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Design and Analysis of Solar-powered E-bike Charging Stations to Support the Development of Green Campus

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Abstract – *Currently, conventional motorcycles that utilize hazardous fossil fuels are expanding rapidly in Indonesia's major cities. Especially in campus environments, the increase in motorcycle usage has the potential to raise emissions of greenhouse gases and toxic microparticles. The green campus concept entails that campus living must implement low-emission energy efficiency, conserve resources, and enhance environmental quality by teaching its residents how to live a healthy lifestyle. However, limiting the number of motorcycles on campus is the main challenge, especially in Indonesia. To overcome this challenge, this study provides a design for the e-bike system that will be implemented at Universitas Muhammadiyah Yogyakarta (UMY). In addition, a solar power plant is integrated into the design to support the adoption of the zero-emission green energy concept on the campus. The design accommodates specifications for a 6 km radius surrounding the school, a two-day lifespan, and 100 electric bicycles. The experiment's findings indicate that the solar-powered e-bike design requires 99 solar panels with a capacity of 150 Wp, 9 SSCs with a capacity of 100 A, and three inverters with a capacity of 2,500 W. It is projected that this device will reduce exhaust emissions by 7.62 tons of CO_2 per year once it is entirely operated.*

Keywords*:* *Green campus; e-bike charging station; solar power plant; zero-emission*

I. Introduction

In their daily activities, residents need transportation as a means of supporting their activities. Along with the times, the use of motorized vehicles in Indonesia is also getting bigger with a growth of 6% per year [1, 2]. Most of the transportation is conventional vehicles that use fuel that emits carbon dioxide emissions into the atmosphere. Recently, the amount of particulate matter < 2.5 m released into the atmosphere is increasing [3, 4]. This condition causes an increase in air pollution which is linked to premature death due to diseases related to respiratory organs [5–7]. Therefore, reducing pollution from vehicles can be achieved by using environmentally friendly vehicles, one of which is an electric vehicle (EV).

Research on EVs is increasing in recent years [8, 9]. The main challenge in EV research is the high development cost [10–12]. However, EV can theoretically be applied from light to heavy vehicles. The application of the EV concept to light vehicles is more applicable because of the low-cost development process and its simplicity instruments [13]. One of the low-cost EV development projects is an electric bike (e-bike). E-bikes use energy that comes from batteries. Charging the battery can be done via a regular power grid. However, this method has not been able to completely reduce exhaust emissions because most of the power plants especially in Indonesia, are still using fossil-fueled steam power plants. Another alternative to develop

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zero-emission EV concept is by charging the electric bicycle battery to a self-sustaining solar power plant [13].

The utilization of solar power plant makes it an alternative that can be applied in various places [14] including the campus environment e.g., in Universitas Muhammadiyah Yogyakarta (UMY). By carrying out the green campus concept, UMY promotes research related to the design process to the implementation of the e-bike system [15]. Many students travel to UMY campus by motorbike. In fact, the distance between campus and where they live is quite close. The availability of e-bikes can reduce the use of motorcycles which in turn can reduce the use of fuel energy and simultaneously reduce air pollution [16–19]. Furthermore, if students carry out activities on campus, the electric bicycle battery can be charged using a solar panel energy source that is installed in the parking lot.

Charging stations started in 2001 with the introduction of a segway [20]. Currently, various types of products, such as e-bikes are sold by various companies. Although it is difficult to define the shape of the charging station clearly, the charging station has the general features of being environmentally friendly, easy to install, has common socket compatibility, and is connected to the power grid as a power source [21–24]. Charging stations usually use a charging method using a special charger with an external adapter with the battery voltage range varying depending on the e-bike manufacturer. Therefore, the socket at the charging station must be made general with a voltage of 220 V 50Hz according to the characteristics of electricity generation, especially in Indonesia. A charging station that can charge e-bikes in a UMY environment is required with zero-emission specifications. Zero-emission characteristics are obtained by integrating solar panels on the charging station [25–27]. Charging station requirements for e-bike charging must meet safety standards including the level of current ripple required by batteries with various e-bike power adapters [28–30].

The purpose of this research is to design an e-bike charging stations to support the implementation of the zero-emission green campus concept in UMY. Comprehensively, this study presents a calculation of the electrical energy requirements needed in the implementation phase of the e-bike charging station. Furthermore, the need for solar panels and their supporting equipment will be presented, bringing this project closer to the real-world implementation stage.

The rest of this paper is outlined as follows. Preliminary design is described in Section II. Section III reveals experimental results. Section IV provides discussions. Section V concludes this study.

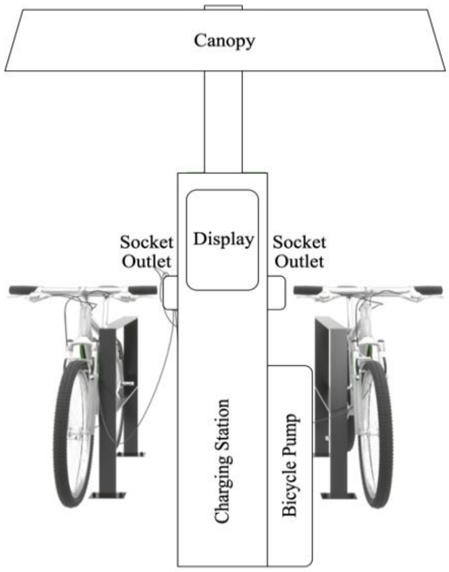

Fig. 1. Desain of charging station which is integrated with a bike parking lot

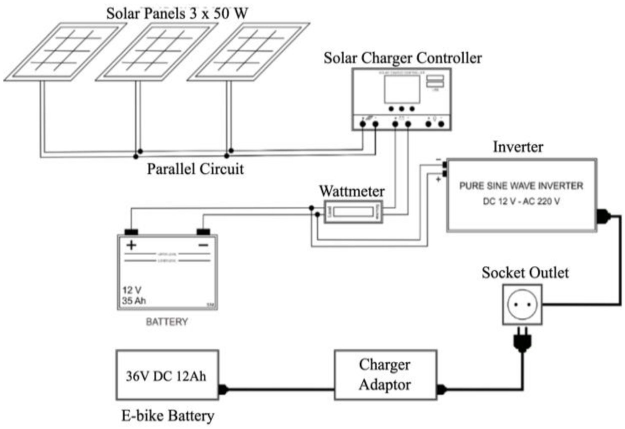

Fig. 2. Preliminary design of a solar power plant using 150 Wp solar panels with a capacity of 142 Wh

II. Design of Solar-powered E-bike Charging Station

The design of the charging station can be seen in Fig. 1. The requirements for supporting components for the charging station will be explained as follows. This research was initiated by calculating the need for electrical energy used by electric bicycles to cover 6 km i.e., the distance usually taken by students who live around the UMY campus. Measurements are made by operating an electric bicycle with that distance. Then, the amount of energy required is measured to determine the specifications of the battery power used. Furthermore, the amount of energy needed is used to calculate the need for solar panels and other equipment needed in solar power plant at the charging station unit. The solar power plant unit scheme is designed as shown in Fig. 2. To calculate the reduction in CO_2 gas emissions, a comparative analysis is carried out by calculating motorcycle exhaust emissions during the same distance. Reducing CO_2 gas emissions is equivalent to the amount of CO_2 gas emissions produced by several motorcycles which are replaced by electric bicycles.

II.1 Electric Bike

An electric bicycle is a bicycle that uses an electric motor as a source of movement and a battery as a source of energy [9]. Electric bicycles are equipped with pedals like ordinary bicycles, which can be used to move the electric bicycle when it runs out of electrical energy in the battery. Batteries are generally charged using a regular power grid with a charging device. Electric bicycles do not produce exhaust emissions compared to conventional motorcycles.

II. 2 Batteries

Batteries or accumulators are electrical energy storage equipment used to supply electric motors. The battery can be recharged using a power source through a battery charger or charger. The type of battery that is widely used is lithium battery. Batteries store energy when solar panels cannot function optimally such as at night or during rain. Batteries that are suitable for use in solar power plant project are batteries that have low self-discharge characteristics [31].

II.3 Electric Motor

An electric motor is a device that converts electrical energy into rotational motion energy which is used to drive bicycle wheels. The type of electric motor that is widely used for e-bike is brushless electric motor [32].

II.4 Controller

An e-bike is a bicycle that uses an electric motor as a source of movement and is equipped with pedals like ordinary bicycles, which can be used to move the electric bicycle when it runs out of electrical energy in the battery. The transition from electric mode and manual mode is processed by a controller which processes data related to driving experiences [33]. Electric bicycles do not produce exhaust emissions compared to conventional motorcycles.

II.5 Solar Panel

Solar panels are the main component of a solar power plant which functions as a converter of solar energy into electrical energy. Solar panels are equipment made of two types of semi-conductor materials which when exposed to sunlight can produce direct current (DC). The growth of solar panels used increases by 9.9% per year in EV projects [34].

II.6 Solar Charger Controller

Solar charger controller (SCC) is an electronic device that is used to regulate the direct voltage that will be charged to the battery to match the required voltage. This device is also integrated with an output voltage terminal to the load. There are 2 types of solar charge controllers that are often used, namely, PWM pulse width modulation (PWM) and maximum power point tracking (MPPT) types [35].

II.7 Inverter

An inverter is an equipment to convert direct current (DC) from battery or SSC into alternating current (AC). The inverter output is usually an AC sine wave with a voltage of 220 volts in Southeast Asian countries.

III. Experimental Results and Discussion

The experiment is divided into several stages. Each experiment will be accompanied by a comprehensive explanation. At the end of this section, a comparative analysis will be compared between e-bike and conventional motorbike in terms of exhaust emissions.

TABLE I
CHARACTERISTICS OF A REGULAR E-BIKE

Day	Experimental Features			
	V_{init} (V)	Distance (km)	V_{final} (V)	Charging Power (kWh)
	40	3	38.65	–
1	38.65	–	40	0.035
	40	3	38.65	–
	38.65	3	37.30	–
2	37.30	–	40	0.058
	40	3	38.65	–

III.1 Testing of Charging and Discharging Characteristics of a Regular E-bike

The first test was carried out on a regular e-bike to determine the battery voltage of an e-bike starting from a full state and after traveling. On the first day of testing, the battery was fully charged with a voltage of 40 volts used to travel 3 km and then recharged and used to cover the same distance. On the second day, the experiment was carried out like the first day's experiment with the battery at the condition after the first experiment, the voltage was 38.65 volts. In this test, the battery voltage is measured in each condition and the time and energy used during battery charging. The test data are shown in Table I. From the battery voltage test and the energy used to charge the battery, it was found that the battery voltage was reduced by about 3 volts after 6 km and to fully charge the battery required energy of 0.058 kWh or 58 Wh.

TABLE II
CHARACTERISTICS OF SOLAR PANEL DURING VARIOUS WEATHER CONDITIONS

Time	Characteristics				Weather
	Solar Panel Voltage Output (V)	SCC Voltage Output (V)	Solar Panel Current Output (A)	Solar Panel Power Output (W)	
08.00	17.05	14.52	1.27	18.44	partly cloudy
09.00	19.25	14.49	1.96	28.40	sunny
10.00	19.11	14.44	0.98	14.15	partly cloudy
11.00	19.05	14.50	1.10	15.95	sunny
12.00	18.60	14.44	0.98	14.15	partly cloudy
13.00	17.88	14.48	0.46	6.66	cloudy
14.00	19.50	14.49	1.81	26.22	sunny
15.00	18.32	14.45	0.74	10.69	partly cloudy
16.00	16.26	14.46	0.14	2.02	sunny

TABLE III
CHARACTERISTICS OF SCC OUTPUT

Weather	Characteristics of SCC		
	Voltage Output (V)	Current Output (A)	Power Output (W)
sunny	14.49	1.96	28.40
partly cloudy	14.44	0.98	14.15
cloudy	14.48	0.46	6.66

III.2 Energy Requirements for E-bikes

The calculation of electric bicycle energy in this study is simulated with the number of electric bicycles with an average distance of 6 km i.e., 3 km commuting to campus and 3 km for the return. From the data listed in Table I, a bicycle requires 58 Wh of energy to charge the battery after traveling a distance of 6 km. It can be concluded that 100 e-bikes require energy of 100 x 58 Wh = 5,800 Wh.

Assuming there is a power loss that occurs in the supporting equipment, the energy requirement needs to be increased by 20%, so that the daily energy requirement is = 120% x 5.8 kWh = 6.96 kWh. Assuming that not every day the weather is sunny, there needs to be energy reserves for 1 day of cloudy weather, then the calculation uses the energy requirement for 2 days which is 2 x 6.96 kWh or 13.92 kWh or 13,920 Wh. This amount of energy requirement is used to calculate the need for solar panels and supporting equipment.

III.3 Testing of Preliminaries Design

Testing of preliminaries design (Fig. 2) is performed by assembling solar panels and battery charging equipment. The specifications of the testing equipment are:

1) 3 solar panels with a capacity of 50 Wp arranged in parallel.
2) The solar charge controller uses a PWM type with a capacity of 20 A and a voltage of 12 volts.
3) 12 Volt battery with a capacity of 35 Ah.

The test was carried out by placing a total of 150 Wp solar panels under the hot sun from morning (08.00) to the end of the afternoon (16.00). Then, the battery charging voltage and current are measured to evaluate the power generated by the solar panel in different weather conditions. The test started with a battery that was initially rated at 12.78 volts. Voltage and current measurements are carried out every 1 hour accompanied by the weather conditions at that time. The test data are arranged in Table II. From the table, it is found that if the weather is sunny, the output power of the solar panels is greater, and vice versa. Table III shows the overall characteristics of power generated by solar panels in different weather conditions.

III.4 Calculation of the Need for Solar Panel

From testing solar panels with a capacity of 150 Wp, it was found that the maximum power obtained was 28.40 watts. For energy calculations, it is assumed that the solar panels work for 5 hours every day. The energy that can be produced by 150 Wp solar panels is = 28.40 Watts x 5 hours = 142 Watt-hours = 142 Wh. To meet the energy needs of 13,920 Wh, then 150 Wp solar panels are needed with number of solar panels = 13,920/142 = 98.03 ≈ 99 units. The 99 units of solar panels will be distributed into 3 charging stations with 33 units each.

Therefore, the number of the component should be a number that can be divided into three.

III.5 Calculation of the SCC Capacity

To calculate the capacity of the SCC required the maximum current value of each solar panel used. The 150 Wp solar panels have a maximum current of 8.72 A. A total of 99 solar panels arranged in parallel have a maximum current of 99 x 8.72 A = 863.28 A. From the result, it is found that the total current capacity of SCC required is at least 863.28 A. In this design, the maximum current capacity of SSC is 100 A, so the required number of SCC is 863.28 / 100 = 8.63 ≈ 9 units. These 9 SCCs will be distributed into three charging stations with 3 units each.

TABLE IV
THE FINAL SPECIFICATION OF THE PROPOSED E-BIKE CHARGING STATION

Parameters	Value	Unit
Energy needs in 2 days	13,920	Wh
Anticipate cloudy/rainy weather	2	days
Solar panel (SP) capacity each unit	150	Wp
Number of SPs	99	units
Maximum Current of SCC	100	A
Number of SCCs	9	units
Number of SP for each SCCs	11	units
Total capacity of inverter	7,000	W
The need for inverter	3 x 2,500 W	units
Battery voltage	12	Volt
Battery power	100	Ah
Battery Depth of discharge (DoD)	80	%
Number of batteries	15	unit

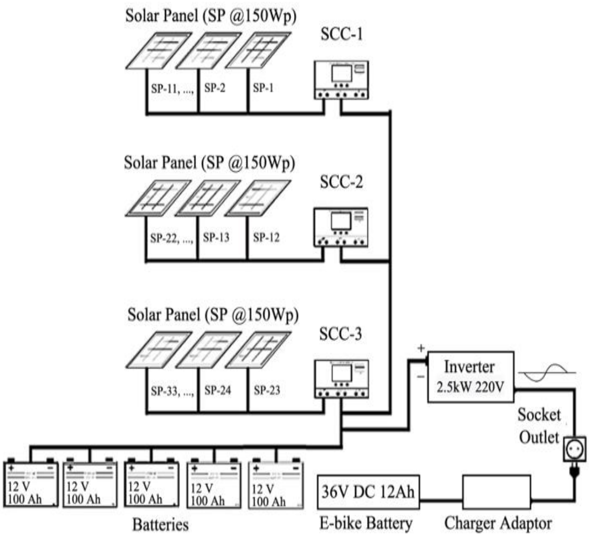

Fig. 3. Electrical design of a solar-powered e-bike charging station

III.6 Calculation of the Need for Inverters

To calculate the number of inverters used, the battery charge time is required in the calculation. From the electric bicycle test data in table 1, it is known that charging the battery takes 50 minutes or rounded up to 1 hour. To meet the energy needs of 100 electric bicycles for 1 day of 6.96 kWh for 1 hour, an electric power of 6.96 kWh / 1 hour = 6,960 rounded to 7,000 Watts is needed. This power is used to calculate the total inverter power of at least 7,000 watts. In order to be distributed to three charging stations, more than 3 inverters are used with 1 inverter per station with a capacity of 7,000 W / 3 = 2,300 W ≈ 2,500 W.

III.7 Calculation of the Need for Batteries

To calculate the number of batteries required, it is based on the energy requirement for 2 days which is 13,920 Wh. In this design, a 12 V battery with a capacity of 100 Ah was chosen, which has the ability to store energy of 12 V x 100 Ah = 1,200 VAh = 1,200 Wh. Assuming a depth of discharge (DoD) value of 80% means that each battery can only provide energy of 80% of the battery capacity, so each battery is expected to provide energy of 80% x 1,200 Wh = 960 Wh. To store electrical energy for 2 days of operation with a capacity of 13,920 kWh, the number of batteries is 13,920 / 960 = 14.5 units ≈ 15 units.

Fig. 4. Test setup of the proposed solar-powered e-bike charging station

III.8 Final Design of the Proposed Charging Stations

To implement the final design, the specifications for the charging station are required which are listed in Table IV. This solar power plant can charge the batteries of 100 electric bicycles. As depicted in Fig. 3, this power plant consists of 3 generating units that can operate separately and independently without connection to the power grid. Each generator is expected to produce one third of the total electricity demand. With a design like this, the reliability of the system can be better and the coverage area of placing charging stations is wider. If there is one system that fails to operate, then the other systems can still serve charging even if the capacity is not full.

The design for one unit of this generator can be seen in Fig. 4. This series of solar power plants consists of 3 SCC 100 A, each of which is used to control the output voltage of 11 parallel solar panels. The SCC output is used to charge 5 12 V 100 Ah batteries and is also connected to a 2,500-Watt 220 V inverter. This circuit is expected to produce energy per day of 3 x 11 x 142 Wh = 4,640 Wh or 4.64 kWh. Energy of 13,920 Wh can be produced by operating 3 generating units with the same capacity simultaneously.

IV. Discussion

The use of EVs such as e-bikes as a modern green transportation system will have an impact on reducing exhaust emissions in the form of carbon dioxide [36–38] and micro-particulate matters [39]. Data from Ministry of Public Works, Research and Development Agency for Research and Development Center for Roads and Bridges reveal that the average CO_2 produced by conventional gasoline or fossil fuel vehicles with a specific specification of 125 cc is 44.1 grams CO_2/km [40]. Using this basis, the CO_2 emissions produced by motorcycles that will be replaced by electric bicycles can be calculated as follows. If the value of CO_2 gas emissions from 1 motorcycle is 44.1 grams CO_2/km and the distance traveled by the research scheme is 6 km/day, then each value of CO_2 gas emissions from 1 motorcycle = 6 x 44.1 = 264.6 grams CO_2. For 100 motorcycles, the emissions produced per day are 100 x 264.6 grams of CO_2 = 26,460 grams of CO_2 = 26.46 kg of CO_2. To calculate CO_2 gas emissions for 1 year for 100 motorcycles with 6 km, it is assumed that 288 working days, the value of 1 year CO_2 gas emissions is = 288 x 26,460 grams CO_2 = 7,620,480 grams CO_2 = 7,62 tons of CO_2. With the use of 100 electric bicycles with battery charging from solar power plant as a substitute for motorcycle transportation, 100 units are expected to reduce CO_2 gas emissions on campus and its surroundings by 26.46 kg CO_2/day or 7.62 tons CO_2/year. Furthermore, it is estimated that emissions reductions are 60%-93% in the US and 28%-93% in China compared to converting gasoline-powered vehicles to EVs [41]. Results indicate that systems located in commercial or office parking lots and used to charge EVs during working hours can be a feasible solution in all locations from a technical and environmental standpoint.

V. Conclusion

E-bikes are predicted as a convenient transportation to support the green campus concept because of their easy maintenance and low implementation costs. The charging station on the e-bike can encourage the massive deployment of this EV because it provides wide accessibility in the campus area. The concept of green energy on this campus is currently only a quasi-implementation because, the application is mostly on converting energy into electrical energy. Whereas electrical energy is still supplied by conventional power plants, e.g., coal and oil. This study presents the concept of zero-emission in the design of a charging station that supports the implementation of e-bike system in UMY. This paper demonstrates the difficulty of solving important problems that must be addressed in the development of solar-powered charging stations. (1) The energy used by 1 electric bicycle to travel the distance from residence to campus with 6 km is 58 Wh, and for 100 bicycles it takes 5.8 kWh per day. (2) The energy required to charge the batteries of 100 electric bicycles including the energy loss in the equipment required is 13.92 kWh for 2 days of charging. (3) To obtain energy of 13.92 kWh/day, 99 solar panels with a capacity of 150 Wp are required and 9 Solar Charger Controllers with a capacity of 12 volts 100 amperes. (4) To store the electrical energy produced by solar panels, 15 batteries with a capacity of 100 Ah 12 V are needed. (5) To convert the DC battery voltage to 220 V AC voltage, 3 inverters with a capacity of 2,500 W are needed. (6) At the end, a reduction in greenhouse gas emissions of 26.46 grams CO_2/day or 7.62 Tons CO_2/year can be realized when the system fully operated. This study concludes that the proposed design can be implemented to completely realize the zero-emission green campus concept.

Acknowledgment

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