Development and Testing of Prototype-Scale Off-Grid Solar Power Generation for Electric Charging Station

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Abstract: The demand of electricity that keeps increasing necessitates additional electricity generation. The highly dependence of power generation on fossil fuels implies the intensive use of this resources that may cause them finish sooner than predicted. On the other hand, the use of fossil fuels for transportation is quite dominant. The development and use of electric transportation system is a solution for reducing fuel consumption. However, the electricity for supplying the electric transportation system is mainly from the generation system that uses fossil fuels. For further improvement, the energy supplied to the transportation system should come from the renewable energy generation. This may lead to minimum use of fossil fuels besides giving minimum effect on environment. This paper presents the development of renewable energy generation where the generated power is used to supply the storage that charges the electric bicycle. The power is generated by solar photovoltaic panels and it is saved in a battery. The charging for the bicycle is taken from the battery. The developed system is off-grid since the system may be placed in the non-electrified area. This prototype will be a role model regarding the combination of renewable energy generation and green transportation system.

Keyword: Solar PV, Electric bicycle, Charging station, Renewable energy.

INTRODUCTION

Electrical power is expected to be the main and important commodity in the future. There are some reasons behind this prediction. This power may be generated using various resources. The generated power may be efficiently transmited across long distance. From the consumer perspective, this power may be used for different purposes depending on the apparatus using this power. The increasing price of fossil fuels is another reason why people move to use electricity. As a result, the demand for electricity tends to increase in the future [1].

The generation of electric power so far depends on fossil fuels. Consequently, the more demand to fulfil, the more fuel is required. Considering the quantity of fossil fuels that may be more limited in the future, electricity generation must use different resources preferably renewable resources [2]. Besides economic aspect, environmental conservation is another consideration of using renewable resources [3].

It is broadly accepted that power generation using renewable energy resources is the main issue for sustainable energy supply. This is due to this is either inexhaustible or non-polluting. There is a worldwide trend to gradually include renewable energy generation for fulfilling the electricity demand. Considering the current growth rate of renewable energy generation, it is predicted that the goal of replacing fossil-fuel based electricity generation with renewable energy generation will be faster than expected. There are some practical data indicating that the combination of some renewable energy sources for electricity generation will reach 100% therefore completely eliminating the electricity generation depending on fossil fuels [4].

In term of transportation system, people mobility is one of the phenomena related with economic growth and country development. This would be a common challenge on how to enhance people mobility and, at the same time, to reduce congestion, traffic accident and air pollution. It is reported that urban road transport is the main source of air pollution, which contributes 75% - 85% of pollutant emission [5]. Therefore, the attempt of reducing gas emission may be carried out while still letting the people move for their activities. The need of reducing greenhouse gas from transportation sector may lead to 2 innovations, electric vehicle and car club. The last scheme enables fewer car owner that may lead to use less fossil fuel. These schemes are expected to enable gas emission control, sustainable development, economic growth and energy security [6].

Another issue regarding transportation sector is the dominant use of vehicle or motorcycle powered by fossil fuel-based engine. This sector is indicated to cause intensive consumption of fossil fuel leading to persistent reduction of fuel deposit. Together with other sectors that also take fossil fuels, the trend of fuel consumption will continue increase, which causes the fuel deposit is predicted to finish faster. According to

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studies on 2019 carried out by international oil companies and independent energy organizations, it is predicted that oil reserves will be depleted in about 50 years. Some developed countries are taking studies on how to completely fulfil energy demand for electricity, heat and transportation from renewable energy resources by 2050 [7]. On the other hand, environmental effect of fossil fuel consumption is another great concern. Transportation sector seems to be the one responsible for both problem. In one hand this sector takes much fuel causing considerable fuel deposit reduction, and, on the other hand, this leads to pollution problem [8]. It would be a dilemma, while transportation sector is required by people, yet it may lead to some drawbacks. Without a strategic intervention, the problem of fuel consumption and CO_2 emission may persist or even rapidly increase [9]. Looking for answers on how transportation system is operated using resources other than fossil fuel that concurrently implies minimum environmental problems would be the best option in this situation [10].

Solar photovoltaic is prospective for future application of energy generation due to the simplicity of energy conversion and the lifetime of the device. These advantages lead to the extensive use of solar photovoltaic either in the form of stand-alone scheme or grid-connected system [11]. The construction of solar photovoltaic may be adaptable in the form of ground-mounted, rooftop, building integrated, and roof-jack mounting. On the other hand, the performance of solar photovoltaic depends mainly on conversion efficiency determined by the factor of material, construction and spectrum [12]. For optimal energy conversion, some strategies are further taken into practice that may include providing heat exchanger, or using an active cooling to avoid temperature increase that may reduce the efficiency [13].

The use solar PV panels for electricity generation, which is used for charging the electric vehicle or motorcycle would be the more comprehensive solutions for some aforementioned problems [14-15]. These include minimizing the use of fossil fuels for power generation and for engine operation. This scheme also reduction of air pollution.

This paper proposes the generation of electricity using solar PV and the use of the generated power to energize electric bicycle [16]. An accumulator is employed to store the energy generated by solar panels. The energy generated by the panels is not always used and therefore it is necessary to save it in the battery. The stored energy is used to charge the electric bicycle when it is parked. The developed system includes 4 components: (1) solar PV panels that generate power, (2) solar charger controller (SCC) that regulates the charging power and avoids over-charging of battery, (3) battery that stores the energy from the panels, and (4) inverter that converts the DC power from the battery into AC power to energize the bicycle.

The generating system is developed as off-grid or stand-alone, which is not connected to the grid. The main reason of this choice is because the size of the system is small, and the generation system is only to supply the charging system for electric bicycle [1]. Moreover, the system may be located at the area of non-electrified. The system works well for generating power sufficient to charge the electric bicycle.

SYSTEM DESIGN

The system includes solar PV panels that generates power, and the output is regulated to charge the battery. The inverter is employed to provide AC power to charge the Li-ion battery of electrical bicycle. This system is developed in form of parking station where the bicycle is parked when it is not in use. This parking station is portable that can be located at the place where the electricity may be unavailable. However, it is required to have sufficient sunlight during the daylight. The diagram of the developed system is shown in Figure **1**. For safety, a number of fuses are inserted between solar panels and SCC, between SCC and

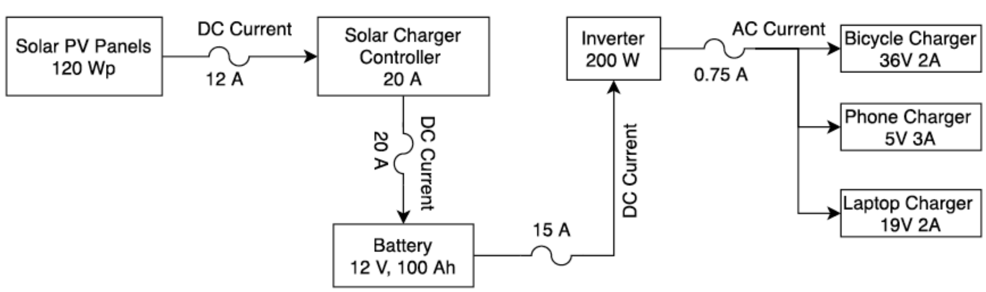
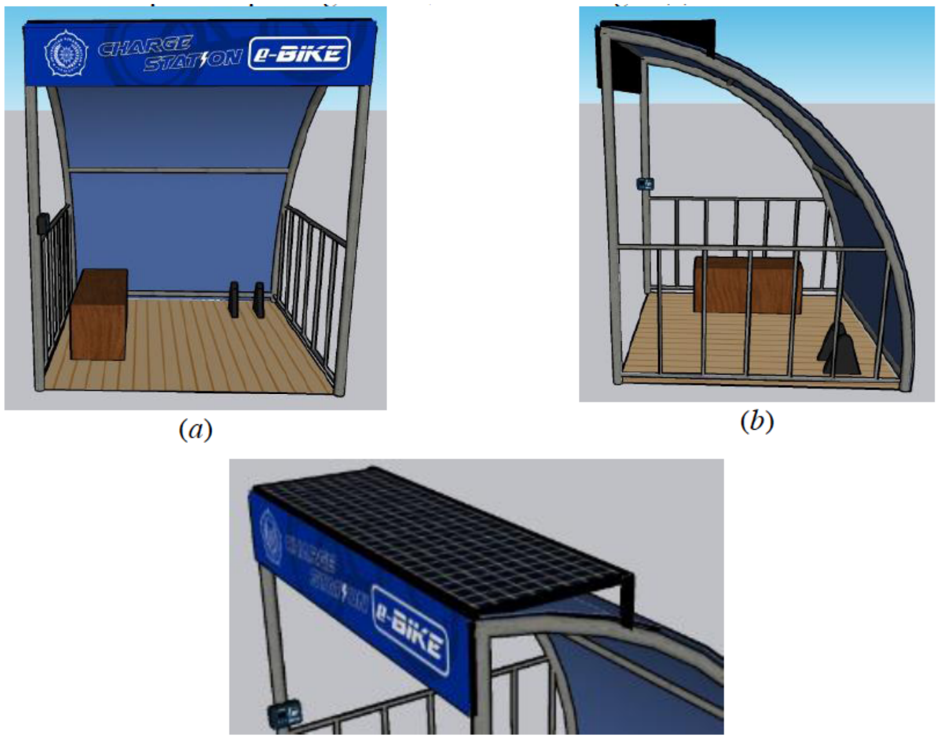


Figure 1: The scheme of solar PV power generation integrated with charging system.



(*a*) (*b*) (*c*)

Figure 2: The design of parking station with solar panel on the top.

battery, between battery and inverter, and between inverter and charging ports. Besides for charging the Li-ion battery of electric bicycle, the system also provides the charging for smartphone and laptop.

The design of parking station is given in Figure **2**. The main frames are made from metal with proper type and size covered by fiber glass, as shown in Figure **2**(***a***) and (***b***). The solar PV panels are placed on the top of the parking station, as shown in Figure **2**(***c***).

The support for the panels is made from metal with the size of 200 cm x 67 cm. The back side of the panels is elevated with 30 cm and is supported by a metal. The design of the roof of parking station is shown in Figure **2**(***c***). On the right side of the floor, a long box with the size of 100 cm x 30 cm x 15 cm is placed. This consists of two compartments that are used to put the battery in the front side and electric panel in the back side. This box is designed to be strong enough for the people to sit down. The box design is shown in Figure **3**. The electric panel is made from aluminum plate with the size of 40 cm x 30 cm x 15 cm. This contains some electric devices. The design of the panel is given in Figure **4**.

Figure 3: The box on the floor.

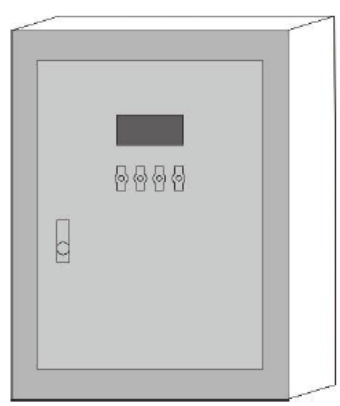


Figure 4: The electrical panel box.

The electric bicycle will be automatically charged when it is parked. The proper position of the bicycle will make the connection of the bicycle charging socket with the outlet of power source from the inverter. This also locks the bicycle, which can only be unlocked electronically using RFID Card. The locking and charging port of the bicycle is shown in Figure **5**.

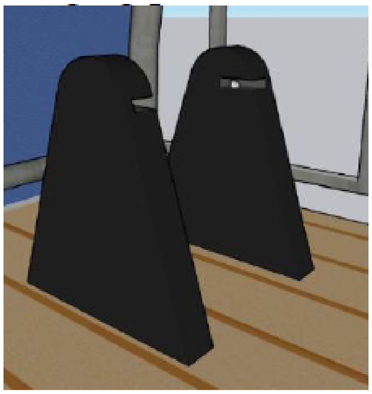


Figure 5: The bicycle locking system with charging port.

SYSTEM IMPLEMENTATION

Following the design, the implementation on the real system is given by the following. The whole system consisting of the main frame, covered by fiber glass with solar PV panel on top is given in Figure **6**. There are also some equipment and devices included in the system.

The long box that is also used as a seat is placed on the right-side floor as shown in Figure **7**(***a***). Inside the box, as shown in Figure **7**(***b***) an accumulator is placed in the front side and an electric panel is placed in back side. As a stand-alone system some additional facilities are also provided, including the charger ports for mobile phone and laptop.

When the bicycle is not in use, it is parked in the given place. There is locking system for the bicycle to avoid this is stolen by people. Once the bicycle is properly locked the socket of the bicycle is connected

Figure 6: The parking system with charging facilities.

(*a*) (*b*)

Figure 7: The parking system with charging facilities.

to the electricity outlet and the charging starts. The charging system for the bicycle is shown in Figure **8**.

Figure 8: The bicycle charging system that also lock the bicycle.

RESULT AND DISCUSSION

Table 1: The Specification of the Installed Solar PV Panel

Model	SP 120-18M
Peak Power (Pmax)	120 W
Cell Efficiency	21.50%
Max. Power Volt (Vmp)	19.2 V
Max. Power Current (Imp)	6.25 A
Open Circuit Volt (Voc)	24.8 V
Short Circuit Current (Isc)	6.65 A
Power Tolerance	+ - 3%
Max. System Voltage	1000 V
Series Fuse Rating (A)	12
Number of bypass diode	3
Operating Temperature	-4°C to 85°C
Max. System Voltage	1000 V DC
Standard Test Condition	1000 W/m^2, 25°C, AM=1.5

The system implementation started with the installation of solar panels followed by some assessments for the generation performance. Some alignments were carried out in term of panel position/direction to assure that generation achieves the maximum point. The measurements were carried out for the generation panels for both sunny and cloudy conditions. The specification of solar PV is given in Table **1**.

For the developed system, 2 panels are connected in parallel and the measurement of solar PV performance was carried out for the condition of sunny and cloudy condition. There were 5 samples taken for the measurement and the parameters measured for the condition of sunny and cloudy are given in Table **2** and **3**, respectively.

It may be observed from the measurements that at the sunny condition, the output voltage of the panels is higher than that at cloudy situation. While the data were taken at the different day, they can still be roughly compared. The average of output voltage from panels at sunny and cloudy conditions when it is disconnected to SCC is 21.06 V and 20.22 V, respectively. It may also be observed from Table **2** dan Table **3** that the output voltage of panels when it is connected to SCC at sunny condition is slightly higher than that at cloudy situation. The average of output voltage at sunny and cloudy conditions is respectively 13.96 V and 13.59 V.

Consequently, the output current from the panels is also higher at sunny condition than that at cloudy situation. The average of output current from the panels at sunny and cloudy condition is 7.996 A dan 7.226, respectively. Moreover, the output voltage of SCC at sunny condition is higher than that at cloudy situation. The average value of this is 13.34 V and 12.94 V, respectively. While these voltages are different, both of them are higher than the voltage of

Table 2: The Measurement of Solar PV Performance at Sunny Condition

No	Time	Temp (°C)	Panels Output				SCC Output		
			V-out disconnected from SCC (V)	V-out connected from SCC (V)	I-out (A)	P (W)	V-out (V)	I-out (A)	P (W)
1	10.00	38	20.86	13.90	8.68	120.65	13.5	10.1	136.35
2	11.00	40	21.35	14.01	9.04	126.65	13.5	10.4	140.40
3	12.00	39	21.39	14.05	8.70	122.24	13.4	9.8	131.32
4	13.00	39	20.76	13.88	7.30	101.32	13.2	8.3	109.56
5	14.00	40	20.93	13.95	6.26	87.33	13.1	7.2	94.32

Table 3: The Measurement of Solar PV Performance at Cloudy Condition

No	Time	Temp (°C)	Panels Output				SCC Output		
			V-out disconnected from SCC (V)	V-out connected from SCC (V)	I-out (A)	P (W)	V-out (V)	I-out (A)	P (W)
1	10.00	38	19.86	13.54	7.71	104.39	12.7	7.2	91.44
2	11.00	30	20.44	13.68	7.92	108.35	12.9	7.7	99.33
3	12.00	31	20.67	13.70	7.67	105.08	13.1	8.5	111.35
4	13.00	32	20.39	13.62	7.02	95.61	13.1	7.9	103.49
5	14.00	25	19.74	13.41	5.81	77.91	12.9	6.2	79.98

battery. It is necessary to enable current flowing from the SCC into the battery and to make the charging of battery happens. This situation is shown in Figure **9** that indicates the reduction of output voltage at cloudy condition for both panel and SCC.

It may be noted from the tables that the charging current at sunny condition is higher than that at cloudy situation with the average of 9.2 A and 7.5 A, for sunny and cloudy condition, respectively. This implies that at sunny condition the charging for the battery is faster than that at cloudy condition. This may happen that, in one day, the condition may change between sunny and cloudy and, therefore, the charging speed may be different according to the weather condition.

The tables also describe that, in general, the power generated by panels at sunny condition is higher than that at cloudy situation. The average of this is 111.64 W and 98.27 W, for sunny and cloudy condition, respectively. This confirms that the output of solar PV is affected by the level of sunlight, where the sunny condition gives better performance than at the cloudy situation.

Another device included in this system is inverter. This is employed to provide AC power for different purposes, including bicycle battery charger, smartphone charger, and laptop charger. However, the main purpose is for charging the battery of bicycle. In this study, the performance of the inverter was also checked. The measurement results are given in Table **4**.

From the test, it may be observed that for the condition of no load, there was a measured input

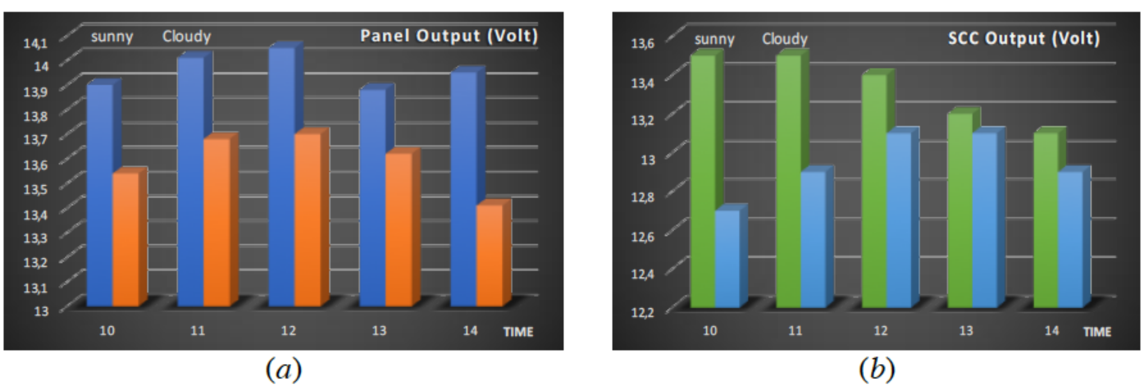


Figure 9: The output voltage of (**a**) panel and (**b**) SCC for sunny and cloudy condition

Table 4: The Measurement of Inverter

Load	DC Input			AC Output		
	Voltage (V)	Current (A)	Power (W)	Voltage (V)	Current (A)	Power (W)
No load	12.4	0.2	2.48	218	0	0
Battery Charger (72 W)	11.9	6.1	72.59	202	0.34	68.68

current of 0.2 A and the power of 2.48 W. This is due to the internal power use in the inverter *e.g*. fan. In addition, there is internal losses in the device. When a load of 72 W was applied to the inverter, the input power of 72.59 W was measured. This again confirms the losses of the inverter that results in additional power at the input terminal. It may also be observed that the voltage at both input and output terminal drops due to this loading. This is because the current increase that leads to the bigger voltage drop.

The charging process for the battery was also observed in this study. The battery of electric bicycle is 36 Volt, 10 Ah. The charging progress of the bicycle battery is shown in Table **5**. The power that is used to charge the electric bicycle is from the battery that stores energy from the solar PV panels. The battery of bicycle is normally not charged until it is fully charged but bicycle is charged when it is parked and not in use. In general, the charging process is running well, and this indicates that the inverter works properly.

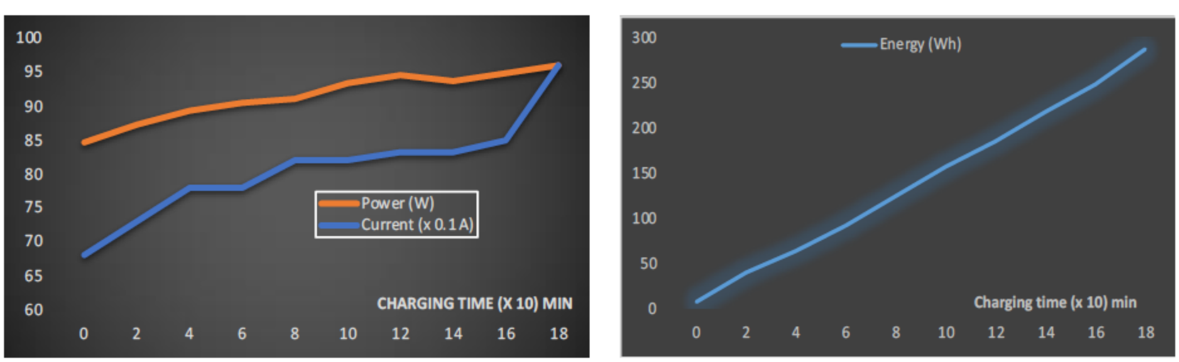
Table 5: The Charging Progress of Bicycle Battery

Charging Duration (Min)	Charging Current (A)	Power (W)	Stored Energy (Wh)
0	6.8	84.5	7
20	7.3	87.3	39.2
40	7.8	89.1	62.2
60	7.8	90.3	92.1
80	8.2	91.1	123.9
100	8.2	93.3	156.5
120	8.3	94.3	184.1
140	8.3	93.7	217.3
160	8.5	94.6	249.0
180	9.6	95.9	286.8

The fluctuation of charging current and the related power is shown in Figure **10**(***a***). This figure indicates that the charging current varies due to factors affecting the panel output. The power is basically related with the current and therefore the power changes according to the current. Please be noted that the curve of current at Figure **10**(***a***) is multiplied by 10 in order to have a proportional plotting in the plane. The value of current is comparatively small and therefore plotting together in the same plane will make the figure unclear. The progress of storing energy in battery is shown in Figure **10**(**b**). The charging process of bicycle's battery is accumulative and, therefore, the energy stored in the battery is about linear. Taking into account the average of charging current of 8.08 Ampere and the battery deficiency of 20%, for the battery of 100 Ah, it will be fully charged after 10 hours. However, as previously described, the battery will not be fully charged since it may be used before it. On the other hand, the bicycle will always be charged when it is parked in the station.

CONCLUSION

The generation system using solar PV panels is developed as off-grid or stand-alone system. The system is integrated with charging station for electric bicycle. The power generated by the panels is regulated by Solar Charger Controller (SCC). This assures that the voltage is big enough and enables current flowing from SCC to the battery. To provide power for charging purpose, an inverter is employed to convert the voltage from battery into AC voltage. From the charging progress, it may be confirmed that the inverter properly works. The weather condition affects the performance of solar PV generation where for the sunny condition, the generated voltage is higher and the charging current is higher than that at cloudy situation.



(*a*) (*b*)

Figure 10: (**a**) The charging current and the related power (**b**) the progress of storing energy.

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