable, low-carbon economy. As a result, the utilization of renewable sources provides a long-term, resilient foundation for global energy needs [10]. A Solar Power Plant operates by harnessing sunlight through photovoltaic cells, which convert solar photon irradiation into electrical energy. The performance of a SPP is influenced by various factors, including environmental conditions, photovoltaic module temperature, weather patterns, and solar light intensity, each playing a critical role in determining overall efficiency and system longevity [11]. Environmental challenges such as extreme temperatures, high ultraviolet exposure, and dust

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accumulation are particularly significant in regions with desert-like climates. In these areas, such conditions can accelerate the degradation of photovoltaic modules, leading to issues like delamination, discoloration, and hot-spot formation. These degradative effects ultimately reduce power output and affect the long-term viability of solar installations [12]. The operation of photovoltaic (PV) modules relies on their capacity to absorb sunlight and convert it into electricity, making them one of the most promising sources of renewable energy. In ideal conditions when sunlight intensity is high and light directly strikes the photovoltaic surface each square meter of photovoltaic material can generate approximately 900 to 1000 watts of electricity. This high efficiency is achieved as the photovoltaic cells, composed of thin silicon layers and other semiconductor materials, absorb photons, which then excite electron movement and generate an electric current [13]. Research has shown that further optimization can be achieved by carefully arranging photovoltaic cells and selecting specialized material coatings. Such improvements can boost efficiency by up to 9% by minimizing thermal and mechanical degradation and enhancing light absorption during peak sunlight hours [14]. One key advantage of SPP is its adaptability, as it generates Direct Current (DC) electricity that can be converted into Alternating Current (AC) through an inverter, making it suitable for a wide range of applications. Even under cloudy conditions, SPP can continue producing electricity with minimal sunlight, ensuring a reliable power supply. However, they are vulnerable to various environmental factors, including shading from dust, bird droppings, and other obstructions. Studies emphasize that proper maintenance, along with the use of protective coatings, is essential to prevent power losses due to these factors, as neglecting such maintenance can lead to significant performance declines over time [15]. The ability of SPP to operate under diverse weather conditions, combined with its potential for efficiency optimization, positions it as a versatile and reliable source of sustainable electricity generation. As a sustainable energy source, SPP represents a crucial investment for countries aiming to reduce their dependence on fossil fuels, decrease greenhouse gas emissions, and meet growing energy demands. Advances in photovoltaic materials, along with ongoing research in module design, temperature regulation, and maintenance techniques, are helping to extend the lifespan and efficiency of photovoltaic systems. Such advancements firmly establish SPP as a foundational technology for clean energy initiatives and reinforce its role in future energy strategies cantered on sustainability and environmental preservation.

METHOD

In this research, the method used was a simulation method. Based on its primary objective, this research is categorized as applied research and was designed using the HOMER computer simulation software. The chosen research location was an apartment building in Tangerang City, Banten. This location was selected due to the building's energy requirements, providing an ideal context for analyzing the performance of a Solar Power Plant as a backup power system. The data collected included information on the building's electricity consumption and requirements, serving as the foundation for modeling the solar power plant system. The Solar Power Plant was modeled using HOMER software, with technical parameters tailored to the apartment's energy profile. The simulation results were then analyzed using the performance ratio method to evaluate the system's efficiency under various conditions. The Solar Power Plant to be designed will serve as an auxiliary energy source for apartment buildings. This backup power source is an alternative energy supply intended to provide electricity in the event of a disruption or blackout from the main power supply, ensuring continuous energy availability for the building. The SPP design will consider several critical aspects, including the geographical location of the building, solar irradiation data, and ambient temperature around the study site. It will also account for the building's electrical consumption, the specific components and quantity of each component required, as well as the configuration

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of these components to support the necessary electrical load. The system design involves selecting components such as solar panels, inverters, and batteries, each chosen based on their capacity to meet the building's energy needs. Additionally, the arrangement of these components will determine which loads within the building can be effectively powered by the SPP, ensuring that essential systems have sufficient backup during an outage. However, aspects such as balancing the three-phase load distributed by the inverter, conductor cable installation, detailed economic calculations, and the protective measures required for SPP operation are beyond the scope of this study. Due to these limitations, these aspects are recommended as areas for future research and analysis, enabling a more comprehensive assessment of SPP integration in large-scale residential buildings.

A. Design and Capacity Calculation for Solar Power Plant as a Backup System

Designing a Solar Power Plant requires comprehensive data on solar irradiation, the building's electrical loads, energy consumption, and the main components of the SPP system. With this data, the number, capacity, and arrangement of essential SPP components can be calculated to meet energy demands effectively. Specifically, the backup power system for the apartment building requires an estimated 32,452.48 kWh of energy per day. To account for potential variations, a compensation tolerance factor of 15% has been applied in the calculations [16]. A key part of the design process is determining the panel generation factor, which is essential to accurately size the photovoltaic system. Solar irradiation levels vary by location, affecting the power that solar panels can generate. In the area surrounding The Lana building, average solar irradiation is approximately 4.8 kWh/m² per day. The panel generation factor or maximum daily sunlight hours required to reach 1000 W/m² of solar energy is about 4.8 hours [17]. This allows for efficient energy conversion under peak sunlight conditions, ensuring that the SPP can reliably generate power to meet backup requirements.

The SPP must generate approximately 7775.07 kWp to match the building's daily energy needs for backup power. However, to align with the existing generator capacity of 3000 kWp in the building, the SPP capacity will be capped at this value. The chosen PV modules for this project are Canadian Solar HiKu7 CS7N-655MS, each with a capacity of 655 Wp, monocrystalline type, and an efficiency of 21.1%. To achieve the necessary capacity, 4580 PV modules will be installed. Ensuring this total capacity requires an understanding of the series and parallel configurations of the PV modules, known as the PV array. For the series configuration, the maximum input voltage for the CAT BDP250 inverter is set at 1000 volts, while the open-circuit voltage for each CS7N-655MS PV module is 45.6 volts [18]. This configuration will maximize the system's output while adhering to technical constraints and safety standards. The panel generation factor or the maximum daily sunlight duration needed to achieve 1000 W/m² in the apartment building area is determined to be 4.8 hours per day. Then, to obtain the power capacity of the Solar Power Plant system for the apartment building, it can be calculated using Equation (1) as follows:

$$P_{PV} = \frac{E_{PV}}{PV_{genfact}} \quad (1)$$

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The energy required to be generated by the Solar Power Plant to match the energy used by the backup power system is 7775.07 kWp. However, the capacity of the SPP to be designed will be matched to the capacity of the generator used by the apartment building, which is 3000 kWp. The PV module selected is the Canadian Solar HiKu7 CS7N-655MS with a capacity of 655 Wp, monocrystalline type, and an efficiency of 21.1%. To determine the number of PV modules based on the desired capacity, Equation (2) will be used as follows:

$$PV_{req} = \frac{P_{PV}}{PV_{rateout}} \tag{2}$$

The series configuration of the PV modules is determined to consist of 22 units. the total number of PV modules required to achieve the SPP capacity is 4576 units. Figure 1 shown illustrates a series-parallel circuit diagram of a photovoltaic array using Canadian Solar HiKu7 CS7N-655MS modules. This diagram displays the arrangement of photovoltaic modules in rows and columns connected in series and parallel. Each row consists of modules connected in parallel to increase the system's total power capacity. The photovoltaic modules are arranged in multiple rows with specific spacing between them, allowing ventilation and reducing shading between modules to maximize sunlight absorption efficiency. The overall dimensions of this array setup are approximately 59.37 meters in length and 28.67 meters in width. This arrangement takes into account the size of the photovoltaic modules and the optimal spacing between them, estimated to be around 0.5 meters for each row, to maximize the light absorption area and system efficiency. This configuration is designed to meet the power requirements of The Lana apartment building, where the number of modules and the series-parallel connection pattern will influence the output power and stability of the SPP system. This diagram provides a visual representation of the layout and scale of the photovoltaic array installation, which will serve as a primary component of the solar power generation system in the building. It also illustrates how the photovoltaic components are connected to achieve the desired output, taking into consideration technical factors such as optimal voltage and current that can be generated.

Figure 2 shows the layout illustration of the photovoltaic array in apartment complex area. The diagram depicts the placement of photovoltaic panels on the rooftop or an open area strategically positioned around the building, particularly in areas that receive maximum sunlight exposure. The photovoltaic array location is situated behind Tower 1 and beside Tower 2, utilizing an area of 17,183.93 m², with the main section measuring approximately 100 meters by 63 meters, along with additional areas adapted to the building's contours. The placement of this photovoltaic array is designed to optimize sunlight absorption, thereby enhancing the energy generation efficiency of the Solar Power Plant system. The spacing between buildings, as well as the size and orientation of the photovoltaic array, takes into account geographical conditions and potential shading, which are crucial for ensuring that the panels receive maximum light intensity. This positioning also minimizes the possibility of shading from the building structures, which could otherwise reduce the performance of the photovoltaic modules.

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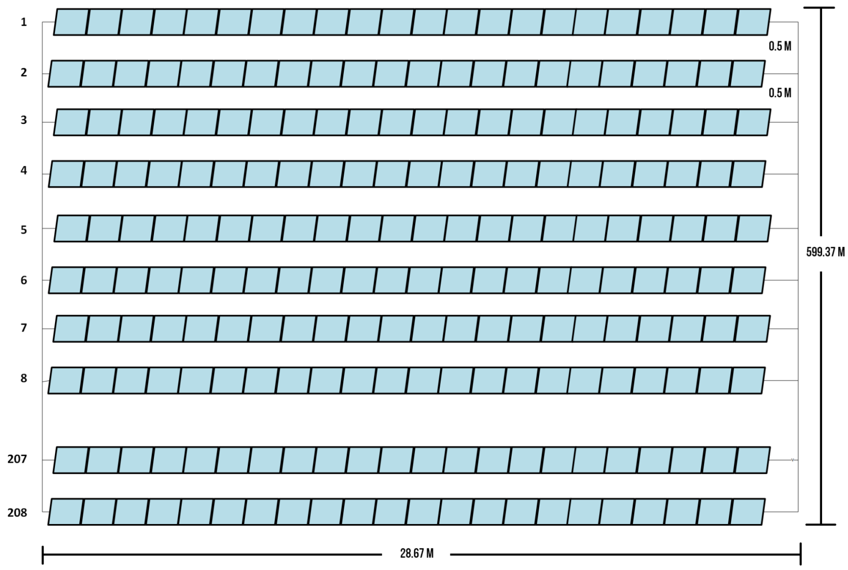

Figure 1. Series-Parallel Configuration of PV Array

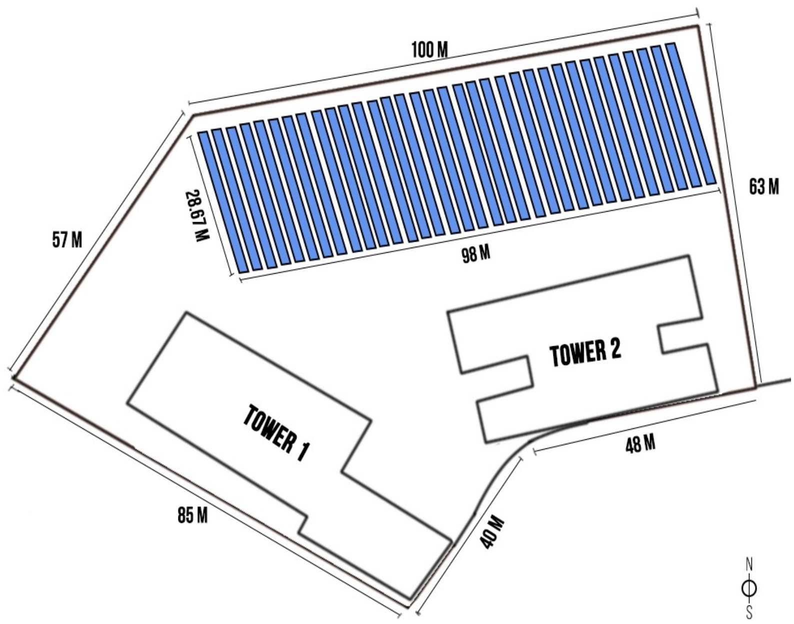

Figure 2. illustration of Photovoltaic Array Placement in The Apartment

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B. Energy Storage Requirements and Optimization for Solar Power Backup

The PV system's energy storage relies on batteries, which serve as the crucial medium to store and supply electricity to the apartment building when needed, particularly during times when the main power supply is unavailable. The battery capacity must be carefully calculated to ensure it can meet the building's electricity demand as a reliable backup power source. This storage capacity is influenced not only by the amount of energy required but also by the duration for which the battery can sustain power supply. In grid-connected systems with backup batteries, a storage capacity that covers a single day is commonly chosen, especially in regions susceptible to storms. After a storm, clear skies often allow the solar system to recharge quickly, making daily storage capacity practical for uninterrupted power supply [19]. In this design, the required energy storage capacity for the battery bank is approximately 32,452.48 kWh, aligning with the building's energy demands for effective backup coverage. The battery system's voltage is set to match the PV array system at 1000 Vdc, ensuring compatibility and efficiency in energy transfer. To optimize battery lifespan and performance, the Depth of Discharge (DOD) is set at 80%, which allows the battery to discharge a significant portion of its capacity while maintaining longevity. Additionally, system losses are anticipated to be around 15%, accounting for factors such as component degradation and inefficiencies inherent in the energy storage process [20]. These specifications ensure that the battery system is robust enough to provide reliable backup power, while also being efficiently integrated with the PV system. By accounting for factors like DOD and system losses, the design optimizes both the efficiency and durability of the energy storage solution, enabling it to meet the apartment building's energy needs under varying conditions. Additionally, system losses in the battery are estimated at 15% due to new components [21]. The total battery capacity will be calculated using Equation (3) as follows:

$$CB_{cap} = \frac{D_{oA} * E_{PV}}{VB_{sys} * DoD * B} \quad (3)$$

After calculations using Equation (4), the required total battery capacity is determined to be 47,724.24 Ah to store and supply the energy needed for the backup power system of the apartment building. Each battery unit having a capacity of 4560 Ah, the total capacity of the designed battery system depends on the number of battery units arranged in parallel. The number of units required for the parallel configuration can be determined using Equation (5) as follows:

$$NB_{paralel} = \frac{CB_{cap}}{CB_{rateout}} \quad (4)$$

$$NB_{seri} = \frac{VB_{sys}}{VB_{rateout}} \quad (5)$$

Figure 3 shows the series-parallel configuration in the battery bank designed for the energy storage system of the Solar Power Plant at the apartment building. The diagram illustrates an arrangement of 42 battery units organized in 11 rows and multiple columns, where each row of batteries is connected in parallel to increase the total energy storage capacity. Each battery unit has a specification of 24V with a capacity of 460Ah. This series-parallel configuration is designed to meet backup energy needs with adequate storage capacity. By connecting the batteries in series, the total voltage can be increased to match the system specifications, while the parallel arrangement serves to enhance the ampere-hour capacity to supply sufficient power over a specific duration. This combination ensures that the battery bank can store and

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supply energy efficiently, aligning with the electrical load requirements of the apartment building.

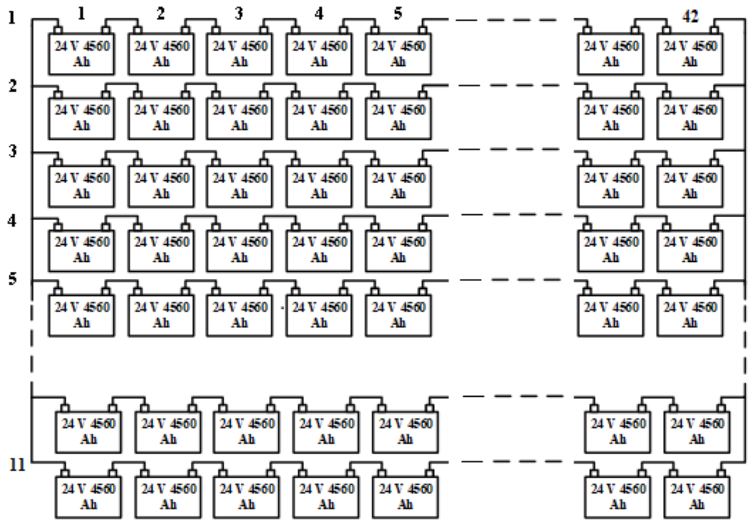

Figure 3. Series-Parallel Configuration in Battery Bank for SPP System at The Apartment Building

RESULT AND DISCUSSION

The PV array of this Solar Power Plant has a series-parallel configuration of 22 series strings and 208 units arranged in parallel, totaling 4576 PV modules. Therefore, the total capacity of the PV array, using CS7N-655MS modules with a capacity of 655 Wp each, is 2,997,280 Wp. The system voltage for this PV array is 1000 Volts. The designed area for the PV array will have a length of 599.37 meters, with a spacing of 0.5 meters between parallel rows, and a width of 28.67 meters, resulting in a total array area of 17,183.93 m². The schematic of the SPP system designed as a backup power source for the apartment building. The schematic includes two buses: an AC bus and a DC bus. The DC bus operates at 1000 Vdc, while the AC bus operates at 400 Vac. The DC bus is connected to Canadian Solar HiKu7 CS7N-655MS PV modules with a capacity of 655 Wp each and a derating factor of 85% due to dust and high temperature. The DC bus is also connected to a Bae Secure Solar PVV 4560 Ah storage battery with an efficiency of 95%. These two buses are linked by a Caterpillar BDP 250 kW inverter, which converts DC voltage to AC voltage. In this system configuration, the SPP is used solely as a backup energy source to supply the apartment building and is only activated when the main PLN power supply is disrupted. The PV array, consisting of 45 units in a fixed orientation (without a solar tracking system) and arranged in a series-parallel configuration, is oriented towards the equatorial line with an azimuth angle of 180°. Since the research location is in the southern hemisphere, the PV modules are oriented to face north.

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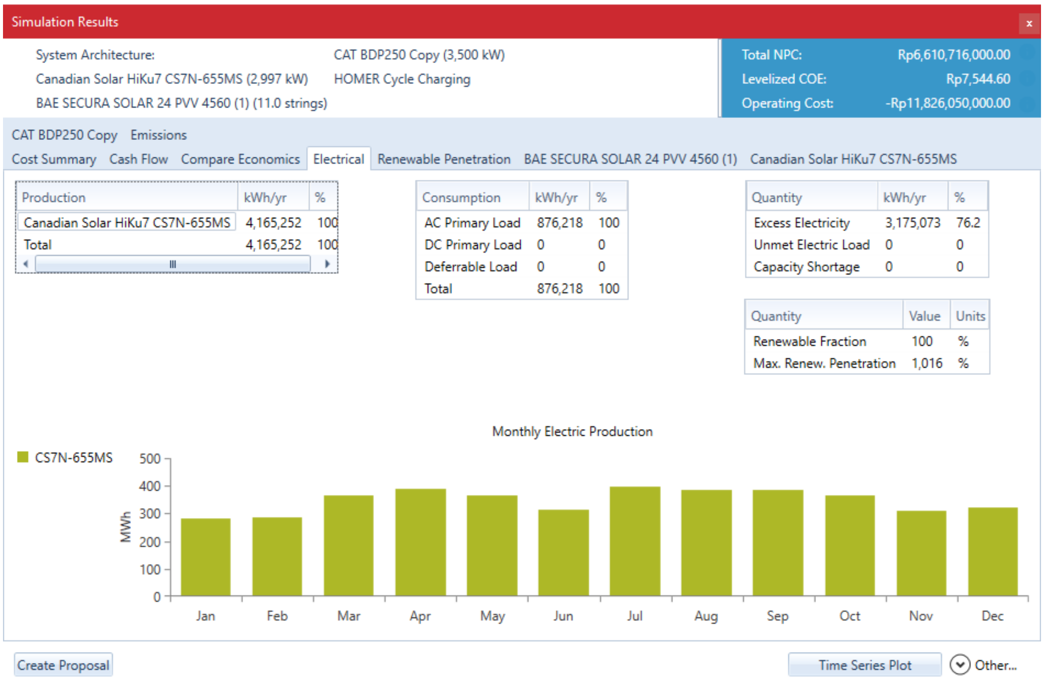

Figure 4. Simulation Results of Electrical Energy Production from the Solar Power Plant for The Apartment Building

Figure 4 displays the simulation results of electrical energy production from the Solar Power Plant designed for The Lana apartment building, using HOMER software. The PV modules with a total capacity of 2,997 kW, and the CAT BDP250 inverter with a 3,500-kW capacity. Additionally, a battery storage system with 110 strings is utilized to ensure energy reliability. The simulation shows various metrics, such as total electricity consumption, which is 876,218 kWh per year, with the PV array generating a total of 4,165,252 kWh annually. This results in a substantial excess electricity production of 3,175,037 kWh, representing 76.2% of the total generated power. The renewable fraction of the system is 100%, indicating that the SPP fully meets the building's energy requirements through renewable sources, though excess electricity may occur due to overproduction relative to consumption.

Figure 5 shows the operational simulation results of the PV array using the Canadian Solar HiKu7 CS7N-655MS modules within the Solar Power Plant for the apartment building, as simulated in HOMER software. The top section summarizes system parameters, including the rated capacity of 2,997 kW, with an average output of 475 kW and an annual production of 4,165,252 kWh. The inverter, a CAT BDP250 with a 3,500-kW capacity, supports the power conversion for optimal energy use. The summary also provides financial metrics, such as total NPC (Net Present Cost), Levelized Cost of Energy (LCoE), and operating costs. The intensity of colors in the graph represents the variation in power output, with brighter colors indicating higher energy production, up to a maximum of approximately 2,696 kW. The graph provides insight into seasonal and daily power fluctuations, demonstrating how environmental factors such as sunlight availability affect the PV array's performance. This visual representation helps assess the consistency and reliability of the PV array in meeting the building's energy needs throughout the year. The capacity factor value indicates how efficiently the PV array utilizes its capacity. A higher capacity factor signifies better performance of the PV array in generating electricity. The capacity factor for the SPP system at The Lana apartment building is 15.9%.

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This value is derived from its average annual output of 478 kW, compared to the total SPP capacity. According to [22], the capacity factor does not account for environmental factors or degradation in the solar PV system, and is generally low for solar PV systems due to low conversion efficiency, typically ranging between 15% and 35%. Therefore, the capacity factor value for the SPP at the apartment building is considered adequate for operation.

Figure 5. Operational Simulation Results of PV Array CS7N-655MS for The Apartment Building

Figure 6 illustrates the monthly energy production of a solar power system over one year, based on a HOMER simulation. Energy production, measured in Kilo-Watt-Hours (kWh), varies month by month, reflecting seasonal changes in solar availability. The highest energy output occurs in July, with a production level of 396,071.36 kWh, indicating optimal solar conditions. Other high-production months include April, August, and September, each exceeding 360,000 kWh. In contrast, January and February record the lowest production levels at approximately 282,359.87 kWh and 285,190.76 kWh, respectively. Overall, the chart provides a clear view of the annual energy production cycle, highlighting the months with peak and lower solar efficiency.

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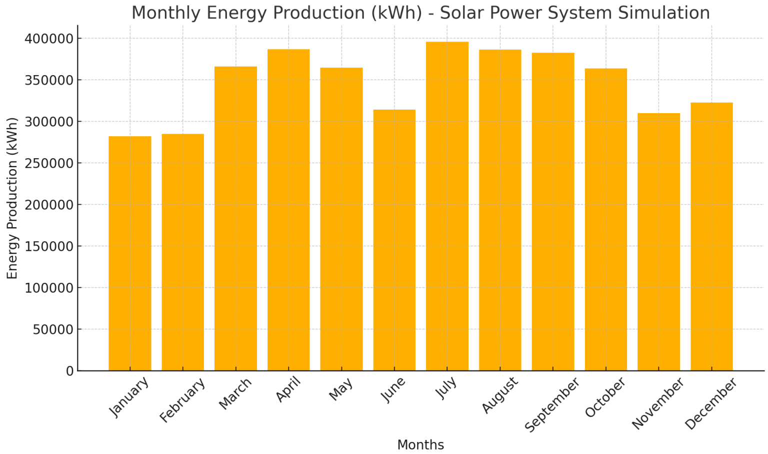

Figure 6. Monthly Energy Production of Solar Power System (kWh) Based on HOMER Simulation

Validation will be carried out by comparing the theoretical calculation results with the HOMER simulation results. The theoretical calculations for determining the energy production from the SPP have been conducted. The comparison between the theoretical calculation results and the HOMER simulation results is conducted to understand any differences and to provide an overview of the energy production of the designed SPP.

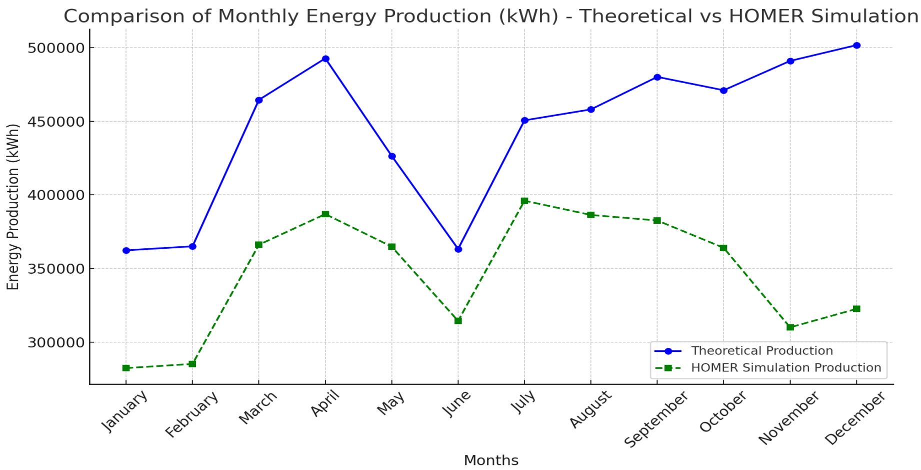

Figure 7. Comparison of Monthly Energy Production - Theoretical vs. HOMER Simulation Results

Figure 7 is the comparison chart showing both the theoretical and HOMER simulation monthly energy production values (in kWh) for the solar power system. The theoretical production is depicted with a solid blue line, while the HOMER simulation values are shown with a dashed green line. This chart highlights discrepancies between the expected and simulated values, with theoretical estimates generally higher than those produced by the HOMER simulation, particularly in the mid-year months. The comparison chart above visualizes the monthly energy production in kilowatt-hours from a solar power system, based on theoretical calculations and HOMER simulation data. The theoretical production, represented by a solid blue line, consistently shows higher values than the HOMER simulation results (depicted by a dashed green line). This discrepancy may highlight potential overestimations in theoretical calculations compared to the simulated values that factor in real-world inefficiencies. The trend lines, shown in lighter shades for each dataset, further illustrate these patterns. The theoretical trend line has a slight upward slope, indicating a gradual increase in energy production across the year, with peaks in April and December and a noticeable dip in June. Conversely, the HOMER simulation trend line suggests a more stable or slightly declining trend, with fluctuations but no significant seasonal increase. This divergence suggests that while theoretical models predict higher production in certain months, the simulation data is more conservative, possibly accounting for factors like weather variations or system losses. This chart effectively underscores the differences in energy production estimates between theoretical and simulated approaches, providing insight into how both methodologies might complement each other in predicting solar system performance.

CONCLUSION

The study demonstrates the potential of implementing a Solar Power Plant (SPP) as an effective backup power source for apartment buildings, reducing reliance on conventional generators and promoting sustainability. The designed SPP system, with a capacity of 2997.28 kWp and supported by HOMER software simulations, is capable of generating approximately 4,165,252 kWh annually with a performance ratio of 79.32%. This system exceeds the backup power needs of the apartment and aligns well with the building's energy profile. The comparison between theoretical calculations and HOMER simulation data shows some discrepancies, likely due to real-world factors such as weather variations and system inefficiencies. Nonetheless, the system's renewable fraction of 100% underscores its capability to meet energy demands entirely through renewable means. Moreover, the excess power generated offers additional benefits, potentially reducing operational costs and environmental impacts by decreasing dependency on non-renewable energy sources. Overall, this research provides a practical framework for integrating SPP systems in residential buildings, showcasing the feasibility and environmental benefits of solar energy as a reliable backup power solution. Future studies may expand upon this work by exploring economic analyses, optimizing three-phase load balance, and incorporating additional protective measures to further enhance the system's efficiency and resilience.

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