An Optimum Design and Economic Analysis of Renewable PV-Standalone Power Plant for Electric Vehicle Charging Station in Indonesia

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Abstract. Electric vehicles have recently been increasing in popularity and market demand which can be used as a key indicator for the future due to climate change and global warming so that CO² emission reductions are needed. In addition to environmental factors which are the main motivation for the increase in electric vehicles, this type of transportation reduces dependence on fossil fuels and contributes a lot to energy independence. The increasing popularity of electric vehicles requires a country to build a charging station for the community in the future, including Indonesia. For that reason, this study was made to obtain the most optimal PV-standalone design as a charging station with the economic analysis. Semarang city is the location of choice because of the potential for strategic resources and is one of the cities with the highest number of vehicles. The result is that 23.2kW PV, 9kW converter, and 40kWh battery are the most optimal for charging stations in the city of Semarang with 10 electric cars every day, with a total daily load of 88kWh / day.

1. Introduction
Along with the increasing of electrical needs and industry, electricity becomes an important role in the economy and welfare of a country including replacing fossil fuels to maintain nature by reducing CO² emission. The availability of power supply has been widely discussed in various types of literature as a basic requirement for a country’s development. All this can be achieved if a country can utilize electricity from all available renewable energy as a prerequisite to meet the daily power demand of consumers [1]. The technical, economic and environmental factors of a renewable energy resource encourage a country to maximize the use of energy for example from photovoltaic (PV) for power generation in the power system segment. To achieve an economic development that has sustained in the future we need to secure electrical energy with minimum cost and safe for the environment [2, 3].

To replace the use of fossil-fueled vehicles, we can use electric vehicles that are more environmentally friendly [4]. Based on International Energy Agency or IEA data (2019), 1.97 million units of electric cars were sold worldwide during 2018, this data increased 68% compared to 2017. With the increasing number of existing electric vehicles, Indonesia has to prepare to build a charging station
in the future. In comparison, the energy consumption intensity of passenger cars is 8.3 liters / 100 km and electric cars are 15.0 kWh / 100 km. Total fuel savings in 2050 for gasoline can be as much as 2.18 million kl and for diesel by 0.08 million kl. Thus, the policy to utilize electric vehicles in addition to potentially reducing fuel consumption, also reduces the level of energy needs of passenger cars by 22.7% in 2050. The electricity demand will increase from 36.9 GWh in 2025 to 46.3 TWh in 2050 with the use of a battery electric car, it is necessary to develop approximately 1,000 general electric charging stations of the fast charging type, making it easier to process the battery charging [5]. The potential for new and renewable energy in Indonesia is quite large, with very diverse types of variations. However, the potential for renewable energy is still not optimally developed due to various implementation obstacles, such as high investment costs and a geographical location. The Indonesian government once explained that electric vehicles, namely hybrid and pure electricity, could reach 20 percent of the target of 2 million units of total sales by 2025. That means the population touches 400 thousand units.

There is some literature describing the optimal design and some economic analyzes with other models and software. However, few works are done to study about economic analysis of stand-alone PV for charging stations with battery. This current study focuses on utilizing photovoltaic energy to meet the electricity requirements of the load demand using battery storage. This paper consists of the detailed feasibility study, techno-economic evaluation and optimal design of renewable PV power plant for electric vehicle charging station were done to achieve maximum results by comparing the net present cost (NPC) and cost of energy (COE) of the system.

2. Load Demand

This study outlines an economic analysis feasibility study of a PV in Semarang City, Indonesia with geographical location of latitude 6°58'00.0"S and longitude 110°24'60.0"E. The location has a good level of solar radiation. The site under consideration represents fairly dense settlements with lots of water near sea which is good for PV cooling. The scope of this work is an Electric Vehicle Charging Station (EVCS) that could produce electricity for 10 Electric Vehicle (EV) with a battery capacity of 8.8kWh each every day, so the total daily load approximately 88kWh. The daily load profile from the EVCS can be seen through in Figure 1.

![Daily load profile](image)

Figure 1. Daily load profile

The tests were simulated for charging the Prius PRIME PHEV car with the battery capacity of 8.8kWh and full specifications are shown in Table 1.

| Parameters          | Specification   |
|---------------------|-----------------|
| Engine capacity     | 1797 cc         |
| Engine power        | 72 kW/ 5200 rpm |
### Engine Specifications

| Component          | Specification       |
|--------------------|---------------------|
| Engine torque      | 142 Nm/ 3600 rpm    |
| Fuel tank capacity | 43 L                |
| Motor              | PMSM 53 kW          |
| Generator          | PMSM 23 kW          |
| Battery capacity   | Li-ion 8.8 kW       |
| Weight             | 1526 kg             |

### System Component Description
In this study, HOMER is used to design the system, the design of the system under consideration is shown in Figure 2. Schematic diagram consists of a PV-array, battery, converter and EVCS as a load. The PV-array is operating simultaneously to cover the 88kWh demand load. The output from PV-array is DC then converted into AC by the converter or stored to the battery, then interconnected with AC bus and integrated AC supply.

![Schematic design](image)

**Figure 2.** Schematic design

3.1. Photovoltaic (PV) array with solar irradiance data
A solar irradiance data per year is defined by the daily radiation for horizontal PV-array, measured in kWh/m², and this data are collected from the NASA website [7]. The Clearness index is an atmospheric factor ratio of the solar radiation on the earth’s surface to the solar radiation on top of the atmosphere. This factor depends on dust, moisture, clouds and temperature difference from the higher atmosphere to the lower atmosphere [8]. Fig.3 shows the annual solar irradiance data of Semarang. The power output from PV-array can be calculated using this formula [9]:

\[
P_{PV} = Y_{PV} f_{PV} \left( \frac{G_T}{G_{T,STC}} \right)
\]  

(1)
Where, $P_{pv} = \text{output power from PV} \ (kW)$, $Y_{pv} = \text{rated capacity from PV} \ (kW)$, $f_{pv} = \text{derating factor from PV} \ (%)$, $G_T = \text{solar irradiance} \ (kWh/m^2)$ and $G_{STC} = \text{solar irradiance at standard test condition} \ (1kW/m^2)$. From the figure 3, it can be seen that the highest peak of solar irradiance at September with 0.666 kWh/m$^2$, the lowest peak of solar irradiance at January with 0.393 kWh/m$^2$ and the annual average of solar irradiance was 5.479 kWh/m$^2$.

![Solar Irradiance Data](image)

**Figure 3. Solar Irradiance Data**

In this study a Peimar SG290MFB flat plate was used, with Table 2 as a parameter for specification is shown. The PV-array power rating is 290W, power efficiency 17.8% and initial capital cost Rp14,400 /W. This PV module has the same capital and replacement cost that is Rp14,400,000. This PV-array has no operation & maintenance cost as the advantages and only needs free maintenance for cleaning and others.

| Parameter                        | Specification        |
|----------------------------------|----------------------|
| **Capital Cost**                 | 14400000 Rp/kWh      |
| **Replacement Cost**             | 14400000 Rp/kWh      |
| **Operation and Maintenance Cost** | 0 Rp/kWh/year       |
| **Lifetime**                     | 25                   |
| **Derating Factor**              | 80                   |
| **Tracking**                     | -                    |

### Table 2. Parameter of PV

#### 3.2. Converter

The proposed hybrid system power plant needed to be integrated with an AC-DC converter to facilitate the EVCS. The characteristics of a converter are its inversion and rectification efficiencies, which are assumed 95%. Other parameters to be taken into account are their capital costs and replacement costs expressed in Rp. All technical specifications are shown in Table 3.
### Table 3. Parameter of Converter

| Parameter                          | Specification       |
|------------------------------------|---------------------|
| Capital Cost                       | Rp45000000/kWh      |
| Replacement Cost                   | Rp45000000/kWh      |
| Operation and Maintenance Cost     | 0                   |
| Power                              | 9kW                 |
| Frequency                          | Adjustable 45-65Hz  |
| Lifetime                           | 15 year             |
| Efficiency                         | 95%                 |

### 3.3. Battery

Batteries store the electricity generated by PV in off-peak periods, when the power demand is usually low and fed back into the system during peak periods or when PV is not generating enough energy. Batteries also reduce the fluctuation effect associated with renewable energy resources because of its stochastic characteristic. The calculation of the battery charging power based on the maximum charge current as follows [9]:

\[
P_{batt,\text{max,mc}} = \frac{N_{batt}\times I_{\text{max}}\times V_{\text{nom}}}{1000}
\]

where \( N_{batt} \) = the number of batteries in the storage bank, \( I_{\text{max}} \) = the storage's maximum charge current [A] and \( V_{\text{nom}} \) = the storage's nominal voltage [V]. All technical specifications of the battery are shown in the Table 4.

### Table 4. Parameter of Batteries

| Parameter              | Specification |
|------------------------|---------------|
| Capital Cost           | Rp85000000/kWh|
| Replacement Cost       | Rp85000000/kWh|
| Operation and Maintenance Cost | 0              |
| Nominal Voltage        | 6V            |
| Maximum Charge Current | 167Ah         |
| String size            | 40            |
| Total Power            | 40kWh         |
| Lifetime               | 15 year       |
| Efficiency             | 90%           |

### 3.4. Electric Vehicle Charging Station (EVCS)

EV Charging Station or charging point for electric vehicles is an element in the infrastructure that supplies electrical energy to recharge the batteries of electric vehicles, such as electric cars or hybrid cars. In general, there are several ways to recharge batteries in electric vehicles, including conductive charging, inductive charging and replacing batteries. In this study we used conductive charging because this is the most suitable choice to be implemented in Indonesia because it offers the advantage of cheap manufacturing systems. The formula for charging station power consumption as the main system load as follows [10]:

\[
P_c = \int_{t_0}^{t_0+T} P(t) \, dt = (1 - SOC\text{inl})Qr
\]

5
Where \( P_c \) = power consumption with time \( T \), \( T = \) charging duration, \( P(t) = \) charging power at the time, \( SOCinl = \) State of charge of the battery, \( Q_r = \) rated capacity of the battery in electric vehicle.

The component of the charging station showed in Fig. 4. EVCS will use BougeRV Level 2 EV Charger 240V 16A and SAE J1772 2010 standard as a port charger and connector. The full specifications as shown in Table 5. The charging station load is modeled assuming 10 vehicles per day and the capacity of the battery each vehicle is 8.8 kWh per vehicle.

![Component of a Charging Station](image)

**Figure 5.** Component of a Charging Station

**Table 4.** Specification of BougeRV Level 2

| Parameters        | Specification              |
|-------------------|-----------------------------|
| **Input**         | 220-240AC 16A 60Hz          |
| **Output**        | 220-240AC 16A 60Hz          |
| **Output power**  | 3.8 kW                      |
| **Insulation**    | > 1000 MΩ                   |
| **Resistance**   |                             |
| **Protection**    | Lightning protection        |
|                   | Leakage protection           |
|                   | Overcurrent protection       |
|                   | Over-under voltage protection|
| **Connector**     | SAE J1772 2010 standard     |

### 4. Methodology

Methodology in designing and optimizing renewable power plant by combining elements of power plants that is PV, battery and converter then calculating economic analysis. Economic analysis is used to determine the optimal size of the PV, battery and converter. Cost analysis is carried out by calculating the net present cost (NPC), total annualized cost (TAC), and cost of energy (COE) which are detailed in the formulation below.

#### 4.1 Net Present Cost

The NPC indicates the installation costs and operating costs over the lifetime of the system, including all the components minus salvage calculated by the following calculation:

\[
NPC = CC + RC + O\&M + FC - S
\]

Where:

- \( NPC = \) Net Present Cost [Rp]
- \( CC = \) Capital Cost [Rp]
- \( RC = \) Replacement Cost [Rp]
- \( O\&M = \) Operational & Maintenance Cost [Rp]
\[ FC = \text{Fuel Cost} \ [\text{Rp}] \]
\[ S = \text{Salvage} \ [\text{Rp}] \]

4.2 Total Annualized Cost
TAC is the annualized cost of each component and equipment of the system including capital costs, operating costs, maintenance costs, replacement costs, and fuel costs (fuel cost) or can be formulated as follows:

\[ TAC = CC + OC + MC + RC + FC \] (5)

TAC = Total Annualized Cost [Rp]
CC = Capital Cost [Rp]
OC = Operation Cost [Rp]
MC = Maintenance Cost [Rp]
RC = Replacement Cost [Rp]
FC = Fuel Cost [Rp]

4.3 Cost of Energy
COE is the average cost per kWh of the use of electrical energy produced by the system. In general (for AC and DC loads) COE is calculated using the following equation:

\[ COE = \frac{TAC}{L_{prim,ac} + L_{prim,dc}} \] (6)

COE = cost of energy [Rp/kWh]
TAC = total annualized cost [Rp]
\( L_{prim,ac} \) = primary load AC [kWh]
\( L_{prim,dc} \) = primary load DC [kWh]

5. Results and Discussion
The design of the power plant system consists of PV-array, battery and converter mentioned in the methodology. To get the best combination, first we need to calculate the economic analysis of the power plant, includes how to make a decision which is limited by a variety of related problems to produce the best choice from a variety of alternative choices. We investigate the economic analysis of the proposed PV-standalone system based on the components specifications, costs, meteorological data, and electrical datasheet. The simulations were carried out each yearly hour. Few cases were examined, to find the optimal system configuration we have to find the minimum total net present cost (NPC), refer to Fig. 5. NPC is taken as the cost of a system during 25 years of the whole project lifetime.
The most reliable and cost-effective configuration from the proposed PV-standalone system is 23.2kW PV, 40kWh battery and 9kW converter. Fig. 6 shows the cash flow of the proposed system by components during the project year. The initial cost of the system was found to be Rp714,690,853, there is a replacement cost of Rp168,847,960 in the 15th year of the project to replace the battery and converter, as well as a salvage cost of Rp35,300,978 at the end of the project. The total net present cost from the system was found to be Rp848,237,835. The cost of energy estimated to be Rp2,363/kWh and the annual cost or TAC reached Rp65,614,910. The total NPC system consists of Rp472,941,338 or 37.83% for the cost of PV-array, Rp320,848,865 or 55.7% for the cost of battery and Rp54,447,631 or 6.42% for the converter, all that includes the replacement and operation costs. Table 6 shows all the costs related to the optimal PV-standalone system.

Figure 5. Configurations of the system

Figure 6. The cash flow of the system
Table 6. Net Present Cost of the system

| Name of Components      | Capital | Replacement | Operating | Resource | Salvage | Total    |
|-------------------------|---------|-------------|-----------|----------|---------|----------|
| Generic 1kWh Li-Ion     | Rp340M  | Rp151M      | Rp0.00    | Rp0.00   | -       | Rp472M   |
| Peimar SG290MFB         | Rp334M  | Rp0.00      | Rp0.00    | Rp0.00   | -       | Rp320M   |
| System Converter        | Rp40M   | Rp17M       | Rp0.00    | Rp0.00   | -Rp3M   | Rp54M    |
| Total System            | Rp714M  | Rp168M      | Rp0.00    | Rp0.00   | -Rp35M  | Rp848M   |

The yearly mean power generated by PV-standalone system is given in Fig. 7. The annual product of electricity generated by the system has a total 36,883 kWh/year with all of that produced by PV-array. The PV-standalone power system successfully fulfills the un-scheduled load demand by 32,120 kWh/year, besides the dumped energy was about 4,763 kWh/year because there is no schedule for production and demand.

**Figure 7. Power Generated by PV-array**

6. Conclusion

The purpose of this paper is to design and analyze modeling technique which implements renewable energy source like PV to design a power plant for EVCS. Solar power plant to fulfill the load demand is the purpose of the study. The most optimum build from the system mainly comprises of 23.2kW PV, 40kWh battery and 9kW converter. The total NPC system consists of 37.83% for the cost of PV-array, 55.7% for the cost of battery and 6.42% for the converter. The result shows that 36,883 kWh/year energy produced by PV. However, the excess electricity was up to 4,763 kWh/year from the total production because of the unscheduled timing between the power generation and power demand. The economic analysis consists of calculating Net Present Cost, Total Annualized Cost and Cost of Energy with the number Rp848,237,835, Rp65,614,910 and Rp2,363/kWh respectively, and the proposed PV-standalone power plant system for EVCS is the most recommended choice with its cost-effectiveness and expected to spread across the country of Indonesia in near future.

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