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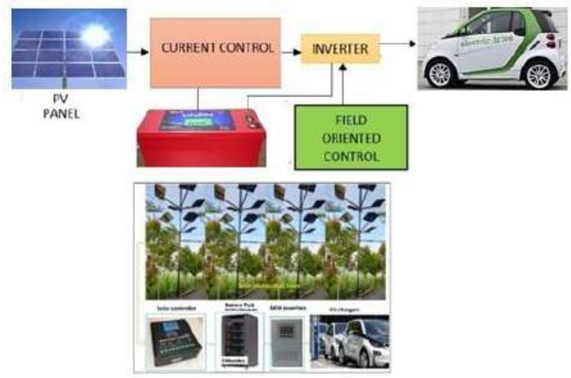
# ANALYSIS OF ELECTRIC VEHICLE CHARGING WITH RENEWABLE ENERGY

Wardoyo[1*], Aris Ansori[2]

[2]Mechanical Engineering, Universitas Negeri Jakarta, Rawamangun Muka Raya Street, RT. 11/RW.14, Rawamangun, Pulo Gadung District, East Jakarta City, Special Region of Jakarta 13220. Indonesia
[2]Mechanical Engineering, Universitas Negeri Surabaya, Ketintang Street, Ketintang, Surabaya, East Java, Indonesia

*Corresponding author
wardoyo@unj.ac.id

**Graphical abstract**




**Abstract**

The transport sector is user of fossil fuels, and the second contributor of pollutants after the industrial sector. The transition of fossil fuel vehicles to electric vehicles (EV) alternative to reduce environmental pollution. The problem from the use of electric vehicles is the improvement of the supply network for charging electric vehicles. The use of rene energy sources (RES) for EV charging can overcome the incr the power supply grid and offer a promising solution to the pr of environmental pollution. In this paper, the research obje to assess the technological of Solar Photovoltaic system for e vehicle charging power source installed along the roa proposed system consists of an 8 KW solar photovoltaic and inverter, the system can generate 27411,3 KWH/year of elec The results show that this electric vehicle charging system is save electricity purchase to charge electric vehicles b 4.105/year. The annual electric vehicle charging capabili reach 650 electric cars and 1561 electric bicycles.

Keywords: renewable energy, solar photovoltaic, EV chargin electric vehicles



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## 1. Introduction

The transport sector is the second largest contributor of hazardous pollutants and $CO_2$, which impacts environmental health and global warming. impact Fossil fuel vehicle emissions contribute significantly to greenhouse gases, ozone layer depletion, and acid rain. in addition, it causes respiratory health problems, skin irritation and other health problems. The implementation of electric vehicles is one of the efforts to address environmental pollution issues and focuses on reducing $CO_2$ emissions in the transport sector [1-2]. Since 1900 electric vehicle (EV) technology has been commercialized and continues to evolve in both design and control systems [3-4]. However, the usage rate of electric vehicles is still low due to several obstacles, such as expensive initial investment, battery degradation, lack of convenient charging locations, range anxiety, government regulations. based on the International Energy Agency's ‘Global EV Outlook’ report, it is estimated that the use of electric vehicles by the end of 2030 could reach up to 130 million EV worldwide [5]. some countries make regulations to increase the use of electric vehicles with various initiatives to financial incentives to promote the use of electric vehicles and complete the transition to electric transportation. The driving power of electric vehicles comes from the electrical energy stored in the battery. Therefore, the battery storage system uses a type of lithium-ion (Li-ion) rechargeable battery which is the most widely used due to its high energy density. In addition, Li-ion batteries still have limitations such as limited energy density, decreased battery cell performance, and limited charging rate due to electrochemical processes [6-7].

Electric vehicle charging can be connected to the power grid to recharge the battery. Therefore, electric vehicle charging stations are needed. The Indonesian government is targeting the construction of 4,300 Public Electric Vehicle Charging Stations (SPKLU) by the State Electricity Company (PLN) by the end of 2025. This step is taken to support the shift to electric vehicles in order to reduce carbon emissions, as well as to facilitate the charging of electric vehicles. However, the construction of electric vehicle charging stations whose power plants still emit $CO_2$ emissions is a problem in itself because instead of reducing carbon emissions, it adds to carbon pollution, such as Sweden when a power plant produces 1 kWh of electricity emits 0.013 kg of $CO_2$, and China with the same energy emits 0.711 kg of $CO_2$ [8]. while according to PLN, power plants in Indonesia still contribute 14% of total national carbon emissions. Therefore, the creation of vehicle charging stations using renewable energy power sources is the right solution to reduce the increase in $CO_2$ pollution.

The use of clean, renewable energy sources provides a more sustainable alternative. However, some constraints in renewable energy-based electric vehicle charging systems require large areas to harvest the renewable energy. One of the renewable energy sources that has been applied in several countries as a source of electrical energy for solar electric charging stations, such as in California, United States, has implemented a solar electric vehicle charging station that can operate on and off the grid with a photovoltaic capacity of 100 kW and an energy storage system of 635 kWh, and can charge electricity for simultaneous charging for 16 electric cars, Hong Kong country, solar electric vehicle charging station with on-grid and off-grid system. [9-14].

In addition, several studies have attempted to improve the technological advancement and effectiveness of solar energy EV charging station models, such as; According to Goswami et al, the design of a 100 kW Solar Power Plant with a storage model is part of a charging station that at least dependence on grid electricity and increases profitability, in addition, Maximum Power Point Tracking (MPPT) control using Stochastic Firefly Algorithm (SFA) can Maximum the power from the solar panel system, when demand is low, the station will draw power from the battery; when demand is high, the station will draw power from the grid. this system can reduce investment costs and increase charging station profits. this combination system allows the battery to be charged quickly and increases the profitability of the charging station. [15]. Paula et al, the use of Hybrid Renewable Energy Systems with off-grid combines batteries, wind resources, and solar PV, the power grid only powers the electric vehicle charging system, the most appropriate hybrid renewable energy system configuration for electric vehicle chargers using a multi-criteria process with renewable energy electricity demand systems and localized electric vehicle charging systems is determined [16-17].

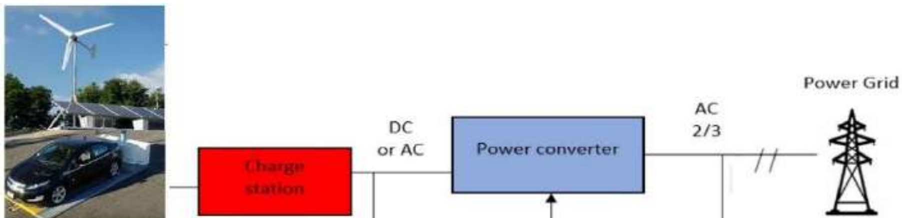


Figure 1. Electric vehicle charger hybrid model

Meanwhile, the intelligence-based control system has been developed to optimize the operating system of a renewable energy electric vehicle charger system. DC microgrid-based electric vehicle charger system operation system with artificial neural network-based active power management controller with three ways of functioning. The available PV power and current battery charge level determine the operation mode. The PV array and battery system are the ideal power sources for this adaptive interaction active power management controller (APMC). Power is drawn from the power grid if the PV and battery power is insufficient to meet demand. Excess power from the solar PV system is fed into the power grid when generated and the battery system is fully charged [19-24].

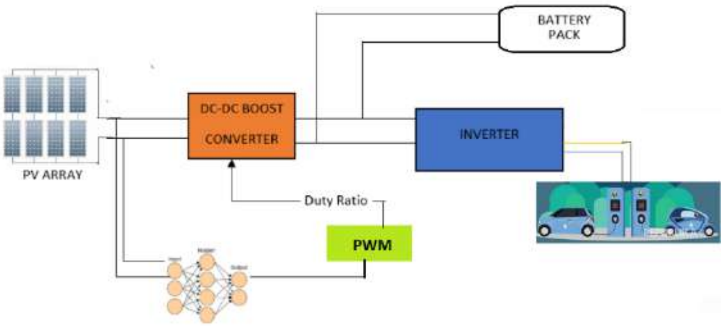


Figure 2. Solar electric vehicle charger using artificial intelligence

Several studies have highlighted the utilization of solar energy as a source of electrical energy for electric vehicle charging. however, there are still few in-depth technological and economic analyses. technological and economic studies of solar energy utilization with rooftop solar for lighting applications [24]. Review of techno-socio-economic studies of electric vehicles in the energy system [25]. Therefore, in this paper examines more in-depth related to the technological and economic models of solar photovoltaic in Indonesia for electric vehicle charging stations, such as the international standards established for EV charging, the topology of solar charging stations, and the economic aspects obtained during the implementation of the technology. This study aims to analyze the feasibility value of solar-powered fast charging to develop potential synergies between solar photovoltaic and grid power sources in improving renewable energy based electric vehicle charging infrastructure.

## 2. Material and Method

### 2.1 Material

Equipment and instruments used to analyze the performance of solar photovoltaic technology as a source of electrical energy for charging electric vehicles, such as; solar PV Monocrystalline type SOL-24250 W with specifications; maximum power (Pmax) = 250 Wp, voltage at maximum power ($V_{mp}$) = 30.3 V, current at maximum power Imp = 8.25 Ampere, open circuit voltage $V_{OC}$ = 36. 3 Volt, short circuit current $I_{SC}$ = 8.75 A, module efficiency = 15,37%, Temperature Range = 45 $^{o}$C - 80 $^{o}$C, dimensions = 1640 x 992 x 35 mm, maximum system voltage = 1000 Volt DC, maximum series fuse rating = 15 Ampere, 5KW 48 Volt prime inverter, maximum output power = 5 KW, grid voltage 180 - 380 Volt AC, maximum solar array power (Pmax) 5 KW. Schematic of the solar system is presented in Figure 4. Based on data on the potential of solar energy in the city of Surabaya, temperature, duration of solar irradiation from NASA Prediction of Worldwide Energy Resources data and Climatology and Geophysics Station Class I Juanda Sidoarjo, the measurement of electrical energy generated is calculated using PV Syst 6.43 software.


Figure 3. Schematic solar photovoltaic for electric vehicle charger

### 2.2 Method

The solar photovoltaic system used consists of; 152,4 mm diameter iron pipe for solar photovoltaic, solar photovoltaic installation on solar made circular with an angle of 90° between solar photovoltaic with the installation of 4 solar photovoltaic at the top and 4 at the bottom with a cross position. The capacity of one solar photovoltaic with 2 KWP, and a total of 4 with a total of 8 KWP. The installation of solar photovoltaic is adapted to the research location in Surabaya City Indonesia as a case study, which is geographically located 7° 9′- 7° 21′ South Latitude and 112° 36′ – 112° 54′ East Longitude. Installation of solar PV tilt angle of 30°.

The measurement of electrical energy generated by the solar photovoltaic/day was calculated using a KWH meter. the electrical energy generated by the solar photovoltaic is inputted in the PWM solar controller is divided into two measurements, namely; measuring the electrical energy directly used to charge the electric vehicle using a KWH meter, and measuring the electrical energy generated by the solar photovoltaic stored in the battery pack. The total electrical energy used for charging electric vehicles is measured using a KWH meter. The total value of electrical energy consumption is the electrical energy used directly and the energy stored in the battery. Meanwhile, electrical energy consumption for charging electric vehicles used two units of electric cars with a full charging capacity of 37,9 KWH, and 50,6 KWH. The electric bicycles with a full charging capacity of 1.75 KWH. The schematic of the solar photovoltaic performance measurement system is presented in figure 5.

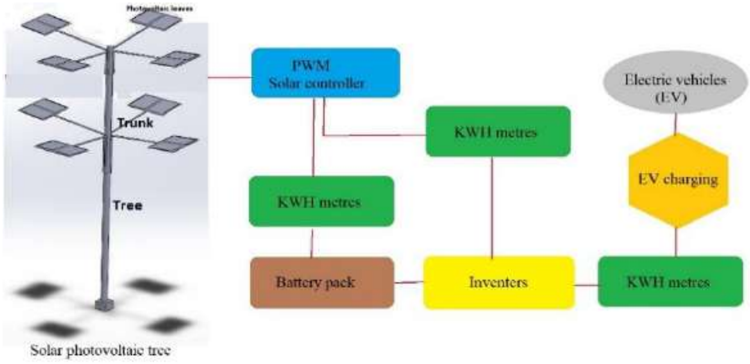


Figure 4. Techno analysis system of the solar photovoltaic

## 3. Results and Discussion

### 3.1 Solar photovoltaic for electric vehicle chargers

The measurement of the solar photovoltaic was carried out using two measurement techniques, namely; first, by measuring the electricity production generated by the solar photovoltaic, and the second technique is to measure electrical energy consumption of the electric vehicle. The decrease in irradiation on the surface of solar photovoltaics mounted on solar is determined by several parameters, including; changes in the angle of incidence of sunlight can have an impact on reducing the production of solar photovoltaic electricity, and environmental weather that has an impact on the instability of the supply of electrical energy for electric vehicle charger needs.

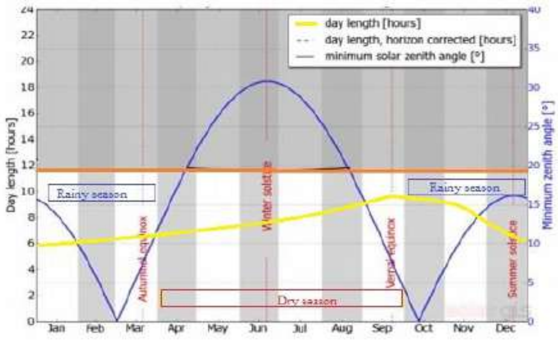


Figure 5. Daily solar irradiation in Surabaya

The solar photovoltaic model with a tilt angle of 20° with of eight solar photovoltaics installed in a circle can increase the capture of sunlight for a full day. Solar irradiation in Indonesian is determined by two seasons in Indonesia, namely the dry season which lasts from april to september, and the rainy season which lasts from october to february. in the dry season there is optimal solar irradiation because the air humidity tends to be very low. solar irradiation in Indonesia, In the time span of western Indonesia time measurement 06.00-18.00, the longest length of solar irradiation occurs in the dry season from April to September can reach the longest solar irradiation of 8.7 hours and the shortest length of solar irradiation occurs 6 hours. While in the rainy season from october to february, the longest irradiation is 6 hours and the shortest is 5 hours.

### 3.2 Solar photovoltaic energy production

Measurements of the electricity production of 8 KWP solar photovoltaic were carried out in the dry season, and the rainy season, the electrical energy produced on average decreased in the rainy season, due to a decrease in solar irradiation on the surface of the solar photovoltaic and the length of irradiation. The electrical energy production of solar photovoltaic for electric vehicle charging in Indonesia is presented in Table 1.

Table 1 Electric energy production from 8 KWP solar photovoltaic

| Month | Monthly Average Irradiation (kWh/m$^2$) | Temper ature (°C) | Irradiation time (%) | Average day length (haour) | Electrical energy production (KWh/day) | Electrical energy production (KWh/month) | Season |
|---|---|---|---|---|---|---|---|
| January | 5,2 | 28.3 | 55 | 5,5 | 62,70 | 1881,00 | Rainy season |
| February | 5,13 | 28.3 | 64 | 5,7 | 64,98 | 1949,40 | Rainy season |
| March | 5,2 | 28.4 | 70 | 5,9 | 67,26 | 2017,80 | Rainy season |
| April | 5,06 | 28.5 | 71 | 6 | 68,40 | 2052,00 | Dry season |
| May | 5,25 | 28.7 | 72 | 6,5 | 74,10 | 2223,00 | Dry season |
| June | 5,28 | 28.2 | 85 | 6,7 | 76,38 | 2291,40 | Dry season |
| July | 5,53 | 28.7 | 88 | 6,85 | 78,09 | 2342,70 | Dry season |
| August | 6,25 | 29.1 | 90 | 7,3 | 83,22 | 2496,60 | Dry season |
| September | 6,65 | 29.3 | 92 | 8,7 | 99,18 | 2975,40 | Dry season |
| October | 6,32 | 29.2 | 80 | 8,2 | 93,48 | 2804,40 | Rainy season |
| November | 5,64 | 28.3 | 60 | 7,8 | 88,92 | 2667,60 | Rainy season |
| December | 4,85 | 28.1 | 37 | 5 | 57,00 | 1710,00 | Rainy season |

The capacity of how many vehicle units are capable of charging is presented in Table 2.

Table 2. Electric energy consumption of charging solar photovoltaic electric vehicles

| Month | Electrical energy production (KWh/month) | Electrical energy consumption (KWh/month) | | Stored electrical energy (KWh) | Season |
|---|---|---|---|---|---|
| | | Electric car 37,9 KWH (units) | Electric bicycle 1,75 KWH (units) | | |
| January | 1881,000 | 44 | 120 | 3,4 | Rainy season |
| February | 1949,400 | 45 | 139 | 0,65 | Rainy season |
| March | 2017,800 | 47 | 135 | 0,25 | Rainy season |
| April | 2052,000 | 48 | 133 | 0,05 | Dry season |
| May | 2223,000 | 53 | 122 | 0,8 | Dry season |
| June | 2291,400 | 54 | 139 | 1,55 | Dry season |
| July | 2342,700 | 56 | 125 | 1,55 | Dry season |
| August | 2496,600 | 60 | 127 | 0,35 | Dry season |
| September | 2975,400 | 72 | 140 | 1,6 | Dry season |
| October | 2804,400 | 68 | 129 | 1,45 | Rainy season |
| November | 2667,600 | 64 | 120 | 32 | Rainy season |
| December | 1710,000 | 39 | 132 | 0,9 | Rainy season |

The solar photovoltaic is effectively irradiated by the dry season sun for 8.7 hours/day, the total electrical energy generated by solar photovoltaic/day can be calculated from the multiplication between the output power of solar photovoltaic and the length of irradiation during Peak Sun Hour. The production of solar photovoltaic electrical energy reaches its peak in the dry season in September with an average electrical energy of 2975,40 KWH/month, and the lowest in the dry season in May with an electrical energy production of 2223,00 KWH/month. While electrical energy production decreased in the rainy season with the highest electrical energy production in March at 2017,80 kWh/month and continued to decline in December at 1710,00 kWh/month. The decrease in electrical energy production in the rainy season is influenced by two important factors for the two seasons in Indonesia, namely; average irradiation and length of irradiation caused by high levels of rainfall.

The electrical energy consumption for electric vehicle charging for each load is an electric car with a full charging capacity of 37,9 KWH, and electric bicycle with a full charging capacity of 1,75 KWH. The results of the calculation obtained the production of solar photovoltaic electrical energy during the dry season in September with the production of 2975.400 KWH of electrical energy that can charge 72 electric cars, 140 electric bicycles, and stored electrical energy of 1.6 KWH. This is due to clear skies, low humidity, and long hours of sunshine every day in the dry season. Meanwhile, in the rainy season, the production of electrical energy decreases from October to March, the lowest production of electrical energy in December due to high rainfall which causes low irradiation time. In the rainy season, the energy source for charging electric vehicles can only charge 39 units of electric cars, 132 electric bicycles, and 0.9 KWH of stored electrical energy.

The results of this study are in line with research on solar energy utilization that has been carried out in several previous studies, such as Jan Engelhardt, et al implementation of a renewable energy source management system for charging electric vehicles [31], Alexander Schuller, et al renewable energy utilization strategy to improve electric vehicle mobility [32], Andre Corsetti, et al charging electric vehicles with smart grid renewable energy in Germany increases charging costs [33]. Qilong Huanga, et al distributed renewable energy management and storage for electric vehicle charging can reduce costs [34]. Omer Gonul, et al. Multi objective renewable energy system can improve electric vehicle charging system. Where, the utilization and management of electrical energy generated from renewable energy sources is able to supply electrical energy for charging electric vehicles and has economic value in the cost of charging electric vehicles.

Based on Minister of Energy and Mineral Resources Regulation Number 1 of 2023 concerning the Provision of Electric Charging Infrastructure for Battery-Based Electric Motor Vehicles, and the tariff for charging electricity at State Electricity Company Indonesia public electric vehicle charging stations is set at USD 0,15/KWH [36]. The results of the calculation of the rainy season charging system income of USD 1,949 and the dry season USD 2,156 so that the income in 1 year is USD 4,105. The revenue from the photovoltaic system is presented in Table 3.

Table 3. Revenue of solar photovoltaic system as electric vehicle charging

| Seasons | Electrical energy consumption (KWH/month) | | Amount of revenue | Month average total load | |
|---|---|---|---|---|---|
| | Electric car | Electric bicycle | (Price USD 0,15/KWH | Electric car (units) | Electric bicycle (units) |
| | | | Rainy season | | |
| October | 2577,2 | 225,75 | USD 420 | 68 | 129 |
| November | 2425,6 | 210 | USD 395 | 64 | 120 |
| December | 1478,1 | 231 | USD 256 | 39 | 132 |
| January | 1667,6 | 210 | USD 282 | 44 | 120 |
| February | 1705,5 | 243,25 | USD 292 | 45 | 139 |
| March | 1781,3 | 236,25 | USD 303 | 47 | 135 |
| Amount | 12991,55 | | USD 1.949 | 307 | 775 |
| | | | Dry season | | |
| April | 1819,2 | 232,75 | USD 308 | 48 | 133 |
| May | 2008,7 | 213,5 | USD 333 | 53 | 122 |
| June | 2046,6 | 243,25 | USD 343 | 54 | 139 |
| July | 2122,4 | 218,75 | USD 351 | 56 | 125 |
| August | 2274 | 222,25 | USD 374 | 60 | 127 |
| September | 2728,8 | 245 | USD 446 | 72 | 140 |
| Amount | 14375,2 | | USD 2.156 | | |

## 4. Conclusions

Indonesia has two seasons, namely six months of dry season and six months of rainy season, this condition greatly affects the high level of solar irradiation in Indonesia. the application of the solar photovoltaic model to harvest solar energy installed on the roadside can produce electrical energy from solar photovoltaic of 27411.3 KWH/year, and can be used as an electric vehicle charging system. The annual electric vehicle charging capability can reach 650 electric cars and 1561 electric bicycles. In addition, the revenue of the rainy season charging system is USD 1,949 and the dry season is USD 2,156 so that the revenue in one year is USD 4,105, indicating that solar photovoltaic can be applied as an effective charging source for electric vehicles.

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