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Prototype of Battery Charger Using Solar Panel with Fast Charging Method

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Abstract

The electrical energy is a part of important roles to support the daily human activities such as the sector of residents, industrial and transportations. The need for electrical energy always increases along with population growth. To meet electrical energy needs, steps are needed to develop and utilize renewable energy such as solar energy. In Indonesia, the utilizing of solar energy source is very potential because it has not been optimally used for the daily activities and Indonesia is a tropical country located on the equator. In this paper, prototype of battery charger fast charging method is carried out by utilizing the solar energy. Battery charging system consists of photovoltaic (PV) or solar panel, battery, buck converter and microcontroller. Buck converter is employed to produce the voltage desired so that current charging refers to charging current limit of battery. Buck converter is controlled by microcontroller with arranging its duty cycle (D) to yield voltage charging. The test results show that the proposed battery charger system can be operated under normal charging and fast charging. The test is done by charging battery from empty to full capacity with the battery capacity of 7 AH 12 volt. The battery charging time is around 12 hours with a charging current of 0.7 ampere (10% of battery capacity) on normal charging. Meanwhile, the battery charging time takes 5.6 hours and the charging current is 1.5 ampere (21.4% of the battery capacity) on fast charging method.

Keywords: Buck converter, Solar panel, Fast charging, Battery charger, Duty cycle

1. Introduction

Solar energy is a source of energy whose availability will never run out. This energy can be used as alternative energy by converting it into electrical energy using solar panels. Solar panels are able to operate properly in all parts of the earth that receive sunlight. Solar panels also do not produce pollution which harms the environment, so they are environmentally friendly [1,2,3]. The use of solar energy sources is very potential in Indonesia because Indonesia is a tropical country which is located on the equator. Sunlight can be received for 10 to 12 hours every day and its intensity is affected by weather conditions such as sunny, cloudy and rainy respectively. However, solar energy has not been optimally used in the daily activities as an electrical energy sources. The average intensity of solar energy per day is 4.5 kWh/m2 [4,5,6].

One of the uses of solar energy is for charging the battery. The electrical energy generated by solar panels still requires a controller which functions to regulate the output voltage and current before being connected to the battery. This controller is known as the charger controller. The charger controller is required to step down the voltage from the solar panels, so that the battery voltage does not exceed the tolerance limits of the battery specifications [1,2].

In the process of charging the battery, the DC current flow from the solar panel will be cut off so that the battery does not experience overcharging and the battery lifetime can be longer. Controlling the battery charging process by connecting and disconnecting the DC current flow from the solar panel to the battery is the most basic function of a charge controller [3]. Many methods of the charger controller have been proposed and discussed by many researchers. A charger controller with a solar energy source has been designed using three stages methods such as constant current charging, constant voltage charging and a float voltage charging [2,7,8]. The constant voltage charging method has also been proposed for solar charger controller [3,9]. Charger controller using methods of bulk and a float voltage charging has been designed and implemented [10]. In addition, design and implementation of solar charger controller with fast charging method has been proposed [1]. However, it hasn't used a microcontroller as an equipment controller yet.

In this paper, design and implementation of battery charger using fast charging method is carried out using electricity source from solar panel. Battery charging system consists of photovoltaic (PV) or solar panel, battery, buck converter and microcontroller. Buck converter is employed to produce the desired voltage so that current charging can be maintained constant according to charge current limit of battery. Buck converter is arranged by microcontroller with controlling its duty cycle to produce voltage charging. The test results show that the proposed battery charger system can be operated properly under normal charging and fast charging. The test is carried out by charging battery from empty to full capacity with battery 7 AH 12 volt. The battery charging time is around 12 hours with a charging current of 0.7 ampere on normal charging. Meanwhile, the battery charging time takes 5.6 hours and the charging current is 1.5 ampere on fast charging. A comparison of the proposed battery charging method with previous battery charging methods can be seen in Table 1.

Table 1. Comparison of Battery Charging Methods Proposed and Previous

No.	Authors	Charging Methods	Controllers
1.	D. K. Yaqin, et al [1]	Fast Charging	Not Available
2.	S. Yoomak,et al [2]	Three Stages Charging : Constant Current, Constant Voltage, and a Float Voltage	Not Available
3.	A. I. Ramadhani, et al [3]	Constant Voltage Charging	Not Available
4.	R. A. Sadewo, et al [7]	Three Stages Charging : Constant Current, Constant Voltage, and a Float Voltage	Arduino ATmega 1280
5.	Budiarto, et al [8]	Three Stages Charging : Constant Current, Constant Voltage, and a Float Voltage	Arduino Nano
6.	I. G. Y. Siregar, et al [9]	Constant Voltage Charging	Not Available
7.	Suriadi, et al [10]	Bulk and Float Charging	Arduino Uno ATmega 328

8.	**Proposed Battery Charger**	**Fast Charging**	**Arduino ATmega 2560**

2. Research Methodology

The design of charging batteries using solar panel with the fast charging method employs a buck converter as a charger voltage controller. Charger voltage is arranged to provide the charger current according to charger current desired. The buck converter is controlled using a microcontroller by sending a Pulse Width Modulation (PWM) signal based on its output voltage and current. The block diagram of the battery charging system with fast charging method is shown in Figure 1.

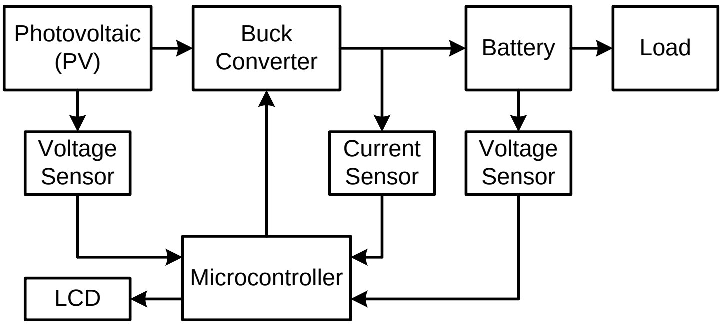

Figure 1. The block diagram of the Fast charging system

Meanwhile, the battery charging process with fast charging method can be seen in Figure 2. The battery charging process is begins by reading the photovoltaic voltage, charging current and battery voltage. The voltage and current are used by the microcontroller to control the battery charging process. The battery charging process will occur if the photovoltaic voltage exceeds 16 volt, the charging current is 1.5 ampere and the battery voltage is below 14.4 volt. The charging process will finish when the battery voltage reaches 14.4 volt.

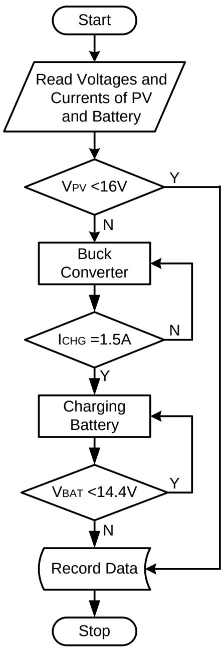

Figure 2. Flowchart of the Fast Battery Charging

2.1. Photovoltaic (PV)

Photovoltaic (PV) is main equipment to convert the solar energy to the electrical energy through a process of photoelectric. The PV energy provided is direct current (DC) voltage [11,12]. Currently, PVs have various forms and types, each of which has its own ability. Several types of PV on the market are Mono-crystalline and Poly-crystalline [12]. Figure 3 show types of photovoltaic.

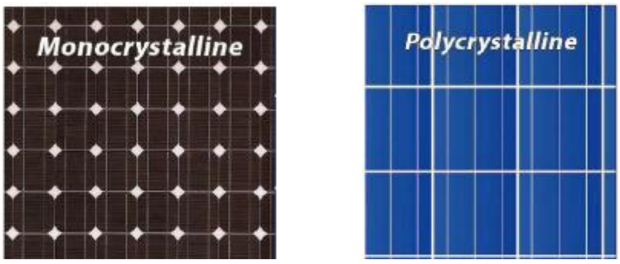

Figure 3. Types of photovoltaic [12]

Capacity of PV (*Wp*) is determined from electrical energy (*Wh*) used load in one peroide time (hour) and magnitude of solar radiation energy (kWh/m2). Several factors that influence PV capacity are weather conditions, temperature (^{0}C), cables, inverter, battery and solar charge controller (SCC).

2.2. Voltage Sensor

The voltage sensor has the function of reading the magnitude of voltage in a system. This voltage sensor converts analog voltage data to digital voltage data for further processing in the microcontroller. The voltage sensor generally takes the form of a voltage divider circuit or what is usually called a voltage divider [13]. Voltage sensor can be seen in Figure 4.

Figure 4. Voltage Sensor [13].

2.3. Current Sensor ACS712

Current sensors are needed to read current in solar panels, batteries and loads. This current sensor converts current into analog voltage to be processed by the microcontroller. The ACS712 current sensor is a low-offset linear Hall circuit with one track made of copper. This current sensor works based on current flowing in a copper cable which produces a magnetic field. Next, the magnetic field is captured by the integrated hall IC and converted into voltage proportionally [13]. Current sensor is shown in Figure 5.

Figure 5. Current Sensor ACS712 [13]

2.4. VRLA Battery

Battery is electronic device that can store electrical energy to be converted into electrical power. Battery produces electricity through a reversible electrochemical process. This process shows that in the battery there is a process of changing chemical energy into electrical energy and conversely from electrical energy to chemical energy. A well-known type of battery is the valve regulated lead acid battery (VRLA). VRLA battery is a type of battery with sulfuric acid electrolyte absorbed by a separator. This battery design is made with the battery cell space in a closed condition (sealed) without holes or air channels. That way, the liquid in the battery will not spill. VRLA battery is also called maintenance free (MF) battery, because the battery is equipped with valve which function to keep the pressure inside the battery from exceeding safe limits. VRLA battery is widely used in large portable electrical equipment, off grid power systems and electrical systems that require large power storage at relatively low costs [8,13]. Figure 6 show VRLA battery type.

Figure 6. VRLA Battery [8,13]

Battery capacity is expressed in Ah (ampere hours). The large capacity of the battery shows that the electrical energy stored is also greater. There are 2 ways to charge the battery, such as normal charging and fast charging [10].

a. Normal Charging

Normal charging is charging with a current of 10% of the battery capacity. The length of charging time can be determined using Equation (1).

$$Charging\ Time\ (hours) = \left(\frac{battery\ capacity\ (Ah)}{charging\ current\ (A)}\right) + 20\% \tag{1}$$

An additional 20% is calculated from the division of battery capacity and charger current.

b. Fast Charging

Fast charging is charging with a very large current. The charging current cannot be more than 50% of the battery capacity.

2.5. Buck Converter

Buck Converter is an electronic circuit that functions as a step down DC to DC voltage converter using the switching method. Buck converter can also be called chopper. The buck converter circuit consists of switching (S), diode, inductor (L) and capacitor (C). Switching components (S) are semiconductor equipments such as transistors, MOSFETs or IGBTs. Figure 7 shows the buck converter circuit [1,7,10].

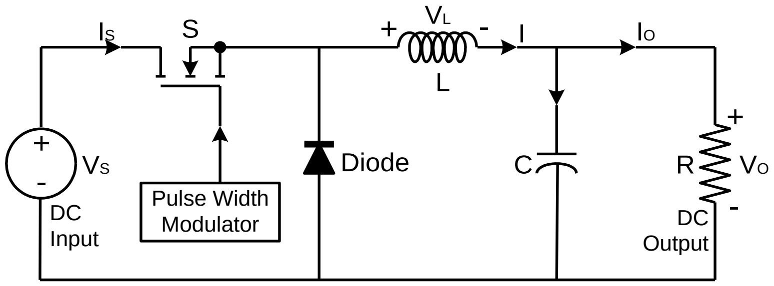

Figure 7. Buck Converter Circuit

The buck converter output voltage is controlled by adjusting the duty cycle (D) value of the pulse width modulation (PWM) signal. This duty cycle setting is done by adjusting the pulse width of the PWM signal. The buck converter output voltage is the average value of the output voltage produced. Figure 8 shows the PWM signal.

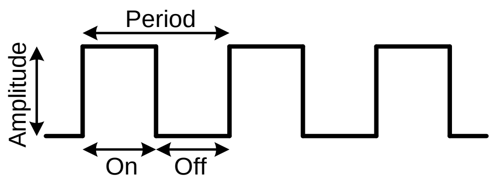

Figure 8. PWM Signal [10,13]

The duty cycle or length of time on is the comparison value between the time on (T_{on}) and the period (T). T_{on} is the time when the output voltage is in the high position, while T_{off} is the time when the output voltage is low. The definition of duty cycle is shown in Equation (2).

$$D = \frac{T_{on}}{T_{on}+T_{off}} = \frac{T_{on}}{T} \tag{2}$$

Where, D, T_{on}, T_{off} and T are respectively duty cycle, time on, time off and period.
The output voltage can vary depending on the size of the duty cycle (D) given. It can be formulated as in Equation (3).

$$V_{out} = D\ x\ V_{in} = \frac{T_{on}}{T}\ x\ V_{in} \tag{3}$$

Where, V_{out}, V_{in}, D, T_{on} dan T are output voltage, input voltage, duty cycle and period respectively.

Equotion (2) shows that the output voltage can be changed directly just by changing the duty cycle value. When the T_{on} value is equal to the period (T), then the output voltage is the same as the input voltage. Contrarily, when the T_{on} value is zero, the buck converter output voltage is zero.

2.6. Arduino ATmega 2560

The Arduino Mega board is similar to the Arduino Uno. Both Arduinos use USB Type A to B for programming. The Arduino Mega uses a higher ATMEGA2560 chip and more digital and analog I/O pins when compared to the Arduino Uno board. Arduino Mega has 15 pins that can be used as PWM output, 16 analog inputs, 4 UART (Hardware Serial Port), 16MHz crystal oscillator, USB Connection, ICSP header, and reset button [13]. Figure 9 shows the Arduino ATmega2560.

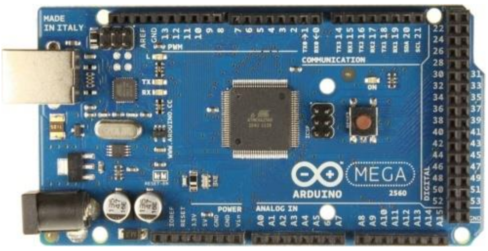

Figure 9. Arduino ATmega 2560 [13]

3. Result and Discussion

Prototype of battery charger using solar panel with fast charging method is shown in Figure 10. The effectiveness of proposes fast charging method is clarified by testing the prototype. Testing is carried out by connecting the solar panel and battery to the input terminal and output terminal on the prototype. Prototype testing consists of solar panel testing, normal battery charging testing and fast battery charging testing. Whereas, the specification of equipments employed in the prototype can be seen in Table 2.

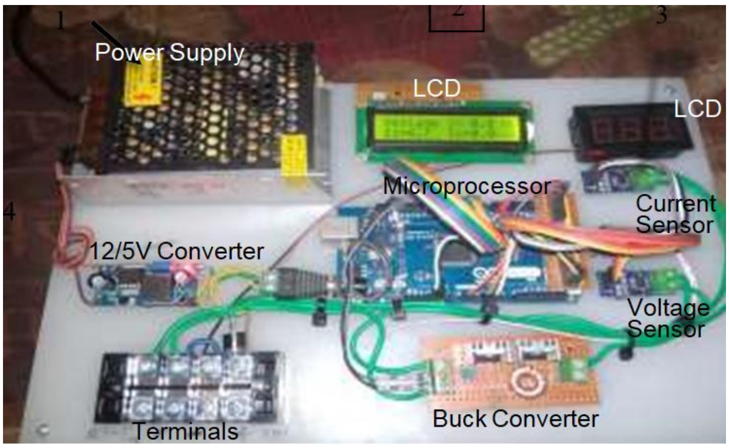

Figure 10. Prototype of the Battery Charging with Fast Charging Method

Table 1. Specifications of Equipments

Equipments	Specifications
Microcontroller	ATmega 2560 type
Solar Panel	100 Wp

Battery	VRLA 12Volts, 7AH
Current Sensor	ACS 712
Voltage Sensor	PZEM-004T

3.1. Testing of Photovoltaic (PV) Panel

PV panel testing is done by measuring the output voltage of the PV panel from 06.00 a.m to 06.00 pm. Table 3 shows the result of PV panel testing. Table 3 shows that maximum PV output voltage is 20.4 volts at 11.00 and minimum PV output voltage is 12.5 volts at 06.00 a.m.

Tabel 3. Results of PV Panel Testing

Time	Voltage (Volt)
06.00	12.5
07.00	13.9
08.00	15.3
09.00	16.8
10.00	19.2
11.00	20.4
12.00	19.6
13.00	19.1
14.00	18.2
15.00	17.3
16.00	15.9
17.00	14.5
18.00	13.1

3.2. Testing of Normal Charging:

Testing of normal charging is carried out by making the current battery charger of 0.7 amperes (10% of battery capacity). Result of normal charging testing can be seen in Table 4. From Table 4 shows that the time of normal charging method is about 12 hours which the battery voltage has reached 14.4 volts (100% of battery capacity).

Tabel 4. Results of Normal Charging Testing

Time (hours)	Battery Voltage (Volt)	Battery Current (Ampere)	Battery Capacity (%)
1	11.8	0.7	81.9
2	12.1	0.7	84.0
3	12.4	0.7	86.1
4	12.7	0.7	88.2
5	13.0	0.7	90.3
6	13.3	0.7	92.4
7	13.5	0.7	93.8
8	13.7	0.7	95.1

9	13.9	0.7	96.5
10	14.1	0.7	97.9
11	14.3	0.7	99.3
12	14.4	0.7	100.0

3.3. Testing of Fast Charging:

Testing of fast charging method is carried out by making the current battery charger of 1.5 ampere (21.4% of battery capacity). Table 5 shows result of fast charging testing. From Table 4 shows that the time of fast charging method is about 6 hours which the battery voltage has achieved 14.4 volts (100% of battery capacity).

Tabel 5. Results of Fast Charging Testing

Time (hours)	Battery Voltage (Volt)	Battery Current (Ampere)	Battery Capacity (%)
1	11.8	1.5	81.9
2	12.4	1.5	86.1
3	13.0	1.5	90.3
4	13.6	1.5	94.4
5	14.0	1.5	97.2
6	14.4	1.5	100.0

After the test results are obtained, the test results are compared with the calculation results according to Equation (1). The calculation result for the normal charging methods with the charger current of 0.7 ampere (10% of battery capacity), as follows:

$$\text{Charging Time} = 1.2\ x\ \frac{\text{Battery Capacity (Ah)}}{\text{Charging Current (A)}}$$
$$= 1.2\ x\ \frac{7\ Ah}{0.7\ A} = 12 \text{ hours.}$$

Whereas, the calculation results for the fast charging methods with the charger current of 1.5 ampere (21.4% of battery capacity), as follows:

$$\text{Charging Time} = 1.2\ x\ \frac{7\ Ah}{1.5\ A} = 5.6 \text{ hours}$$

The test results of prototype and calculation results using Equation (1) show that both methods have almost the same results. The battery charger using the normal charging method produces a charging time of around 12 hours. Meanwhile, the fast charging method produces a charging time of about 6 hours.

4. Conclusion

Prototype of battery charger using solar panel with fast charging method has been designed and implemented. Battery charger system consists of solar panel, battery, buck converter and microcontroller respectively. Main equipment of battery charger system is buck converter. Buck converter is employed to control the output voltage, so that will be obtained the output current charging desired. The proposed prototype of battery charger using solar panel with fast charging method is tested to clarify its performances based on normal current charging (0.7 amperes) and fast current charging (1.5 amperes) methods. The test results of proposed prototype show that the battery charger using the normal charging method produces a charging time of 12 hours and the fast charging method produces a charging time of 5.6 hours.

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