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Design and Economic Analysis of a Solar-Powered Charging Station for Personal Electric Vehicles in Indonesia

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Abstract: Indonesia, known for its abundant renewable resources, especially solar energy, presents a substantial potential for developing solar-powered solutions to meet its increasing electricity demands. This study explores the feasibility of a Solar Power Plant (PLTS) as the energy source for a personal Electric Vehicle Charging Station (SPKL), facilitating the transition from fuel-based to electric vehicles. Using a simulation-based approach, a hypothetical daily electricity load of 12,711 kW was considered. The simulations indicate that an On-Grid PLTS is the most economically viable option, offering significant investment returns. The annual energy output of the PLTS was calculated to be 30,767 kWh. Financial projections suggest a substantial profit by the 25th year, amounting to IDR 374,450,204.39. This research underscores the strategic importance of integrating hybrid technologies in developing renewable energy infrastructures, particularly in regions like Indonesia, where solar irradiance is high. The findings advocate for broader implementation of such systems aligned with national energy sustainability and economic efficiency goals.

Keywords: Hybrid Optimization Model for Electric Renewable (HOMER); Hybrid technology; Renewable energy; Cost analysis; Solar energy

1 Introduction

Solar energy is an environmentally friendly energy source, so apart from being able to be used unlimitedly, it also does not cause pollution, which hurts the environment [1]. Solar energy is a source of electrical energy that is easy to obtain because it only requires sunlight and heat from the sun, so it has the potential to be utilized as well as possible, especially in Indonesia, where sunlight is always available for 12 hours [2, 3]. Indonesia has a significant potential for solar energy, with an average intensity of 4.8 kWh/m^2 [4]. Solar energy has become a widely used source of power in various aspects of everyday life, such as home electricity sources, space heating, and solar water heating [5]. Based on this potential, solar energy can be developed to become an energy source to supply electricity for EV charging stations. Solar power is converted into electrical energy using photovoltaic solar cells. As a country with a high level of electricity consumption, Indonesia is forced to face problems in providing electricity in the future because Indonesia currently still has a high dependence on PLTUs to meet its electricity needs, where coal is the primary fuel source [6]. According to the Central Statistics Agency (BPS), Indonesia's coal reserves can only be exploited for around 62 years [7]. Given the problems faced, using solar energy can be the answer to overcoming these problems.

The government plans to eliminate motorized vehicles that use fossil fuels by 2035 [8]. This elimination aims to realize Indonesia's commitment to becoming a net-zero emission country. In the EU, EVs can reduce carbon dioxide emissions by around 50–60% compared to internal combustion engine (ICE)-based vehicles [9]. There has been a significant increase in the use of electric cars in Indonesia. According to research by Setiawan et al. [10], the use of electric vehicles has increased from 0.08% in 2018 to 0.36% in 2021. In addition, Veza et al. [11] project that around

7.46 million electric vehicles will operate in Indonesia by 2030. Therefore, sufficient electrical energy sources are needed to meet these energy needs.

Indonesia has implemented several regulations to expand solar power plants. The most recent regulation is Minister of Energy and Mineral Resources Regulation Number 2 of 2024, which aims to improve efficiency and transparency in developing rooftop solar power plants. This regulation allows for the installation capacity of rooftop solar power plants to exceed 100% of PLN's installed power based on the capacity of the host electricity system. The regulation also introduces a five-year quota for rooftop solar power systems, determined by the Director General of Electricity every five years. Additionally, the regulation removes the import-export mechanism for excess electrical energy from rooftop solar power plants and exempts capacity fees for all PLN customers.

The community and the government must work together to address these two issues by ensuring the availability of electrical energy sources. The Ministerial Regulation (Peraturan Menteri) of the Ministry of Energy and Mineral Resources of the Republic of Indonesia (Number: 303. Pers/04/SJI/2021) mandates that the public must not delay the use of solar electricity [12]. Utilizing solar energy, one of the green energies, can increase the percentage of reduction in existing carbon gas emissions. The steps that can be taken care of by building a PLTS and an electric vehicle charging station (SPKL), both for the public (SPKLU) and at home [13, 14]. Based on data from the State Electricity Company (PLN), there will be 1,081 SPKLU units and 4,610 home charging units connected to the network in 2023, with a total electrical power consumption of 2,937 MWh [15]. Esfandyari et al. [16] have analyzed the use of PV- batteries for charging EVs on university campuses. Vermaak and Kusakana [17] have analyzed the possibility of utilizing PV-Wind power charging station systems in rural areas of the Democratic Republic of the Congo. With the existence of a home SPKL, it is hoped that it can support the government's program to improve supporting facilities for electric vehicles and be able to meet existing electrical energy needs. Utilizing solar energy is an alternative that can be used as an energy source for home SPKL because it has pretty good economic value, and solar energy reserves are abundant in nature. With the potential for utilizing promising solar energy sources in Indonesia, it would be very profitable if you could build your own PLTS. The construction of PLTS has many advantages, one of which is reducing the cost of daily electricity bills [18].

This research analyzes the cost-effectiveness and economic system of designing PLTS as a home SPKL electrical energy source. Techno-economic analysis was carried out using the HOMER tool. This analysis is needed to determine the feasibility of a design by reviewing its economic effectiveness [19]. The simulation was conducted for SPKL houses in Karanganyar Regency, Central Java. This is done to design efficient, environmentally friendly, sustainable economic development.

2 Methodology

2.1 Simulation Design Method

Before designing a PLTS, arranging the steps in a flow diagram is necessary. The flow diagram for the on-grid PLTS system analysis using HOMER in Bulurejo Village can be seen in Figure 1 below.

Based on the picture, the analysis begins with designing the SPKL system that will be created and collecting data regarding electrical load data and radiation intensity at the planning location. The simulation was carried out using HOMER software to obtain results regarding electricity production and consumption, the net present cost (NPC) value, and the cost of energy (COE) value. HOMER itself is software for renewable energy designed by US NREL [20]. HOMER can make it easier to evaluate the design of power generation systems, both those connected to the electricity network (on-grid) and those not connected (off-grid). HOMER can be used in developing renewable and hybrid energy by comparing the techno-economic effectiveness of several systems through a system optimization algorithm approach. HOMER will review the feasibility of the proposed system. In this research, HOMER analyzes the economic feasibility of using solar energy as electricity generation at charging stations for personal use by comparing NPC and COE values based on the potential intensity of solar radiation available for use as an energy source to supply electricity needs for the power to be consumed [21, 22]. The most optimal configuration will be the leading choice in the HOMER simulation because HOMER will display the results from the lowest NPC value to the highest NPC value [23]. Several factors are used to determine the feasibility of this design.

2.2 Description of PLTS Design Location

Selection of location for PLTS design for SPKL in Bulurejo Village, Gondangrejo District, Karanganyar Regency. This location was chosen because it is in a residential area, which is following the objectives of this design. Apart from that, Karanganyar Regency is a city that is developing into an industrial area, which will increase every year, so it has the potential to serve as a reference for development in other regions. The location is in a low enough area, so it can be used as a reference for the community and government to develop the Solar SPKL. The design location is shown in Figure 2 below.

Figure 1. Research flow chart

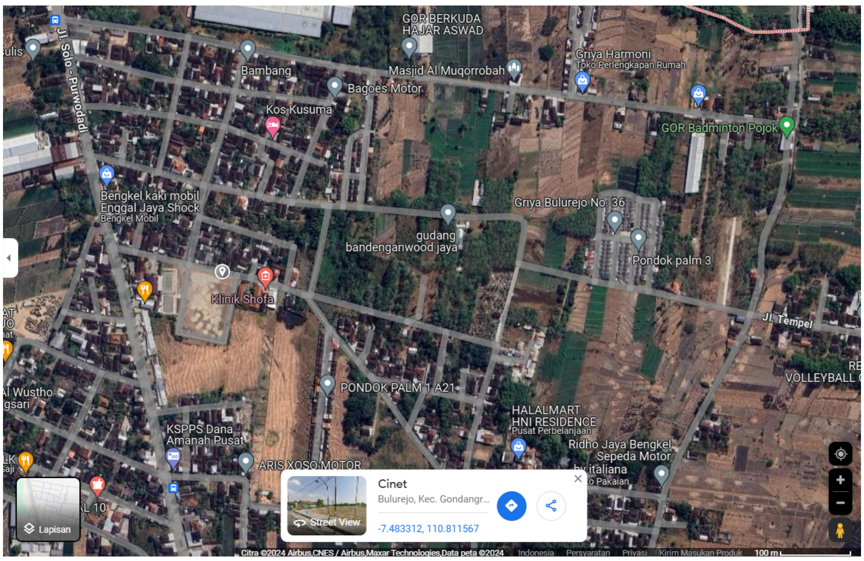

Figure 2. Location of PLTS

3 Results

3.1 PLTS Design

Before designing a PLTS at home, it is necessary to know how much electrical power an electric vehicle consumes so that you can then determine the type of PLTS components that fit your needs. Electrical power consumption in one day is shown in Table 1, and the graph of electricity consumption in one day is shown in Figure 3 below.

Table 1. Electrical power consumption in one day

Vehicle	Hyundai Ioniq 5	Gesits G1
Battery (Wh)	58000	1340
Distance (km)	384	50
Cas Power Consumption (Wh)	7200	350
Charging Time (Hours)	8	4
Distance traveled in 1 day (m)	50	83
Cas Power Consumption (Wh)	7500	2324

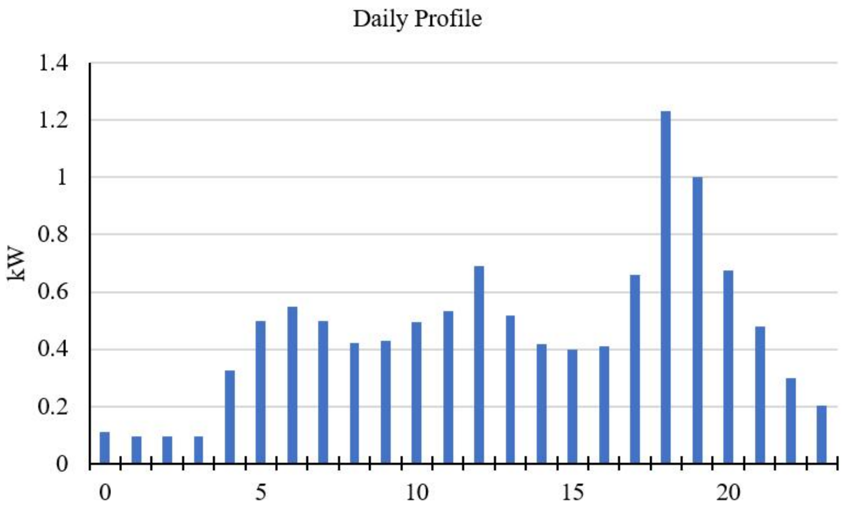

Figure 3. Graph of electricity consumption in a day

Based on the graph above, power consumption in one day is 9,824 kW, where the energy consumed during the day (07.00–17.00) is 3,929 Wh and at night (17.00–07.00) is 5,894 Wh. With a 30% load increase, the following data is obtained:

$$\begin{aligned} Daytime\ energy &= 3.929kWh \times 130\% = 5.108kWh \\ Night\ energy &= 5.894Wh \times 130\% = 7.662kWh \\ Energy\ in\ a\ day &= 5.108 + 7.662 = 12.711kWh \end{aligned} \tag{1}$$

To find out the total energy needed to supply the house's electricity needs in a day, you must know the losses, which will later affect the total amount of energy that must be provided. System losses in photovoltaic (PV) charging stations can be attributed to various factors, including environmental conditions, component characteristics, and design flaws. To minimize system losses in PV charging stations, designers should choose the proper cabling, limit shading effects, and maintain the system regularly. Additionally, installing automatic solar panel trackers can help maximize power output by adjusting the angle of PV panels throughout the day. Table 2 below shows the losses contained in the system:

Table 2. System losses

Types of Losses	Percentage
PV Module	11.5%
Network Inverter	3%
Battery Inverter	6%
Wiring	2%
Battery	15%
Total loss at night	**37.5 %**
Total loss during the day	**22.5 %**

The difference between energy losses during the day and at night lies in the losses of the battery. Energy losses at night include battery losses because the charging station only relies on batteries without PV. After knowing the magnitude of the losses in the system, the next step is calculating the total module energy that must be supplied. The following is the calculation of the total module energy.

$$\begin{aligned} Total\ module\ energy &= \frac{Night\ energy}{100\% - (night\ loss)} + \frac{Daytime\ energy}{100\% - (day\ loss)} \\ Total\ module\ energy &= \frac{7.662\text{kWh}}{62.5\%} + \frac{5.108\text{kWh}}{77.5\%} \\ Total\ module\ energy &= 18.851\text{kWh} \end{aligned} \tag{2}$$

From the calculations that have been carried out, the total amount of module energy that must be supplied to meet the house's electricity needs is 18.851 kWh. After knowing the total amount of module energy, the next step is determining the amount of PV. PV panels are a series of photovoltaic solar modules that convert sunlight radiation into electricity [23]. The power produced by the solar panel module can be calculated using the following equation, ignoring the temperature of the PV [24].

$$PPV = F_{pv} \cdot Y_{pv} \frac{G_T}{G_{T,STC}} \tag{3}$$

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)

To meet the energy needed for the module, the next step must be determining how much PV capacity will be used. In this PLTS, the PV used has a capacity of 20,000 W.

$$PV\ amount = \frac{18.851}{20} = 0.94 = 1\text{PV} \tag{4}$$

From the calculation above, to meet the electricity needs of 18,236.9 W with a PV capacity of 20,000 W, 1 PV is needed. The PV used in the Homer simulation is the type Solar Panel Fronius Symo 20.0-3-M, with Generic PV priced at IDR 135,000,000.00/unit and operational and maintenance costs of IDR 1,000,000.00/year. The PV panel specifications to be used are shown in Table 3 and can be seen in Figure 4.

Table 3. Component drawings and specifications

Component	Specification	Mark
Solar Panel Fronius Symo 20.0-3-M with Generic PV	Rated Capacity	20,000KW
	Temperature Coefficient	-0.4100
	Operating Temperature	45°C
	Efficiency	17.30%
Goodwe On-grid Inverter 3 Phase 20,000-Watt GW20KN-DT	DC Input	26 kW
	AC Output	20000 W
	Maximum Efficiency	98.6%
EnerSys Powersafe SBS 580 battery	Capacity	20 kW
	Voltage	12 V
	Nominal Capacity	7.81kWh
	Maximum Capacity	651Ah
	Capacity Ratio	0.158
	Rate Constant	4.61/hr
	Roundtrip Efficiency	97%
	Maximum Charge Current	580 A
	Maximum Discharge Current	720 A
	Maximum Charge Rate	1 A/Ah

Figure 4. Solar Panel Fronius Symo 20.0-3-M with Generic PV

After determining the number of PVs used, the next step is determining the power and number of inverters. The inverter functions to change the DC (direct current) electric current and voltage produced by the PV array into AC (alternating current) electric current and voltage with a frequency of 50Hz/60Hz [20]. The calculation of the number of inverters is as follows:

$$Inverter\ amount = \frac{12771.2 \times 125\%}{20000} = 0.7982 = 1\ inverter \tag{5}$$

So, the number of inverters that will be used is 1 unit with an inverter with a capacity of 20,000 W. The type of inverter used in the Homer simulation is the Goodwe On-grid Inverter 3 Phase 20,000 Watt GW20KN-DT, with a price of IDR 29,800,000.00 and operational and maintenance costs of IDR 1,000,000.00/year. The inverter specifications to be used are shown in Table 3 and can be seen in Figure 5.

Figure 5. Goodwe On-grid Inverter 3 Phase 20,000-Watt GW20KN-DT

Then, after determining the inverter, choose the battery that will be used. Batteries store energy reserves produced from PV so the generating system can run even at night [21]. The calculations for determining the number of batteries if using a battery with a capacity of 7.81 kWh are as follows:

$$Baterai\ amount = \frac{12381.2}{7810 \times 80\%} = 2.04 = 2\ Baterai \tag{6}$$

From the calculation above, the number of batteries needed to supply the house's electrical power is 2, with a capacity of 7.81 kWh. The type of battery used in the Homer simulation is the EnerSys Powersafe SBS 580 battery, priced at IDR 8,700,000/unit, and operational and maintenance costs are IDR 1,000,000.00/year. The battery specifications to be used are shown in Table 3 and can be seen in Figure 6.

Figure 6. EnerSys Powersafe SBS 580 battery

A simulation using Homer software based on the components calculated and determined above is conducted. The arrangement of On-Grid PLTS in the Homer software is shown in Figure 7.

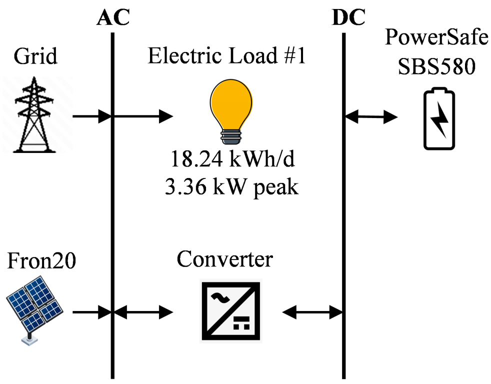

Figure 7. On-Grid PLTS arrangement

4 Discussion

Table 4. Electricity production

Production	kWh/yr	%
Fronius Symo 20.0-3-M with Generic PV	30,767	100
Total	**30,767**	**100**

Table 5. Electricity consumption

Consumption	kWh/yr	%
Primary Load AC	6,888	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	**6,888**	**100**

By utilizing software in the form of HOMER, the simulation is carried out with an optimization process using HOMER software based on previously determined components to obtain the best configuration of the designed off-grid PLTS system. The simulation results carried out on the Homer software for the designed PLTS system are shown in Table 4 and Table 5.

Based on the table above, it can be seen that solar panels produce electrical energy of 30,767 kWh per year, where the energy produced is enough to supply a load of 6,888 kWh per year.

4.1 NPC

The total current net cost represents the economic output of the PLTS system in the Homer software. The value of the NPC depends on the expenses incurred during the design and use of the PLTS. The NPC value for PLTS built for houses in Bulurejo Village, Gondangrejo District, Karanganyar Regency is shown in Figure 8 below:

Figure 8. NPC

4.2 COE

COE is the average cost per kWh, which assesses whether a generating system is profitable to implement or vice versa. COE is calculated by dividing the annual electrical energy production costs by the total electrical energy produced. The following is the COE on PLTS that has been simulated in Homer.

$$COE = \frac{Rp\ 580.073,80}{33952} = Rp\ 17,085 \tag{7}$$

By knowing the COE value, the annual income value from electricity sales can be determined using the following calculation:

$$\begin{gathered} Electricity\ Sales\ Yield\ Per\ Year = COE \times AC\ Primary\ Load \\ Electricity\ Sales\ Yield\ Per\ Year = Rp\ 17,085 \times 6658 \\ Electricity\ Sales\ Yield\ Per\ Year = Rp\ 113,752.691 \end{gathered} \tag{8}$$

However, this gross income has not been deducted from PLTS operational and maintenance costs.

4.3 Comparison of Grid Use with PLTS

This comparison aims to determine the expenditure for using the grid, off-grid PLTS, and On-Grid PLTS for 25 years as a consideration in selecting the energy source used, as shown in Table 6 below.

Table 6. Comparison of grid use with PLTS

Expenditure (25 Years)	Grid	Off Grid PLTS	PLTS On Grid
Capital	IDR 0.00	IDR 155, 380, 000.00	IDR 155, 380, 000.00
Maintenance	IDR 0.00	IDR 24, 286, 786.19	IDR 24,286,786.19
Replacement	IDR 0.00	IDR 7,932,509.42	IDR 7,932,509.42
Electricity	IDR 244,167,475.00	IDR 0.00	- IDR 562,049,500.00
Total	IDR 244, 167, 475.00	IDR 187, 599, 296.61	- IDR 374,450,204.39

Based on this table, the On-Grid PLTS system will provide the highest profit of IDR 374,450,204.39, followed by off-grid PLTS by spending capital of IDR 187,599,296.61 without having to spend money to buy electricity. Finally, the Grid system does not require any capital expenditure but requires a payment of IDR 244,167,475.00 to cover its electricity needs over 25 years.

4.4 Research Limitations

This study simulates a charging station design using HOMER software in Bulurejo Village, Gondangrejo District, Karanganyar Regency. However, this design is still small-scale, specifically for personal charging stations. We are seeing the vast potential of solar power in Indonesia. This charging station design could be applied on a larger scale.

With the government program that supports the use of electric vehicles, this PLTS for SPKL design can help provide eco-friendly public charging stations. Therefore, in further research, it is recommended that a solar power plant for a charging station be designed on a larger scale.

Although this research presents an economic analysis of solar power plant design, some parts still need to be addressed, such as energy losses and performance degradation of the parts used. This is because, in the HOMER program, there is no input or output regarding this matter. Therefore, further research recommends analyzing energy losses and performance degradation in the parts used in more detail to obtain maximum economic results.

5 Conclusions

Indonesia is rich in renewable energy, particularly solar power, which can be easily obtained through sunlight and heat. However, due to high electricity consumption, Indonesia needs help meeting its electricity needs. This research aims to design PLTS for SPKL to support the transition from fuel-motor to electric vehicles. A simulation method was used to simulate an electricity load of 12,711 kW for one day. The simulation found that PLTS On-Grid is the most suitable choice due to its potential to generate 30,767 kWh/year of energy and a profit of IDR 374,450,204.39 in the 25th year. The study concluded that using PLTS on the grid is the most appropriate choice due to its potential benefits and profit. However, the simulation results only reflect the results in the Karanganyar area. If the simulation is carried out in an area with better radiation potential, it will produce more electrical energy. With the potential for most of Indonesia's regions to receive solar radiation throughout the year, this system is suitable for applying eco-friendly energy.

Author Contributions

Conceptualization, S.D.P., A.N.R., F.J.R., A.R.B., and Z.A.; methodology, S.D.P., A.N.R., F.J.R., A.R.B., and M.S.M., S.S.; software, S.D.P. and F.J.R.; validation, S.D.P. and Z.A.; formal analysis, S.D.P. and F.J.R.; investigation, S.D.P., A.N.R., F.J.R., A.R.B., and M.S.M., S.S.; resources, S.D.P. and F.J.R.; data curation, S.D.P. and F.J.R.; writing—original draft preparation, S.D.P. and F.J.R.; writing—review and editing, S.D.P. and M.S.M; visualization, S.D.P. and F.J.R.; supervision, S.D.P. and Z.A.; project administration, S.D.P.; funding acquisition, S.D.P., A.N.R., M.S.M., S.S. and Z.A. All authors have read and agreed to the published version of the manuscript.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

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Conflicts of Interest

The authors declare that they have no conflicts of interest.

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