Mekanika: Majalah Ilmiah Mekanika

Design of a Solar Power Plant System for Government Buildings in the *Ibu Kota Nusantara* of Indonesia Using HOMER Optimization

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Indonesia's social and political landscape necessitates a balanced distribution of development and a restructuring of its population and industries. In response, the government has relocated the capital from Jakarta to *Ibu Kota Nusantara* (IKN) in East Kalimantan, aiming to alleviate the pressures on the central city. Given the region's abundant solar energy resources, this paper explores the potential for investing in solar energy systems within government buildings to align with the innovative city initiative. The study employs the Hybrid Optimization Model for Electric Renewables (HOMER) to evaluate the feasibility of the government's solar energy plan. This simulation tool analyzes investment costs, energy generation potential, and economic viability. The HOMER configuration includes solar panels, batteries, and an inverter integrated with the on-grid electrical system, tailored to meet government building requirements. Simulation results indicate that the proposed model can generate approximately 828,980 kWh annually, with a total energy consumption of around 643,257 kWh. The estimated investment cost is IDR 20,581,290,000, with a production cost of IDR 1,407.11 per kWh and a net payback period of about seven years. This analysis suggests that solar energy systems are well-positioned to thrive in IKN's emerging business environment.

1 Introduction

Ibu Kota Nusantara (IKN) is Indonesia's newly planned capital city, designated to replace Jakarta as the current capital. The new capital is located within the latitude range of 0°38′41.0856″ to 1°8′26.3508″ S and the longitude range of 116°31′33.2976″ to 117°16′15.6144″ E [1]. The relocation of Indonesia's capital to IKN in East Kalimantan is a strategic initiative designed to alleviate Jakarta's socio-economic pressures, promote equitable development, and establish a sustainable governmental center [2]. East Kalimantan was selected for the new IKN due to its high accessibility, proximity to Balikpapan and Samarinda, diverse population, and low conflict potential. Additionally, it has robust infrastructure supported by ports, airports, and water resources from two planned and three existing reservoirs [3]. Consequently, Indonesia is making significant strides towards this transition, demonstrating a serious commitment to reducing greenhouse gas emissions [6].

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Renewable energy is one of the top goals in constructing the IKN. The government intends to include renewable energy sources to lessen reliance on fossil fuels. As Indonesia strives to become carbon neutral by 2060, the utilization of renewable energy sources, including biomass, solar power, and wind turbines, is anticipated to lessen this reliance while supplying sustainable energy to cut carbon emissions [8]. The new National Capital will be a representation of Indonesia as a symbol of national identity by implementing the concepts of Smart, Green, and Sustainable [9-10]. Attention is focused on providing electricity in the region and using clean technology in fossil energy-based power plants such as coal so that the environmental impact is taken seriously. Therefore, special studies need to be carried out immediately in East Kalimantan Province, including in the field of new and renewable energy [11]. East Kalimantan's North Penajam Paser Regency Province includes the archipelago's capital. Given its central location in Indonesia, IKN is anticipated to be in a critical position to promote equitable development across the nation [12]. Indonesia has a relatively high solar energy potential, with an average of around 4.8 kWh per square meter per day and wind energy potential ranging from 3 to 6 meters per second. This potential can be utilized optimally to produce electricity through direct conversion by using new and renewable energy [13]. One promising renewable energy technology is Photovoltaic (PV), which have great potential for solving electricity problems in remote areas. Research and development of PV technology continues to take place from various aspects, including improving the types and types of PV to increase conversion efficiency, socio-economic studies, as well as the application of this technology based on factors such as local weather conditions [14-15]. To meet high electrical energy needs at the lowest possible cost, the simulation starts by analyzing the geographic location of the location, calculating potential electricity production, and estimating the capital of a government building photovoltaic project using the Hybrid Optimization Model for Electric Renewable (HOMER) software. The HOMER simulation's outcomes may be used to examine the variables that affect manufacturing the intended power production system's cost-effectiveness [16-17]. The output of this research is the identification of the city with the most significant potential for system design, taking into account several factors, including Net Present Cost (NPC), Cost of Energy (COE), annual electricity production and consumption power, and Break-Events Point (BEP). It is envisaged that this study will help IKN's sustainable smart city initiative achieve sustainable economic development in the future and secure affordable, environmentally safe electricity [18-19].

Many studies have been conducted on applying renewable energy technologies, particularly solar PV systems, in various parts of Indonesia. However, most of these studies have not explicitly examined the potential and design of *Pembangkit Listrik Tenaga Surya* (PLTS) - Solar Power Generation systems for government buildings in the IKN, a new location with unique geographical characteristics and energy needs. This study aims to replicate the installation of an on-grid PLTS system in government buildings in North Penajam Paser Regency, East Kalimantan Province, the archipelago's capital. This is being done to help the IKN smart city initiative achieve sustainable economic development in the future and secure affordable, environmentally safe electricity. The novelty of this research is that it is a systematic approach through the integration of technical and financial analysis to design a sustainable energy solution that meets the government's electricity needs and supports the environmentally friendly smart city initiative in IKN, with a project estimate of over 25 years.

2 Research Methods

2.1 Research Flow Diagram

This research was carried out in several steps, which had to be carried out in a structured manner. Research was carried out by collecting qualitative and quantitative data about research subjects. The flow of the research process is significant in completing the research [20]. Figure 1 shows the flow diagram for designing a PLTS system for government buildings in IKN. The flowchart emphasizes a structured approach to designing a solar power generation system with a type of government building essential to achieving the desired outcome. The first step in the design process is data collection, which includes a qualitative and quantitative study of the types of energy required and the available solar resources.

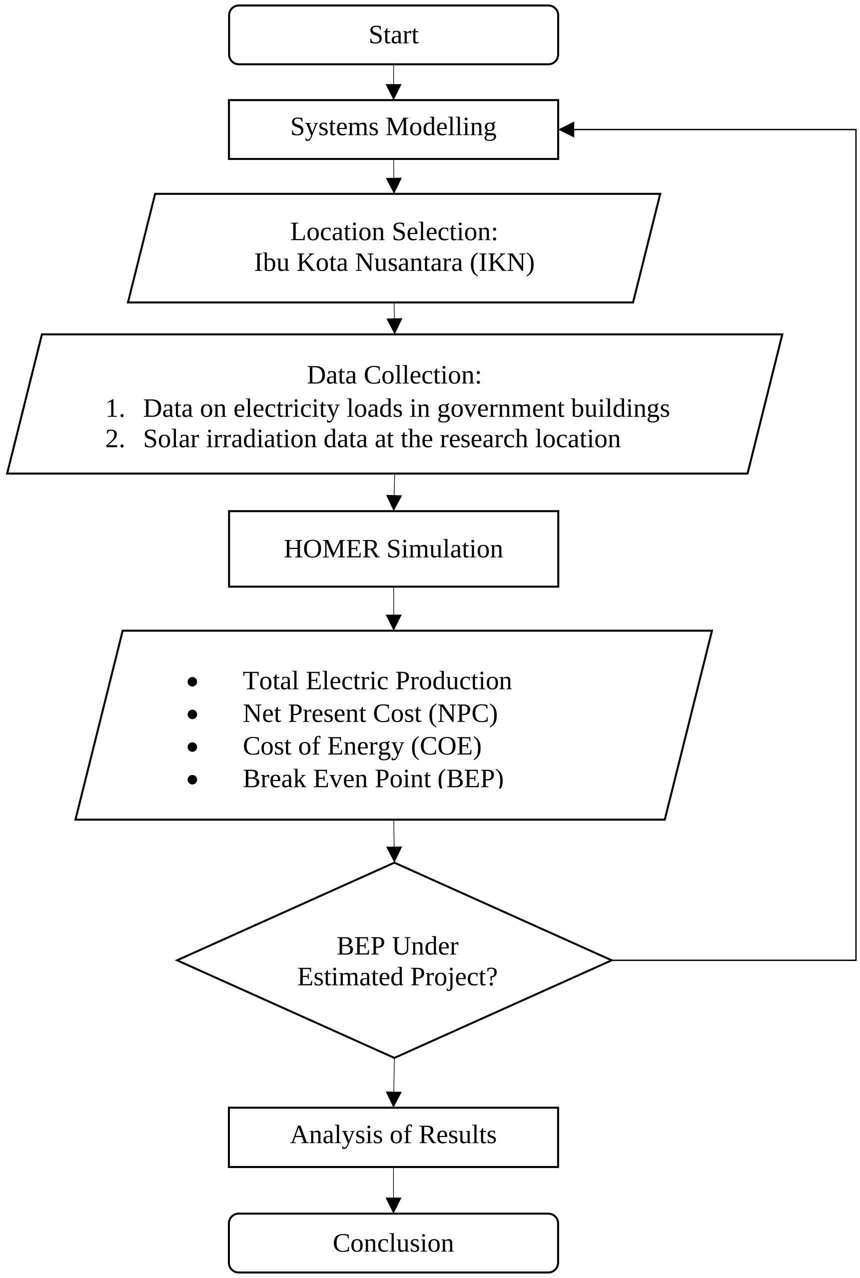

Figure 1. Flowchart of PLTS system design for government buildings

Site assessment comes next in the hierarchy that assesses the geographical and climatic conditions for the applicability of solar energy systems. The next step relates to system modeling conducted using the Hybrid Optimization Model for Electric Renewables (HOMER), in which different designs can be modeled for component optimization concerning cost and energy output. In this breadth of research, a crucial part is validating the simulation approach. This can be done by checking whether the results obtained from HOMER are similar to the findings or experimental work reported in journals on similar PLTS systems. For example, validation of the design model is possible from works that have compared actual production figures to figures generated by software such as HOMER. It is necessary to validate such an assertion to ensure the system design works in theory and practice. In conclusion, the outlined flowchart above has a broad scope for researchers and practitioners by providing a stepwise procedure for designing an efficient PLTS system for government buildings and stressing the importance of empirical data in real-world situations and the need to validate simulation results.

2.2 Modeling PLTS for Government Buildings with HOMER

HOMER is software for renewable energy designed by US NREL [21]. Whether a power production system is off-grid (off-grid) or linked to the grid (on-grid), HOMER facilitates the evaluation of system designs. The information supplied by HOMER often takes the form of daily electrical usage (kWh/day), installation location, installation component pricing, and technical details. Trina Solar 345TSM-345DD14A.08(II) solar panel parameters were utilized in this study. Concurrently, the inverter uses the ABB TRIO-50.0-TL-OUTD-US-480 series and the BAE SUNDEPOT 48-350 battery. A HOMER-designed On Grid system is shown in Figure 2.

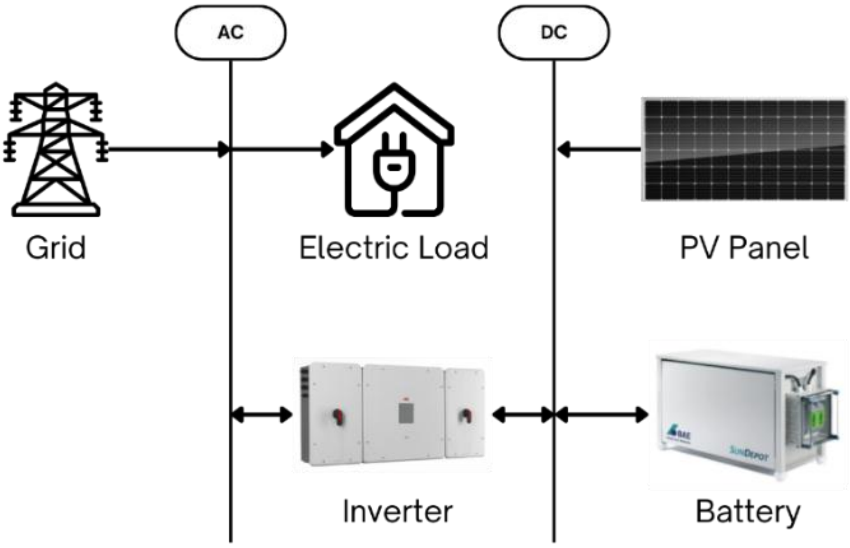

Figure 2. PLTS system modeling scheme for government buildings

In the picture above, the solar panel functions as a DC input connected to the battery. Then, the battery voltage is converted to AC by the inverter and applied to the electrical load. Suppose more energy from the battery is needed to meet the electricity needs of government buildings. Therefore, *Perusahaan Listrik Negara* (PLN) will supply the electricity load. A research diagram regarding the application of PLTS in government buildings can be seen in Figure 3, and the electricity load in government buildings can be seen in Figure 4.

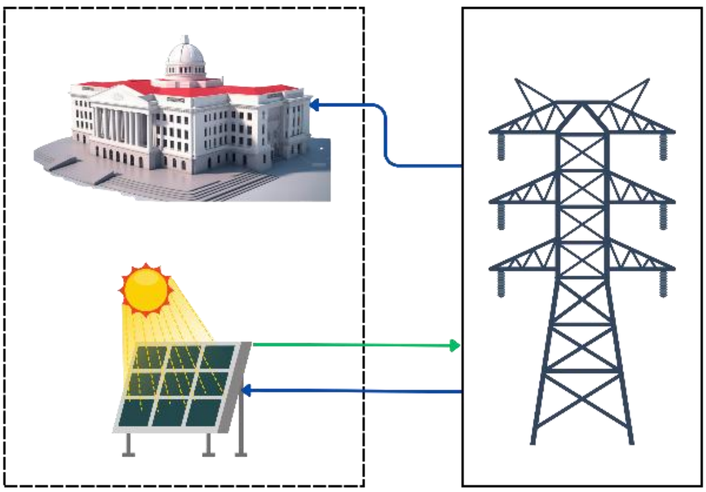

Figure 3. Research modeling scheme

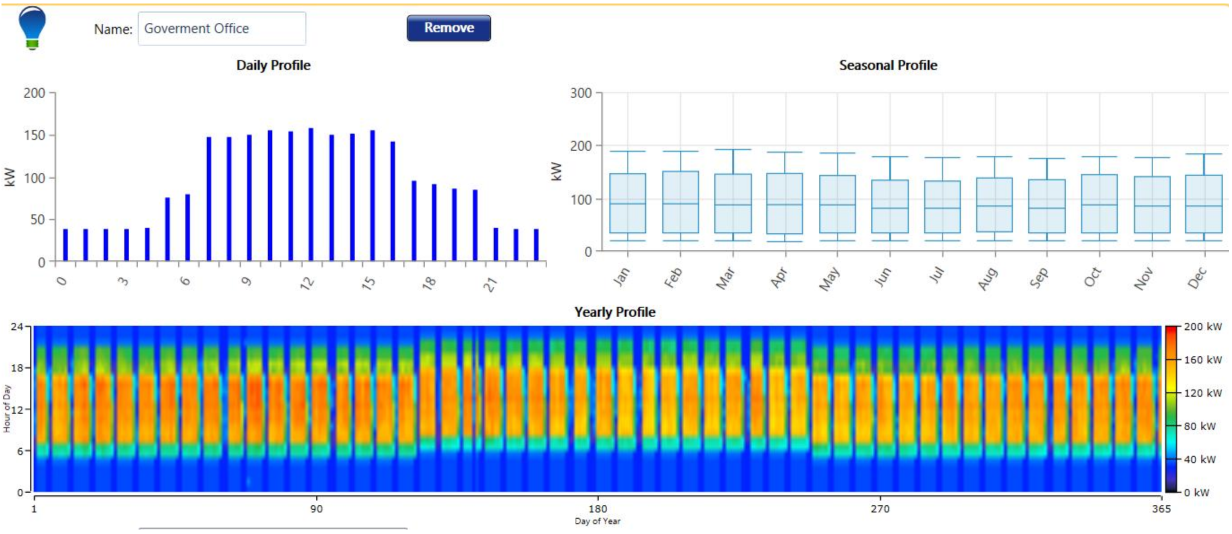

Figure 4. PLTS electricity load profile for government buildings

The expenses of each component used in building the PLTS system are assessed for economic analysis. All of the gear, storage systems, and solar panels that make up a solar PV system add to the overall cost of the investment. Consequently, thoroughly examining each component's expenses will offer a better idea of the project's financial viability and economic efficiency as shown in Table 1.

Table 1. Components of the PLTS system for government buildings

Parameter	Trina Solar345TSM-345DD14A.08(II)	ABB TRIO-50.0-TL-OUTD-US-480	BAE SUNDEPOT 48-350
Capital Costs	IDR 160,000,000.00	IDR 96,600,000.00	IDR 318,000,000.00
Replacement Cost	-	IDR 96,600,000.00	IDR 318,000,000.00
O&M Costs	IDR 16,000,000.00	IDR 9,660,000.00	IDR 31,800,000.00
Lifetime	25 years	15 years	18 years

2.3 Location Description for PLTS System Design for Government Buildings

In Indonesia, the archipelago's capital city will serve as the model for the PLTS system design for government buildings. Specifically, East Kalimantan Province in Kalimantan Island is home to the archipelago's capital, IKN. This area includes portions of Kutai Kartanegara Regency and North Penajam Paser Regency, Figure 5 shows where the PLTS construction plan is located.

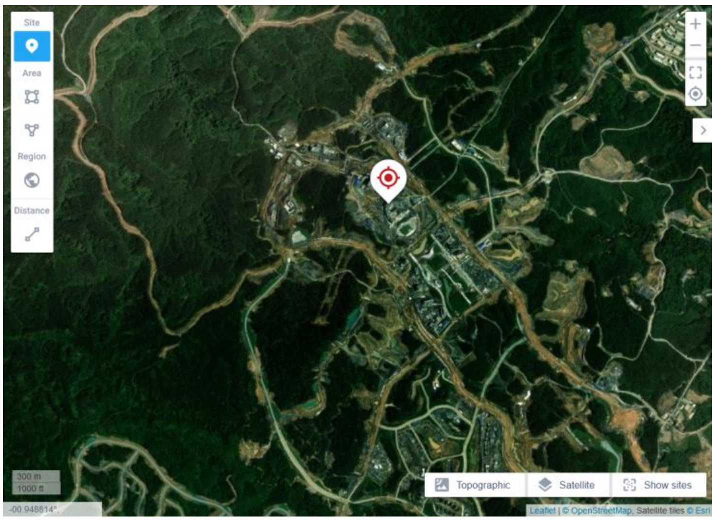

Figure 5. PLTS design location for government building

2.4 Potential Use of Solar Energy

Data on the potential of solar energy to establish a solar power plant in IKN can be processed using information obtained from the Global Solar Atlas website regarding solar radiation strength and regional temperature. Table 2 shows the average monthly solar radiation intensity (Direct Normal Irradiation) at IKN. This data is sourced from HOMER, which is integrated with the National Aeronautics and Space Administration (NASA) Prediction of Worldwide Energy Resources database over nearly 30 years, covering the period from 1993 to 2020 [22].

Table 2. Solar radiation intensity data [22]

Month	Solar Radiation Intensity (kW/m^2)
January	73.2
February	76.8
March	89
April	89.3
May	97.4
June	88.5
July	87.7
August	87.9
September	86.5
October	80.3
November	76.5
December	78.8
Total	1011.9
Average	84.325

Note: Radiation intensity data is in units of kWh/m^2

The higher the intensity of solar radiation, the more efficient the level of energy output that the generating system can produce, as evidenced by recent research from Rozak et al. [23] That shows a direct correlation between solar radiation and photovoltaic efficiency. Another study supports this argument by stating that the intensity of solar radiation is the most crucial limit for photovoltaic conversion efficiency. The use of solar tracking systems, which allows the PV panels to follow the sun, can result in an increase of energy capture by 20% [24].

2.5 Main Components of the System

2.5.1 Total Expenses

Table 3. Daily total load data

Afternoon (07.00 – 17.00)		Evening (17.00-07.00)	
At hour	**Load (kW)**	**At hour**	**Load (kW)**
7	7	18	100
8	25	19	95
9	40	20	130
10	50	21	80
11	80	22	80
12	111	23	30
13	145	0	30
14	140	1	30
15	135	2	30
16	132	3	30
17	130	4	30
		5	30
		6	30
Total load per day (kWh)		1720	
Average load per day (kWh)		71.67	

2.5.2 Photovoltaic Solar Panels

It's a collection of solar modules that use photovoltaic technology to create power from sunshine. [25]. The following formula may be used to determine the power generated by the solar panel module without taking the PV's temperature into account [26] (see Equation 1). The PLTS system uses a Trina Solar 345TSM-345DD14A.08(II) solar panel type. This solar panel, seen in Figure 6, has the specs listed in Table 4.

$$PPV = F_{pv}.Y_{pv}\frac{G_T}{G_{T,STC}} \tag{1}$$

Where,

PPV : Power produced by the PV module (kW)
Fpv : PV derating factor
Ypv : Power output PV at standard conditions (kW)
GT : Instantaneous radiation on the surface of the PV module (kW/m^2)
GT, STC : Instantaneous radiation under standard conditions (1 kW/m^2)

Table 4. Solar panel specifications

Technical Specifications	Mark
Type module	Monocrystalline
Maximum power (*Pmax*)	345 Wp
Maximum voltage (*Vmp*)	38.5 V
Maximum current (*Imp*)	8.96 A
Open circuit voltage (*Voc*)	46.8 V
Short circuit current (*Isc*)	9.55 A
Module efficiency	17.8 %
Derating factors	80 %
Nominal operating temperature	44^o C

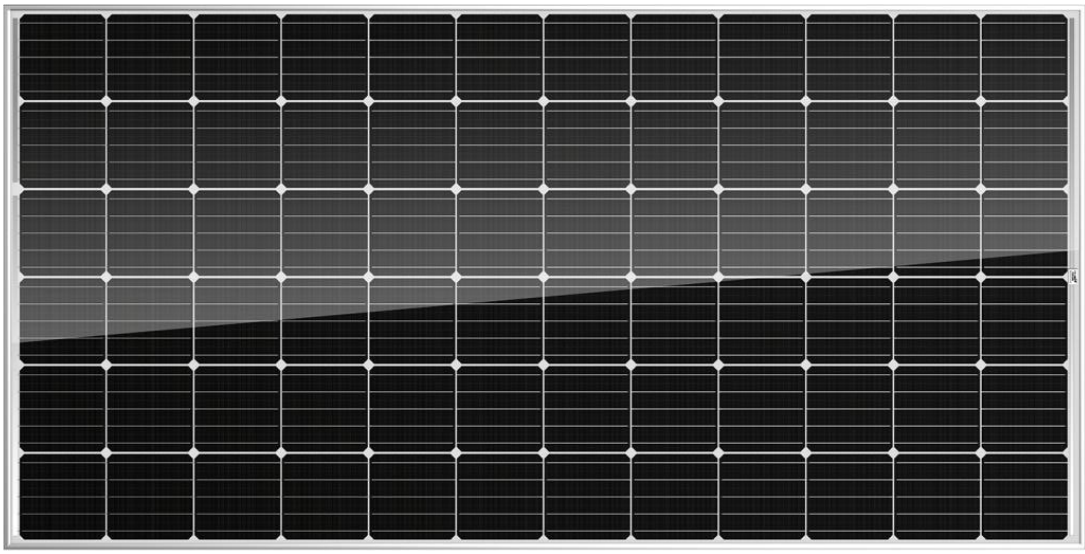

Figure 6. Trina Solar 345TSM-345DD14A.08(II)

2.5.3 Inverters

With a frequency of 50Hz/60Hz, the inverter converts the Direct Current (DC) electric current and voltage generated by the PV array into Alternating Current (AC) electric current and voltage [27]. The inverter used by PLTS for Government Buildings is an ABB TRIO-50.0-TL-OUTD-US-480 model. This inverter, seen in Figure 7, has the specs listed in Table 5.

Table 5. ABB TRIO-50.0-TL-OUTD-US-480 specifications

Technical Specification	Mark
Output power	50 kW
Maximum power	50 kW
Output frequency	50/60 Hz
Input DC voltage	420 – 700 V
Efficiency	98 %

Figure 7. ABB TRIO-50.0-TL-OUTD-US-480

2.5.4 Battery

With the battery acting as a reserve store for PV energy, the producing equipment may continue to function during the night [28]. In this setup, a BAE SUNDEPOT 48-350 battery is utilized. Figure 8 displays the parameters of this particular type of battery. The battery is known for its deep-cycle capabilities, which are crucial for applications in renewable energy systems where batteries are frequently charged and discharged. It is designed to provide reliable energy storage with a long service life, making it suitable for supporting solar power systems that require consistent energy supply during periods without sunlight. Additionally, it includes comparative data from other battery models or relevant studies that highlight the advantages of the BAE SUNDEPOT 48-350 such as its efficiency, cycle life, and cost-effectiveness. BAE SUNDEPOT 48-350 battery specifications listed in Table 6.

Table 6. BAE SUNDEPOT 48-350 battery specifications

Type of Technical Specification	Mark
Type	Lead acid
Normal voltage	48 V
Energy	13.2 kWh
Maximum capacity	327 Ah

Figure 8. BAE SUNDEPOT 48-350

2.6 Economics

The economic aspects of solar power generation systems emphasize the importance of economic feasibility in project implementation. It highlights factors such as investment effectiveness and the impact of eco-innovations, including discount rates and inflation [29]. The project will operate within the Indonesian context, utilizing the rupiah as its currency, with a discount rate of 5.75% and an inflation rate of 4.97% derived from data provided by *Badan Pusat Statistik* (BPS) Indonesia [30]. These economic factors are critical for conducting a thorough financial analysis, guiding budget planning, investment strategies, and overall project viability in the local market.

2.6.1 Net Present Cost (NPC)

Homer ranks the optimization results from the lowest NPC since the NPC represents the total cost of the system over a certain period and determines the outcomes of the most optimum system design [28]. All project-related expenses, including component costs, replacement costs, maintenance costs, fuel costs, and interest rates, are included in the overall cost of NPC. NPC may be calculated using the following method [16] (see Equation 2).

$$NPC = \frac{C_{ann,tot}}{CRF.i.R_{proj}} \tag{2}$$

Where,
Cann, tot : Total annual fee (Rp/year)
CRF : Capital recovery factor
i : interest rate
Rproj : life of use (years)

2.6.2 Cost of Energy (COE)

The average cost of energy used per kWh, or COE, may be defined as the difference between the yearly running costs of a project and the annual quantity of electricity consumed [31]. It is possible to determine the profitability of the production system under design by looking at the COE value. The following formula may be used to calculate COE [16] (see Equation 3).

$$COE = \frac{C_{ann,tot}}{L_{prim,AC}+L_{prim,DC}} \tag{3}$$

Where,
Lprim,AC : AC loads per year (kWh/year)
Lprim,DC : DC loads per year (kWh/year)

3 Results and Discussion

3.1 HOMER Energy Production

HOMER was employed to optimize the simulation and identify the optimal configuration for the system under consideration. The analysis indicates that implementing a grid-connected photovoltaic system PLTS results in the most favorable configuration outcomes. Table 7 presents the annual total energy production generated by the system, highlighting the effectiveness of integrating renewable energy sources within an on-grid framework. This approach not only maximizes energy output but also enhances the overall efficiency and reliability of the energy supply system.

The total energy produced reaches 828,980 kWh, with contributions from solar panels amounting to 231,394 kWh and from the electrical grid at 597,586 kWh. This data demonstrates the effectiveness of utilizing an on-grid system, which allows for optimal use of renewable energy while still relying on the grid when necessary. Combining these two energy sources creates a sustainable and efficient solution to meet energy demands. Meanwhile, Table 8 reveals a total annual energy consumption of 643,257 kWh, consisting of an AC primary load of 627,800 kWh and grid sales of 15,457 kWh.

Table 7. Electric power production per year

Production	Amount of Production Power (kWh/year)
PV	231,394
Grid	597,586
Total	828,980

Table 8. Electric power consumption per year

Consumption	Amount of Power Consumption (kWh/year)
AC primary load	627,800
Grid sales	15,457
Total	643,257

The analysis of this consumption data reveals that the total energy produced substantially surpasses the total energy consumed, indicating a significant surplus that can be harnessed for additional applications. Consequently, the optimized PLTS fulfills energy requirements, enhances economic viability, promotes environmental sustainability, and mitigates reliance on conventional energy sources. The strategic integration of renewable energy systems is essential for advancing sustainable development objectives.

3.2 Homeric Economic Analysis

(a) Net Present Cost (NPC)

The cost of constructing a power plant, including installation and operation, is calculated using net present cost, or NPC. Every system configuration affects the NPC configuration, which varies according to the capital costs, replacement costs, O&M expenses, fuel prices, and salvage for every system component [32]. The optimality of a system setup may be ascertained by calculating the value of the NPC. A lower NPC rating indicates more significant potential for the system. Figure 9 displays the NPC values that were obtained from the simulations that were run. It is evident from Figure 9's data that the NPC value is IDR 20,581,290,000.00.

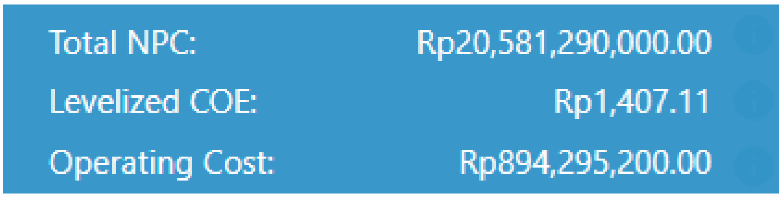

Figure 9. NPC, COE, and operating cost values

(b) Cost of Energy (COE)

The optimality of a system configuration may be ascertained by measuring the size of the COE value. If a system's COE value is lower, it is considered a greater perspective. Figure 9 displays the COE value that was obtained from the simulation that was run. It is evident from this number that the COE value is IDR 1,407.11.

(c) Break-Even Point (BEP)

The Break-Even Point (BEP) is a critical financial metric that indicates the time required for an investment to recover its initial costs through generated savings or profits. In the context of solar power generation systems, the BEP represents the period during which the savings from reduced electricity bills equal the initial investment in solar installation. The system's potential value will be higher if the BEP value is lower. Figure 10 displays the results of the HOMER system simulation for each city.

IRR	13%
ROI	9.1%
Simple Payback	7.1 yr

Figure 10. Result of HOMER

The resultant statistics from Figure 10 indicate that the BEP value is seventy years. A positive impact is indicated upon reaching the BEP under the estimated project. Subsequent savings contribute directly to profit margins, enhancing cash flow and enabling reinvestment into further energy efficiency measures or additional renewable projects. Conversely, suppose the BEP is delayed beyond expected timelines due to unforeseen costs or lower-than-anticipated energy production. In that case, it may deter future investments or lead to financial strain on stakeholders.

(d) Return on Investment (ROI)

A financial term called ROI is used to evaluate the profit or loss an investment generates to its starting cost. ROI is a metric used to assess the profitability or efficiency of an investment. It is expressed as a percentage. The ROI value is 9.1%, as can be shown from the data in Figure 10.

3.3 Proposed System

The optimal configuration was found by analyzing several factors, including total electric power output, total electric power consumption, NPC value, COE value, and BEP value, based on optimization done with HOMER software. Figure 11 shows the monthly power generation based on the system setup. Table 9 below displays the cash flow in the suggested model based on the HOMER simulation in Denpasar City.

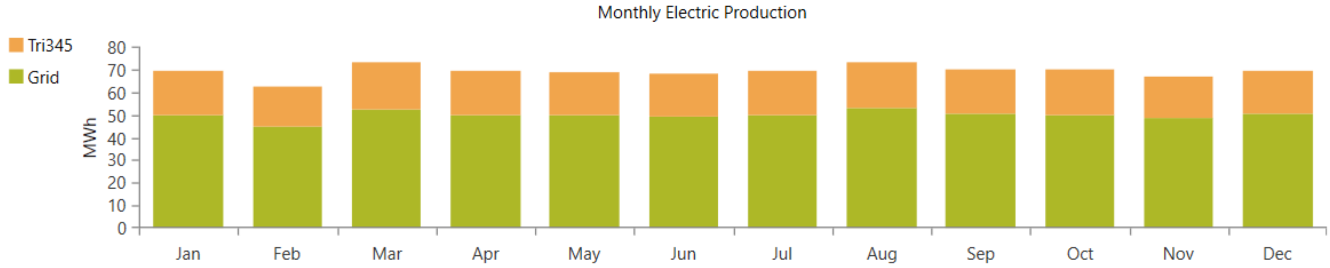

Figure 11. Monthly electricity production using the proposed model

Table 9. Cash flow on the proposed system

Components	Capital	Replacement	O&M	Salvage	Total
ABB TRIO-50.0-TL-OUTD-US-480	48,300,000.00	43,223,451.96	109,826,844.91	- 13,379,700.90	187,970,595.97
BAE SUNDEPOT 48-350	31,800,000.00	28,416,131.99	72,308,357.52	- 9,380,920.48	123,143,569.03
PLN	-	-	19,725,800,168.31	-	19,725,800,168.31
Trina Solar345TSM-345DD14A.08(II)	166,280,193.24	-	378,095,838.38	-	544,376,031.62
Systems	246,380,193.24	71,639,583.95	20,286,031,209.12	- 22,760,621.37	20,581,290,364.94

4 Conclusions

The study models the construction of a Solar Power Generation system for government buildings in East Kalimantan, the IKN. This study simulates and optimizes the generator system design using the Hybrid Optimization Model for Electric Renewable (HOMER) software. With an analysis that takes into account essential variables, including BEP, NPC, COE, and total power generation and consumption, this system is intended to run for 25 years. Simulations show that the PLTS system can produce 828,980 kWh of energy per year, while total electricity consumption is estimated to reach 643,257 kWh annually. The NPC value of this system is around IDR 20,581,290,000.00, and the COE value reaches IDR 1,407.11 per kWh, indicating good investment feasibility, with the BEP estimated to be reached in the 7^{th} year. The initial cost of building a PLTS in the IKN government building is estimated at around IDR 246,380,193.24. This research is expected to significantly contribute to future studies aimed at optimizing cost components and expanding the application of PLTS technology in Indonesia. Addressing environmental sustainability and economic efficiency offers valuable insights for policymakers and stakeholders involved in renewable energy development in urban settings. This revision emphasizes the novelty by highlighting innovative methodologies and contributions to future studies, reinforcing the research findings' significance.

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