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Battery Charging System for Solar Power Plant Using Buck-Boost Converter to Mitigate the Change of Light Intensity in Airport Area

Rachma Prilian Eviningsih
Department of Industrial Electrical Engineering / Surabaya State Electronics Polytechnic
Correspondence author: rachmaevin@pens.ac.id

ABSTRAK

An area in the tropics has considerable potential for solar energy sources and can be used to provide electrical energy supply at airports, especially in inland areas, where Indonesia has about 237 airports. To utilize this solar energy, batteries and charge controllers are required as storage media. When using solar cells to exploit solar energy, the most commonly used charge controller today is the traditional voltage regulator. This regulator limits charging when the output voltage of the solar cell (regulator input voltage) is higher than the charging voltage of the battery. As a result, battery charging stops when the solar cells are obstructed by clouds or in the morning and evening when the sunlight intensity is low. This causes the battery charging system to work less efficiently during the rainy season. In this study, a battery charging system equipped with a buck-boost converter is built. The system uses feedback from solar cell output and battery input current and voltage sensors to control battery charging. A microcontroller acts as the control center of this battery charging system. The system maintains its output voltage according to the recommended battery charging voltage. As a result, the battery charging system operates continuously and stably, regardless of whether the output voltage of the solar cell is lower or higher than the voltage required to charge the battery. During periods of high sunlight intensity, i.e. between 10:00 am and 2:00 pm, the battery charging system test showed an efficiency rate of 78%. Overall, the average charging voltage was about 13.6 Volts with an average charging current of about 1 A. Under these conditions, the 12 Volt battery took about 5 hours to fully charge.

Key Word: *Solar energy, Battery charging system, Buck-boost converter, Charge controller, Microcontroller*

I. INTRODUCTION

The development of various renewable energy sources, such as the installation of solar cells or solar panels in government buildings, airports, and prisons, received an allocation of Rp 1.4 trillion from the Ministry of Energy and Mineral Resources (ESDM) in 2016[1]. Batteries are used as energy storage media for electronic devices that get power supply from solar cells. This battery is a portable power source that can be recharged and easily carried around. Recharging the battery continuously with electricity from PLN will result in a waste of electrical energy from PLN [2][3][4]. Therefore, alternative renewable energy is used as an effort to avoid wasting electrical energy[5].

As Indonesia has a tropical climate, the country has good access to various alternative energy sources, including wind energy, solar power, ocean waves, and others. All of these energy sources can be converted into electrical energy. Solar energy is one excellent option as sunlight is available in abundance and can be converted into electrical energy using solar cells. Solar cells are used to convert solar energy into electrical energy [6][7]. However, special techniques are needed to regulate the voltage from solar cells in order to produce a consistent output voltage, considering that the voltage from solar cells can vary along with fluctuations in sunlight intensity.

Developing a battery charging control system using a Buck-Boost Converter powered by solar cells is one of the options chosen. The Buck-Boost Converter technique was chosen for its ability to keep the output voltage of the solar cells stable, even when weather conditions are unpredictable[8][9][10]. When the sunlight intensity is low, the output voltage from the solar panel is also low, and therefore, the converter will operate in "boost" mode to increase the voltage. Conversely, when the sunlight is very bright, the output voltage from the panel is also high, so the converter will operate in "buck" mode to lower the voltage. This control system keeps the output voltage constant at 13.6 volts DC, which is a commonly used battery charging voltage[11].

$$C_{Rate}=\frac{C}{1\,Hour}$$

The energy capacity that a battery can store (C) is measured in ampere-hours (AJ) or milliampere-hours (mAh). In many situations, trickle charging, which uses a current rate between C/100 to C/10, will keep the battery in good condition for a long period of time. On the other hand, charging with fast charging mode can generate excessive heat, and this can cause harmful chemical reactions in the battery, which can eventually damage the battery quickly. This charging and discharging current of rechargeable batteries is known as the "C-Rate," which can be measured in rates per hour[12][13].

II. METHODOLOGY

1. Solar Cell [1]

A solar cell, also known as photovoltaic, is an electrical device that utilizes the photovoltaic effect to convert light energy into electrical energy. An array of photovoltaic modules, often referred to as solar panels, is used to make solar cells. Solar cells work by using photovoltaic energy, which is the conversion of energy from sunlight into electrons and holes. When a closed circuit is formed, these electrons and holes create a potential difference, which in turn generates the flow of electric current[14][15].

2. Bateray Charging [2]

A battery or accumulator is an electrical cell that can perform electrochemical reactions in an efficient reversible manner. The process of passing electric current into a secondary cell or rechargeable battery is referred to as battery charging[16]. The way a battery is charged is affected by the size and type of battery being charged. Rechargeable batteries are charged by continuously applying electricity to the battery, so that its voltage rises to a predetermined level. However, overcharging can damage the battery and shorten its life. In simple terms, the procedure for discharging a rechargeable battery involves reducing the current flowing through the battery, which reduces the battery's power capacity and lowers the voltage until it reaches a certain limit.

3. Buck Boost Converter [2]

A buck-boost converter aims to change the DC voltage level, either reducing it (buck) or increasing it (boost). In the Non-inverting Buck-Boost (NIBB) circuit, there are two mode switches, namely buck mode switch and boost mode switch. The NIBB circuit has three operational modes, namely buck (decrease), boost (increase), and buck-boost (decrease and increase) [17][18]. The operational mode of the NIBB circuit will switch to boost mode when the input voltage drops below the desired target level. Conversely, the operational mode will switch to buck mode if the input voltage exceeds that target value[19]20].

4. Mode Buck

In buck mode, the buck switch will get a PWM1 switching signal, while the boost switch is open.

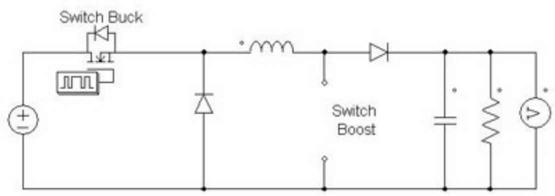


Figure 1. Non Inverting Buck Boost Circuit

Buck mode converter When the buck switch is ON (close), diode 1 works reverse-bias and diode 2 works forward-bias, so the current will fill the inductor while supplying the load.

$$Vi = VL + Vo$$

$$VL = L\frac{di}{dt}$$

$$Vi = L\frac{\Delta i}{ton} + Vo$$

When the buck switch is open, diode 1 and diode 2 will operate in a forward-bias condition, and the current stored in the inductor will be transmitted to the load (debited). $Vo = -VL$

$$Vo = -L\frac{di}{toff}$$

Thus, the equation for Vout is as follows:

$$Vi = Vo\frac{toff}{ton} + Vo$$

$$Vi = Vo\left(\frac{toff}{ton} + 1\right)$$

Vout = Vin . D

5. Mode Boost

In boost mode, the boost switch receives the PWM2 signal for switching, and the buck switch is always in the closed state.

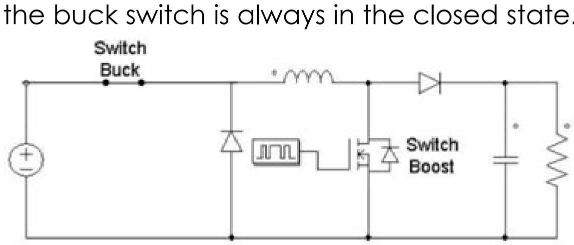


Figure 2. Non Inverting Buck Boost Converter circuit boost mode

When the boost switch is in the ON (open) position, D1 and D2 work in a reverse-bias state, so the current will charge the inductor. This causes the polarity on the left side of the inductor to be more positive than the right side.

$$Vi = VL$$

$$Vi = L\frac{di}{ton}$$

$$Vi \, . \, ton = L$$

When the boost switch is open, D1 will work in reverse-bias condition, while D2 will work in forward-bias condition. As a result, the current stored in the inductor will decrease due to the higher impedance. The reduced current in the inductor will cause a polarity change in the inductor, with the left side becoming more negative. This results in the current flowing through the diode and load being the sum of the current from the source and the current from the inductor. At the same time, the capacitor will accumulate energy in the form of voltage. The Boost Converter produces a higher output voltage than the input voltage.

$$Vo = L\frac{\Delta i}{toff} + Vi$$

With the Vout equation expressed as follows:

$$Vo = Vi + Vi\frac{ton}{toff}$$

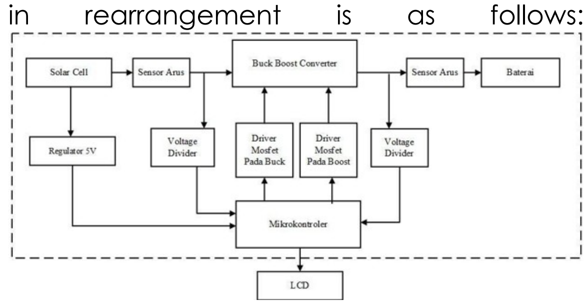
$$Vo = Vi\left(1 - \frac{ton}{toff}\right)$$

$$Vo = Vi\frac{1}{(1-D)}$$

III. SYSTEM DESIGN

1. System Block Diagram

The diagram of the battery charging system with buck-boost converter in rearrangement is as follows:



A functional diagram of battery charging using a buck-boost converter for various lighting levels, as seen in Figure 3.1 below.

Gambar 3.1 Blok Fungsional sistem baterai charging dengan buck boost converter untuk berbagai tingkat pencahayaan

The solar panel acts as a power source to charge the battery, and to keep the voltage stable, a buck-boost converter is used. This is because the output voltage of solar cells tends to fluctuate, ranging from 0 to 21 volts. For the battery charging process, the output voltage of the solar cell is set to always remain stable at 13.6 volts.

In this battery charging system, a microcontroller acts as the control center. The output of the solar cell, which has been regulated by the DC-to-DC voltage regulator, serves as the voltage source for the microcontroller. The MOSFET switch in the buck-boost converter is controlled by the PWM signal generated by the microcontroller.

The buck-boost converter has two MOSFETs, one for buck mode and one for boost mode. The MOSFET in boost mode will switch on and off when the output voltage of the solar cell drops below 13.6 volts, while the MOSFET in buck mode will remain active. Conversely, the MOSFET in boost mode will be disabled and the MOSFET in buck mode will be active when the solar cell output voltage exceeds 13.6 volts.

The microcontroller receives a signal from the voltage divider that provides an automatic command to change the duty cycle of the PWM. In addition, the microcontroller also receives input from a current sensor that monitors the current flowing from the source and output of the buck-boost converter. The output voltage, which has been set at 13.6 volts, is used to charge the battery..

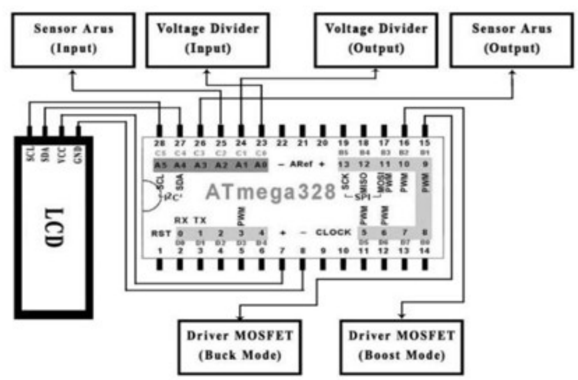
2. Hardware Design

A. Microcontroller System

In this research, the microcontroller acts as the brain of the control system. The microcontroller used is ATMEGA 328. The system is integrated with various supporting devices, as listed in Table 3.1.

No	Pin Arduino	Keterangan
1	Pin A0	Voltage Divider 1 (input)
2	Pin A1	Voltaage Divider 2 (output)
3	Pin A2	Sensor Arus 1 (Input)
4	Pin A3	Sensor Arus 2 (output)
5	Pin 9	PWM mode buck
6	Pin 10	PWM mode boost
7	Pin SDA,SCL	LCD

Gambar 3.1 konfigurasi port mikrokontroller



Gambar 3.2. Rangkain Sistem Mikrokontroler

B. Buck-Boost converter design

The design of the buck-boost convereter is based on several input and output parameters of the buck boost that will be designed, as for these parameters as in table 3.2.

P (daya)	27 Watt
Vinput (tegangan input minimal)	7 V
Vinput (tegangan input rata rata tinggi)	17 V
Voutput (tegangan output yang diinginkan)	13,6 V
Ripple Tegangan Output	1%
RippleArus Induktor	10%
Io	2 A
Rbeban	12 Ω

Tabel 3.2 Parameter perhitungan Buck Boost Converter

The following is a calculation to determine the value of the components used with a voltage input of 7 Volt

A. Determining the dutycycle

$$Vo=\frac{1}{1-D}Vi$$
$$13{,}6=\frac{1}{1-D}7$$
$$D=0{,}48$$

B. Determining the inductor value

$$Io=Ic=2\ \wedge$$
$$IL=Io+Ii=2+2=4\ A$$
$$L=Vi\ x\ D/Delta\ Ilpp\ x\ fsw$$
$$¿\frac{7\times 0{,}48}{0{,}1\times 4\times 15000}$$
$$¿470\ \mu F$$

C. Calculation with 17 Volt input

- DutyCycle Determining the DutyCycle value

$$D=\frac{Vo}{Vin}$$
$$D=\frac{Vo(1-D)}{\Delta\ Ilpp\times fsw}$$
$$=13{,}6¿¿$$
=906 Uh

- Determining Capacitor Value

$$C=\frac{\Delta\ Ilpp}{8\times 15000\times 13{,}6\times 0{,}01}$$
$$¿12\ \mu F$$

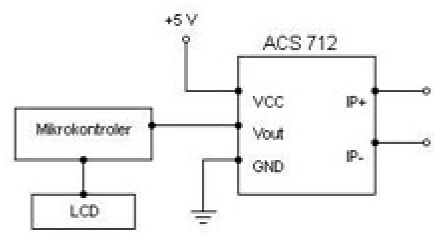
The calculation results for the buck-boost converter show the selection of the smallest inductor of 560 microHenry and the largest capacitor of 470 microFarad. The inductor used is a toroidal type with the following specifications:

Toroidal outer diameter = 575 mm
- Inside diameter of toroida = 36 mm
- Thickness of the toroida = 145 mm
- Relative magnetic permeability (μ) = 52
- Wire diameter = 1.2 mm - Number of turns = 88 turns.

In this buck-boost converter circuit, there are two solid state switch MOSFET transistors used. The buck section uses a P-type MOSFET, called IRF9640, while the boost section uses an N-type MOSFET, called IRF4905.

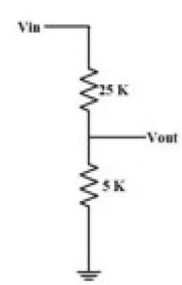
D. Design of current and voltage sensors

The amount of current and voltage generated by the solar cells and required to charge the battery is measured using a current sensor and a voltage sensor. The system uses an ACS712 type current sensor that is based on the Hall effect. This sensor produces an analog signal in the voltage range of 0-5 VDC. The current sensor circuit is described in Figure 3.3, where port A2 on the microcontroller is used to receive the output of the solar cell current sensor, and port A3 to receive the output of the buck-boost current sensor.



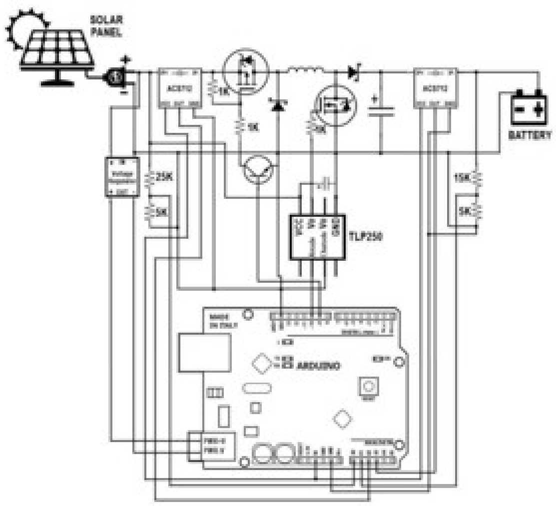
Gambar 3.3 Sensor arus

The voltage measurement system in this system applies a voltage divider circuit, as shown in Figure 3.4.



Gambar 3.4 Rangkaian sensor tegangan

The output of the solar cell voltage sensor is connected to port A0, and the output of the buck-boost voltage sensor is connected to port A1 on the microcontroller. The hardware integration of this battery charging system is illustrated in Figure 3.5 below.

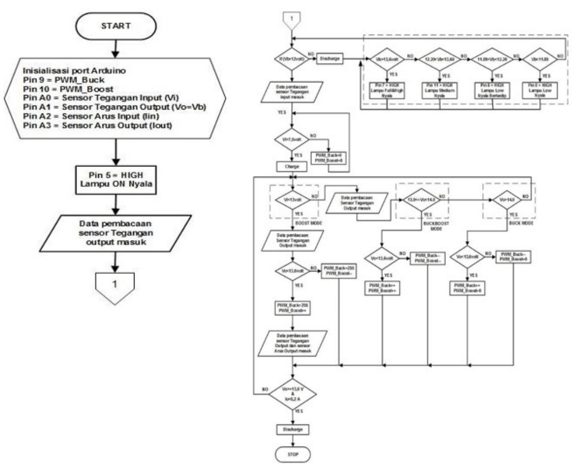


Gambar 3.5 Rangkaian Sistem Battery Charging

3. Software design

The control algorithm used in this battery charging system is part of the program. The algorithm that regulates the charging voltage is illustrated in flowchart 3.6. The following is an explanation of the flowchart:

1. Start is when the program is run.
2. The second step is to configure the ADC pins in ports A0, A1, A2, and A3 to read the input voltage sensor, output voltage sensor, input current sensor, and output current sensor.
3. “The charging procedure starts when the battery voltage drops below 12 volts.”
4. System operation is not possible if the solar cell output voltage is less than 7.50 volts.
5. PWM_Buck will activate and PWM_Boost will be set to selectively change the buck-boost output voltage to 13.60 volts (Boost Mode) when the solar cell output voltage is within the range of 7.50 to 13.00 volts.
6. To keep the buck-boost output voltage fixed at 13.60 volts (Buck-Boost Mode), there will be a switch in the PWM_Buck and PWM_Boost settings when the solar cell output voltage is in the range of 13.00 to 14.00 volts.
7. PWM_Buck will be enabled and PWM_Boost will be turned off to keep the buck-boost output voltage fixed at 13.60 volts (Buck Mode) when the output voltage of the solar cell is above 14.00 volts and a maximum of 21 volts.
8. “The charging process will stop when the output current becomes less than 0.2 amperes and the buck-boost output voltage reaches or exceeds 13.60 volts.”

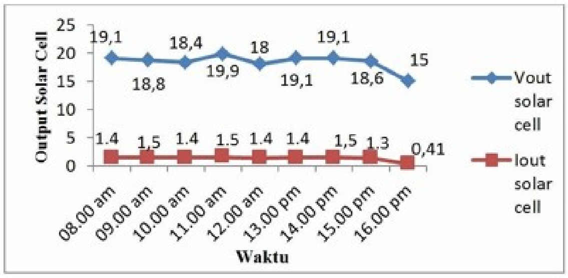


Gambar 3.17 Flowchart algoritma Sistem BatteryCharging

IV. RESULT & DISCUSION

System testing aims to ensure the quality and performance of the system in performing its functions. The testing system includes tests on solar cells, voltage sensors, current sensors, buck-boost converters, and the system as a whole. The purpose of this test is to identify the peak voltage value and the lowest voltage value generated by the solar cell during the sun exposure period from 08.00 to 16.00. The solar cell was connected to a 12 Ohm resistance load, and in this test, the current and voltage at the output of the solar cell were measured.

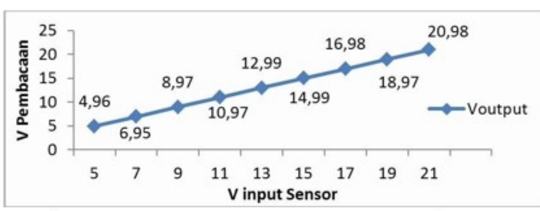
The results of the test can be seen in Figure 4.1 which illustrates the production of the solar cell with respect to the level of solar illumination.



Gambar 4.1 Grafik Vout dan Iout yang dihasilkan Solar cell

Based on information from Figure 4.1, it was found that the peak voltage reached 19.1 Volts with a current of 1.5 A, while the lowest voltage reached 15 Volts with a current of 0.41 A.

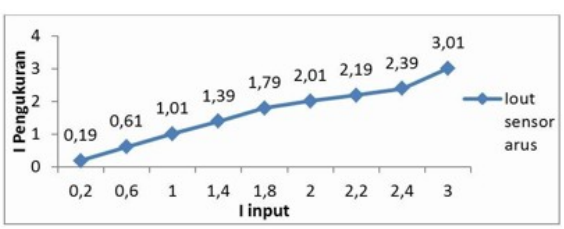
Testing of voltage sensors and current sensors was carried out with the aim of measuring the accuracy of the sensors. The measurement results are compared between the reading by the system and the reading given by the voltmeter, as shown in the graph in Figure 4.2.



Gambar 4.2 Pengujian Sensor tegangan dan arus

Based on the measurement data, the average error in voltage measurement by the system ranges from 0.06% to 0.8%.

The measurement data comparing the system reading with the ammeter is shown in the graph in Figure 4.3.

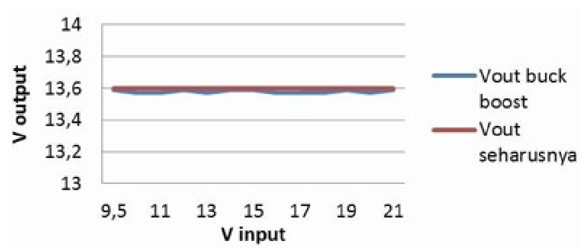


Gambar 4.3 Grafik pengujian pembacaan sensor arus oleh sistem terhadap pengukuran dengan amperemeter.

The measurement data shows that the current measurement error by the system ranges from 0% to 0.8%.

1. Buck Boost Converter Testing

The buck-boost converter test was conducted to assess the system's ability to maintain the output voltage at the targeted value of 13.6 V, regardless of the input voltage variation.

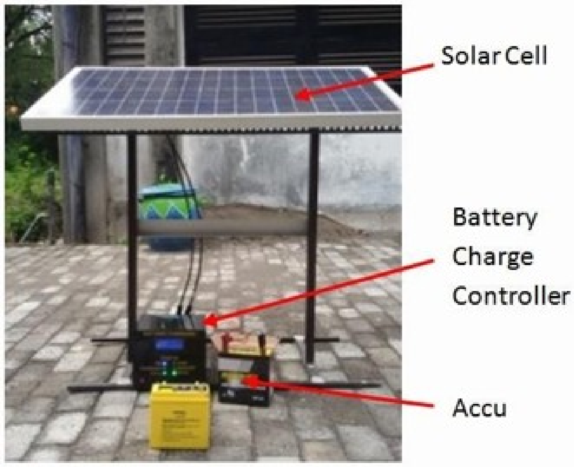


Gambar 4.4 Grafik Voutputbuck-boost terhadap masukan tegangan yang berubah.

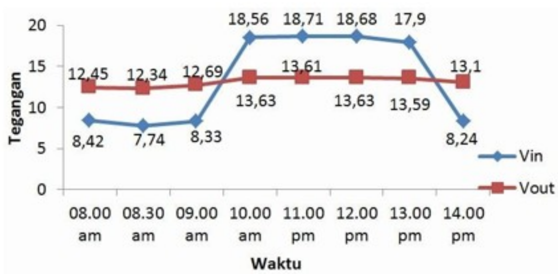
2. Thorough system testing

The target of all tests is a system that is able to cope with fluctuating input voltage variations. In this test, the input voltage range was from 9.5 V to 21 V, and the measurement results showed that the system had an average inaccuracy rate of about 0.07% to 0.2%.

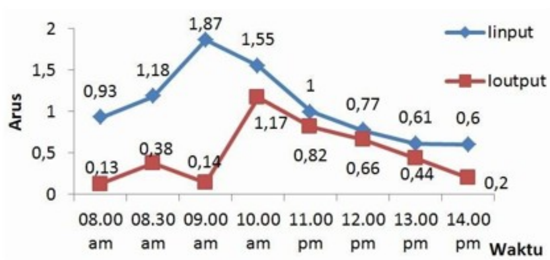
To evaluate the performance of the system at a voltage of 12 volts, the solar cell was installed in an open location that receives sunlight from morning to evening. The system installation, as depicted in Figure 4.5, includes the solar cell, battery charging mechanism, and 12V 10AH dry battery.



Gambar 4.5 Instalasi Pengujian sistem baterai charge controller



Gambar 4.6 Grafik tegangan luaran solar cell dan luaran buck-boost converter pada pengujian sistem secara menyeluruh mulai pukul 08.00 hingga pukul 14.00.



Gambar 4.7 Grafik Arus keluaran solar cell dan luaran buck boost converter pada pengujian sistem secara menyeluruh mulai pukul 08.00 hingga pukul 14.00.

Gambar 4.6 dan Gambar 4.7 menunjukkan hasil pengujian yang dilakukan mulai pukul 08.00 WIB hingga 14.20 WIB. Tegangan rata-rata yang terbaca pada saat pengisian adalah sekitar 13,6 Volt, dan rata-rata arus pengisian adalah di bawah 1 Ampere. Proses pengisian baterai 12 Volt membutuhkan sekitar 5 jam, mulai dari tegangan awal sekitar 12,12 Volt hingga mencapai 12,81 Volt (penuh). Waktu pengisian baterai lebih lama disebabkan oleh cuaca berawan, yang mengakibatkan intensitas cahaya matahari yang rendah.

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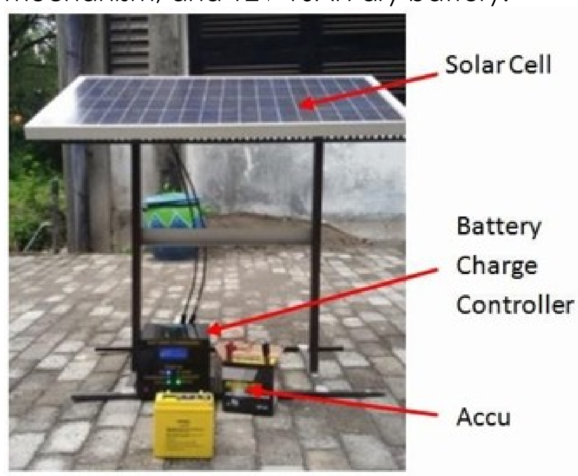
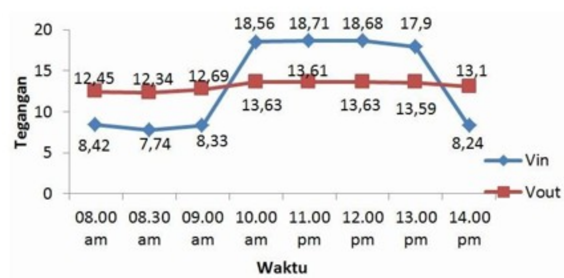
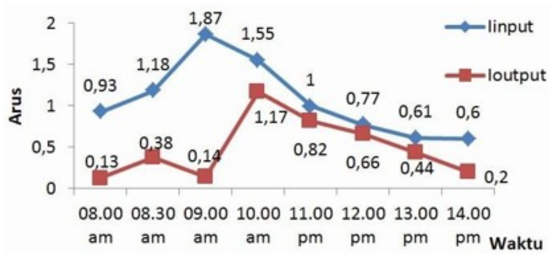


Gambar 4.5 Instalasi Pengujian sistem baterai charge controller



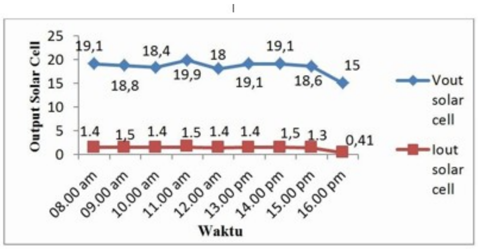
Gambar 4.6 Grafik tegangan luaran solar cell dan luaran buck-boost converter pada pengujian sistem secara menyeluruh mulai pukul 08.00 hingga pukul 14.00.



Gambar 4.7 Grafik Arus keluaran solar cell dan luaran buck boost converter pada pengujian sistem secara menyeluruh mulai pukul 08.00 hingga pukul 14.00.

Figure 4.6 and Figure 4.7 show the results of tests carried out from 08:00 WIB to 14:20 WIB. The average voltage read during charging is about 13.6 Volts, and the average charging current is under 1 Ampere. The process of charging a 12 Volt battery takes about 5 hours, starting from an initial voltage of about 12.12 Volts to reach 12.81 Volts (full). The longer battery charging time was due to cloudy weather, which resulted in low sunlight intensity.

System experiments were conducted to verify the quality and performance of the system in performing its duties. System testing includes testing the solar cell, voltage sensor, current sensor, buck-boost converter, and the entire system. The purpose of this test is to recognize the peak voltage and lowest voltage values generated by the solar cell during the period of sun exposure from 08:00 to 16:00. The solar cell was connected to a 12 Ohm resistance load, and in this test, the current and voltage at the output of the solar cell were measured. The test results can be found in Figure 4.1 which shows the production of the solar cell based on the level of sun exposure.



Gambar 4.1 Grafik Vout dan Iout yang dihasilkan Solar cell

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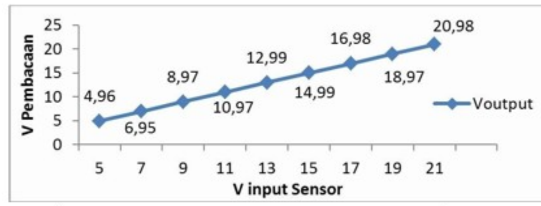
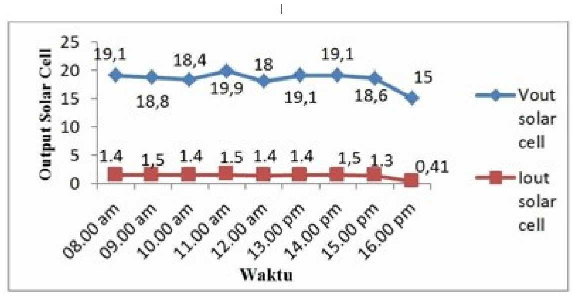


Gambar 4.2 Pengujian Sensor tegangan dan arus

System testing is carried out to verify the quality and performance of the system in carrying out its functions. System testing includes tests on solar cells, voltage sensors, current sensors, buck-boost converters, and the system as a whole. The purpose of this test is to identify the peak voltage and the lowest voltage generated by the solar cell during the period of sun exposure from 08:00 to 16:00. The solar cell was connected to a 12 Ohm resistance load, and in this test, the current and voltage at the output of the solar cell were measured. The results of the test can be seen in Figure 4.1 which shows the production of the solar cell based on the level of solar illumination.



Gambar 4.1 Grafik Vout dan Iout yang dihasilkan Solar cell

P (daya)	27 Watt
Vinput (tegangan input minimal)	7 V
Vinput (tegangan input rata rata tinggi)	17 V
Voutput (tegangan output yang	13,6 V

diinginkan)	
Ripple Tegangan Output	1%
RippleArus Induktor	10%
Io	2 A
Rbeban	12 Ω

Tabel 3.2 Parameter perhitungan Buck Boost Converter

V.CONCLUSION

1. The conclusions from the system tests that have been carried out are as follows:
2. A 12-volt battery can be charged using battery charging with a voltage of 13.6 volts, an output current of 1 ampere, and an average charging time of 4 hours.
3. The output voltage of the battery charging system remains stable despite fluctuations in the input voltage.
4. The system efficiency reaches 78% when the solar intensity is high, specifically between 10:00 and 14:00.
5. The battery charging system will stop if the output voltage of the solar panel drops below 7.5 volts or the charging current drops below 0.2 amperes.
6. The system measurement accuracy for buck-boost output voltage and solar cell output voltage is 0.8%.
7. The system is capable of measuring the charge and discharge current of the battery with an accuracy of about 0.8%.

VI.REFERENCE

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