

The Design of Buck-Boost Converter with Arduino Based on 8x10 Wp Photovoltaic Power Plant

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Abstract— The use of solar panels through the Photovoltaic (PV) process is an efficient way to produce electrical energy. The main barriers to the use of solar panels are their low energy conversion efficiency and high initial costs. Solar panels are unregulated DC power sources that produce fluctuating voltages and currents, so they must be controlled properly in order to work as expected. Usually when solar panels are directly connected to a load, the operating point is rarely at its Maximum Power Point (MPP). Maximum Power Point Tracking (MPPT) is used to generate maximum power from solar panels. The DC to DC conversion functions as an intermediary for the solar panels and the load to deliver the maximum power to the load. In this study, MPPT was used with the Perturb & Observe (P&O) algorithm and DC to DC converter with a buck-boost converter type. Based on the test results between simulation and tool implementation, the input voltage of 17.6 V produces an output voltage of approximately 14.4 V for charging a 12 V battery with the maximum power produced by the PV generator. Based on these tests, it can be concluded that the buck-boost converter design based on the Arduino Uno in the 8x10 Wp photovoltaic power plant can work well.

Keywords— Arduino, Buck-Boost Converter, MPPT Perturbation & Observation, PV Power Plant.

I. INTRODUCTION

Technological developments and the components of electronic circuits, especially power electronics has been able to produce a power supply system voltage DC (Direct Current), which is generated through the conversion of a DC voltage input to output DC voltage form of higher or lower. This DC voltage conversion is commonly referred to as a DC to DC converter. Based on the type of voltage converters, DC to DC converters are divided into three types: a boost converter (step-up), buck converter (step-down), and buck-boost (step-up and step-down). To get an output voltage that is greater than the source voltage, it can use a DC to DC converter with a boost converter type. Then to get an output voltage that is smaller than the source voltage, it can use a DC to DC converter with a buck converter type. Meanwhile, to get an output voltage that can increase and decrease the source

voltage, it can use a DC to DC converter with a buck-boost converter type.^[11] In its development, the application of DC to DC converters is widely applied to a new and renewable energy sources such as solar cells. The DC voltage generated from this renewable energy source is fluctuating. Therefore a voltage converter is needed so that the resulting voltage can be higher or lower than the input voltage, one of them is by using a DC to DC converter. With the buck-boost converter system the output voltage value can be adjusted to be greater or less than the input voltage value.^[9] The problems faced from using a solar panel system are very low charging and efficiency, the influence of environmental conditions, and besides that the solar panel module has non-linear P-V and I-V characteristics.^[15] The condition of the sun's rays always changes every time it causes radiation and varying voltages, therefore it is necessary to track the output power of the solar panels, namely in the form of a Maximum Power Point Tracker (MPPT). MPPT is a method that is useful for optimizing the output power of solar panels by tracking or tracing the peak power points from the output of the solar panels. This MPPT then began to be developed and various algorithm methods emerged for various renewable power plant conditions, including conventional methods, Constant Voltage Controller (CVC), Perturb and Observe (P&O), Incremental Conductance (IC), and Fuzzy Logic Control (FLC). In this study, the Perturb and Observe (P&O) algorithm was used to design the MPPT with a Buck-Boost converter circuit, which has been designed to track peak power points and charge the battery.^[8] Based on the explanation and problems above, this study will design a buck-boost converter prototype that has functions as a voltage converter at the output of the solar panel. The Arduino microcontroller based on the P&O algorithm is used to adjust the pulse width (duty cycle) of the PWM (Pulse Width Modulation), based on changes in the pulse width, the peak power point will be obtained.

II. METHODOLOGY

A. PV Power Plant

The availability of primary PV energy is unlimited and has environmentally friendly characteristics. PV needs to be researched and developed in order to produce energy

conversion that has greater efficiency. PV consists of small parts called solar cells. PV is connected in series and parallel to get the required voltage and current values. The collection of many solar cells is called a PV module [10].

B. Buck-Boost Converter

Buck-boost converter is a DC to DC converter circuit that can produce an output voltage that is lower or higher than the source [6].

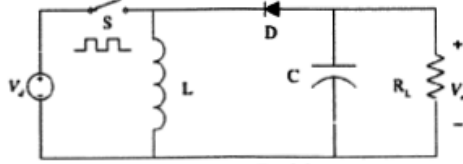


Fig. 1. Buck Boost Converter

The buck-boost converter circuit works in 2 conditions, namely when the switch is connected (T_{ON}) and the switch is disconnected (T_{OFF}). The buck-boost converter circuit when the switch is connected (T conduction) is shown in Figure 2.

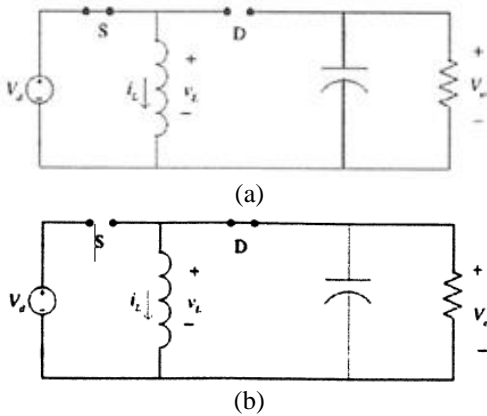


Fig. 2. (a) T_{on} State (b) T_{off} state

The equation for determining duty cycle can be seen in equation 1.

$$V_o = -V_s \frac{D}{(1-D)} \quad (1)$$

Then the load that passed through the buck-boost converter circuit is calculated using equation 2.

$$R = \frac{V_{out}}{I_{out}} \quad (2)$$

The minimum capacitor value from buck-boost converter is calculated using equation 3.

$$C_{min} = \frac{D}{F_s \times R_{lmin}} \times \frac{V_{out}}{V_{c\Delta p}} \quad (3)$$

To determine the inductor value is calculated using equation 4.

$$L_{min} = \frac{R_{lmax} (1-D_{min})^2}{2 F_s} \quad (4)$$

C. Maximum Power Point Tracking (MPPT)

Maximum Power Point Tracking (MPPT) is a technique used to keep a PV system working at Maximum Power Point (MPP). MPPT will maintain output at its highest power, namely at Voltage Maximum Power Point ($V_{m\Delta p}$) and Current Maximum Power Point ($I_{m\Delta p}$). To keep the system working on the MPP, the MPPT method has been developed, such as the Perturb and Observe Algorithm (P&O).

The P&O method is a widely used approach to determining the point of maximum power. This method works by perturbing (interference). The P&O algorithm will increase and decrease the voltage and observe its impact on the source output power supply. P-V curve can be seen in Figure 3.

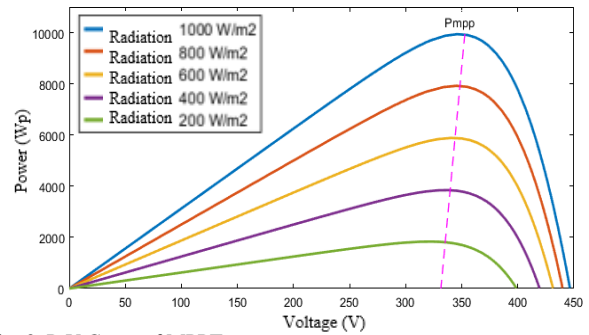


Fig. 3. P-V Curve of MPPT

D. Battery

The battery is a device that converts chemical energy into electrical energy. To find the length of time to charge, it can be found by dividing the battery capacity and the charging current as in equation 5.

$$C_{Battery} = \frac{P}{V} \quad (5)$$

E. Block Diagram of the System

The block diagram in this study consists of a PV generator circuit, current sensor, voltage sensor, MPPT P&O algorithm, buck-boost converter, and a battery as a load. The PV plant consists of 8 solar panels arranged in parallel, then the voltage and current parameters will be measured by a sensor. The results of sensor measurements will be read by Arduino and will be processed through the MPPT P&O algorithm to produce pulse width or the so-called duty cycle. The duty cycle will be superimposed on the carrier signal or Pulse Width Modulation (PWM) and will trigger the gate foot of the mosfet in the buck-boost converter circuit. The block diagram of the system design used in this study can be seen in Figure 4.

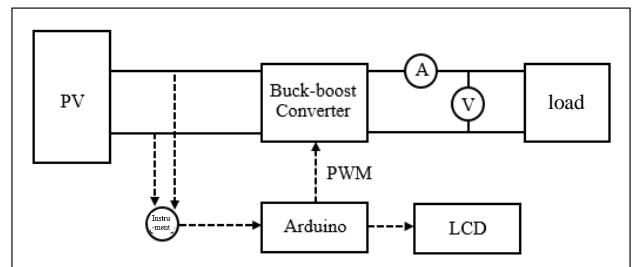


Fig. 4. Block Diagram of System Design

Figure 4 explains the block diagram of the system design as follows:

- A PV plant that is exposed to solar radiation will produce a power, voltage and current value.
- The value of the power, voltage and current of the PV generator is measured through the voltage sensor and current sensor.
- The product of voltage and current is called the change in power. The results of the change in power from the PV

generator received by the voltage and current sensors are then sent to be processed in the MPPT P&O Algorithm. The MPPT P&O algorithm will then produce a duty cycle. The duty cycle functions as a signal generator for the switching control in the buck-boost converter circuit to get the expected output voltage based on the input voltage. This duty cycle requires a Pulse Width Modulation (PWM) control signal as a carrier signal.

- d. The PWM signal will then drive the gate mosfet in the buck-boost converter circuit. The buck-boost converter is used to increase and decrease the output voltage. The output voltage from the buck-boost converter will be used as a battery charge.

F. Photovoltaic Power Plant

The PV generator in this study is a series of solar panels arranged in such a way as to produce the required voltage, current and power. A series of solar panels can be arranged in series, parallel, or series-parallel. The maximum power that can be generated by a PV generator is 80 Wp, with the voltage and current at the maximum power generated is 17.6V and 4.64A. The next results from PV generation are discussed in Chapter IV. In this study, the PV plants are arranged in parallel as shown in Figure 5.



Fig. 5 Photovoltaic Power Plant

G. MPPT P&O Control System Design on the Buck-Boost Converter

This control system design consists of measuring instruments, buck-boost converter design, and controller design. The measuring instrument consists of a current sensor and a voltage sensor. The buck-boost converter design consists of determining the duty cycle value and determining the component value. The controller design consists of the MPPT P&O flowchart, the Arduino program syntax, and the mosfet driver.

1. Measuring Instruments

The current sensor module used in this study is the ACS712-5A module. This module is capable of reading currents of up to 5 A. To see the performance and ensure the accuracy of this sensor, measurements are needed by comparing the module measurements and theoretical calculations. This current sensor measurement can be done by measuring the current flowing at the output of the PV generator by installing a 20 ohm stone load resistor. The current sensor circuit is shown in Figure 6.

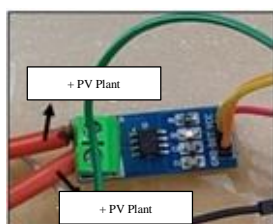


Fig. 6. Current Sensing ACS712 Module

The voltage sensor is done by measuring the output voltage of the PV generator. The voltage sensor module circuit is shown in Figure 7.



Fig. 7. Voltage Sensing ACS712 Module

2. Buck-Boost Converter Design

Buck-boost converter is a DC-DC converter that can increase and decrease the input voltage of the PV generator. The design of the buck-boost converter can be seen in Figure 8.

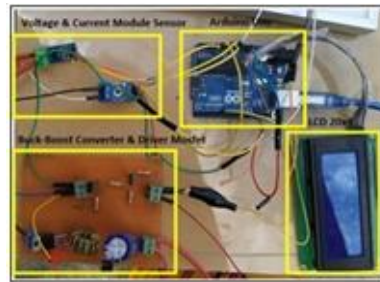


Fig. 8. Current Sensing ACS712 Module

In Figure 8, the buck-boost converter circuit consists of several components such as a mosfet, diode, inductor, capacitor, and resistor. In order for the circuit to work according to the design, it is necessary to calculate the component value.

3. Determination of Duty Cycle Value

The output from the PV generator is in the form of current and voltage which will be forwarded as a reference for the MPPT P&O. The MPPT P&O mechanism will produce a duty cycle. The duty cycle signal will be superimposed by the PWM signal which then the PWM signal will control the switch contained in the buck-boost converter circuit. In order for the buck-boost converter to work properly, the calculations are carried out according to Table 1.

TABLE I. COMPONENT OF BUCK-BOOST CONVERTER

Parameter	Value
$P_{maximum}$	80 Wp
V_{input}	17,6 Vdc
I_{input}	4,64 A
V_{output}	± 14 Vdc
Switching Frequency	500 Hz
Voltage Ripple	0.01 V

The duty cycle required to produce an output voltage of ± 14 V can use Equation 1.

$$\frac{V_{out}}{V_{in}} = \frac{D}{1 - D}$$

$$\frac{14}{17,6} = \frac{D}{1 - D}$$

$$14 (1 - D) = 17.6 D$$

$$14 - 14 D = 17.6 D$$

$$14 = 31.6 D$$

$$D = \frac{14}{31.6} = 0.45 = 45\%$$

The duty cycle required to produce an output voltage of 14 V is 45%. The duty cycle is shown in Figure 9.

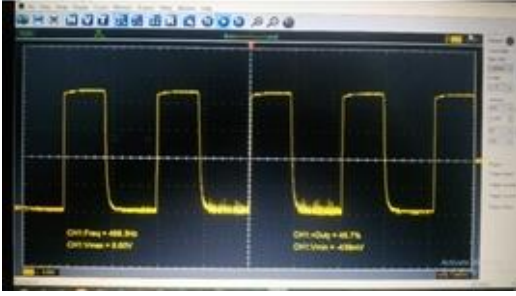


Fig. 9. Duty cycle on the Hantek6000 digital oscilloscope

4. Determination of Component Value

As an increase and decrease in voltage, the buck-boost converter has a functions to keep the voltage within the expected voltage range, but at the peak power point. To determine the load resistance, you can use Equation 2 as follows:

$$R = \frac{V_{in}}{I_{in}}$$

$$R = \frac{17.6}{4.64}$$

$$R = 3.8 \Omega$$

To find the value of the minimum inductor that will be used using Equation 4.

$$L_{min} = \frac{R I_{maks} (1-D_{min})^2}{2 F_s}$$

$$L_{min} = \frac{3.8 (1-0.45)^2}{2 \times 500}$$

$$L_{min} = 0.000143 \text{ H} = 954.5 \mu\text{H}$$

Then an inductor with a value of 2 mH is chosen which is available in the market, as explained in the previous chapter, the inductor value selection must be greater than the value of L_{min} . Then before looking for the capacitor value, it is necessary to find the ripple voltage value on the filter capacitor.

$$V_r = \frac{1}{100} \times V_{out}$$

$$= \frac{1}{100} \times 14$$

$$= 0.14 \text{ V}$$

$$V_{rcpp} = 5 \text{ mV} = 0.005$$

$$V_{cpp} = V_r - V_{rcpp}$$

$$= 0.14 - 0.005$$

$$= 0.135 \text{ V}$$

And to reduce the voltage ripple from the switching process, a capacitor is used whose value can be determined using Equation 3.

$$C = \frac{D}{F_s \times R I_{min}} \times \frac{V_{out}}{V_{cpp}}$$

$$C = \frac{0.45}{500 \times 3.8} \times \frac{14}{0.35}$$

$$C = 40.31 \text{ mF}$$

So, for the use of the ripple filter capacitor 47 mF which is available in the market is selected. After obtaining the parameter values for the buck-boost converter circuit, the values for the inductor, capacitor, and the switching frequency of the circuit are summarized in Table 2.

TABLE II. COMPONENT PARAMETER OF BUCK-BOOST CONVERTER

Parameter	Value
Resistor	3.8 Ω
Inductor	2 mH
Capasitor	47 mF
Switching Frequency	500 Hz

5. Controller Design

A controller is needed in the buck-boost converter circuit to trigger the mosfet gate leg. In this study, the controller used is the Arduino microcontroller and the algorithm used to track power is the Maximum Power Point Tracking (MPPT) Perturb and Observe (P&O). The algorithm will produce a duty cycle which will then be superimposed on the Pulse Width Modulation (PWM) signal. To be able to trigger the mosfet gate leg, a mosfet driver is needed. The control system in this study uses the MPPT P&O algorithm. This flowchart is used to determine the PWM duty cycle that will be sent to the buck-boost converter. The P&O method is presented in a flowchart.

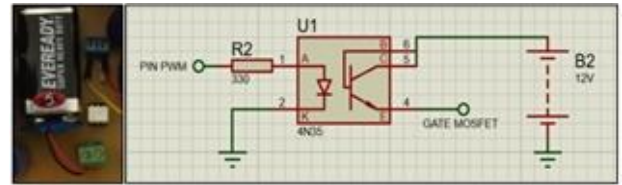


Fig. 10. Mosfet driver circuit

In this study, the magnitude of the PWM signal generated by the Arduino board has a maximum value of 5 VDC, where this voltage is not able to move the switch on the mosfet, so a mosfet driver circuit is needed. With the mosfet driver the magnitude of the PWM voltage will approach the VCC value used in the driver circuit. The mosfet driver circuit in this study uses a 4N25 optocoupler as shown in Figure 11.

H. Battery Capacity Planning

Battery capacity needs to be considered as a storage area for electrical energy generated by a PV plant. Determining the capacity of this battery begins by calculating the amount of energy produced by the PV generator per hour and per day, then selecting the suitable battery capacity to store or store that energy.

The amount of power that can be generated by PV is 80 Wp with 8 solar panels of 10 Wp. The most effective use of PV generators to produce power is 10 a.m. to 3 p.m. or 5 hours/day. Then the total power that can be generated per day is 400 W. The required battery capacity in Ampere hour (Ah) is as in equation 5.

$$C_{Baterai} = \frac{P}{V} = \frac{80 \text{ W}}{12 \text{ V}} = 6.6 \text{ Ah}$$

Then the battery capacity if the PV generator is used for 5 hours is 33.3 Ah. However, due to cost limitations, a 12V 10Ah battery is used. Then the power that a 12V 10Ah battery can store is 120 W.

I. Efficiency

Efficiency states what percentage of the power ratio of the input and output of the circuit. If the efficiency is one hundred percent, the input power is supplied perfectly to the output side of the circuit as the calculation below.

$$\eta = \frac{P_{out}}{P_{in}} \times 100\% \quad (6)$$

$$\eta = \frac{80 W}{80 W} \times 100\% = 100\%$$

III. RESULT AND DISCUSSION

This chapter will discuss the results of testing the entire system and analysis of the data obtained. The data analyzed are in the form of converter voltage test results, converter current testing, converter power testing, converter buck-boost efficiency and simulation validation.

A. Full System Design

Every part that has been made is then designed to be a complete design. This section consists of a PV generator, current and voltage sensors, Arduino Uno as an MPPT P&O microcontroller, buck-boost converter and mosfet driver, and a 12V 10 Ah battery load. The whole system circuit is shown in Figure 11.



Fig. 11. PV generator systems

Figure 11 shows the manufacture of hardware devices from this system which includes a PV generator circuit, a current sensor circuit and voltage sensor, buck-boost converter circuit, MPPT P&O algorithm on Arduino, and 12V 10Ah battery load.

B. Design Result Datasheet

The following is a table of specifications for each component used in this study.

TABLE III. SOLAR CELL SPECIFICATION

Specification	Value
Power Maximum	80 Wp
Voltage Maximum	17.6 V
Current Maximum	4.5 A
Open Circuit Voltage (V _{oc})	22.0 V
Voltage System Maximum	700 V
Dimension of PV	354x251x17 mm

TABLE IV. SPESIFICATION OF COMPONENT

Spesification	Value
Inductor	2 mH
Capasitor	47 mF
Resistor	5Ω 20W
Frequency	500 Hz
Diode	MIC 10A
Mosfet	IRF540

TABLE V. SPESIFICATION OF BATTERY

Spesification	Value
Baterry Merk	GS Astra Premium
Baterry Code	12N10-3B
Nominal Voltage	12 V
Capacity	10 Ah

C. Voltage Testing of Implementation Tool

In this test consists of measuring the input voltage and output voltage. The input voltage is measured using a voltage sensor module so that the reading of the measurement results is directly on the LCD. The output voltage is measured using a digital multimeter. The presentation of Table 6 is the result of testing the input voltage and output voltage based on data collection time and radiation at the time of data collection. In Table 4.4, the theoretical calculation of the converter output voltage is carried out based on Equation 1. For the calculation, data was taken at 12.00 with 757 W / m² radiation and 0.45 duty cycle, then the theoretical output voltage is:

$$V_{out} = 17.6 \times "0.45" / "1-0.45" = 14.40 V"$$

TABLE VI. VOLTAGE TESTING RESULT OF CONVERTER

Time (Hours)	Radiation (W/m ²)	Duty Cycle	Input Voltage Converter (V)	Output Voltage Theory (V)	Output Voltage Converter (V)
06:00	41	0.41	1.6	1.12	0.4
07:00	82	0.41	3.5	2.43	1.98
08:00	121	0.41	5.7	3.96	2.54
09:00	382	0.41	11.8	8.20	7.61
10:00	407	0.45	13.4	10.96	9.24
11:00	549	0.45	16.5	13.50	12.31
12:00	757	0.45	17.6	14.40	13.41
13:00	632	0.45	17.1	13.99	12.74
14:00	570	0.45	16.4	13.41	12.08
15:00	338	0.41	11.4	7.92	6.31
16:00	124	0.41	4.4	3.05	2.3
17:00	143	0.41	5.8	4.03	3.01
18:00	39	0.41	1.1	0.76	0.3

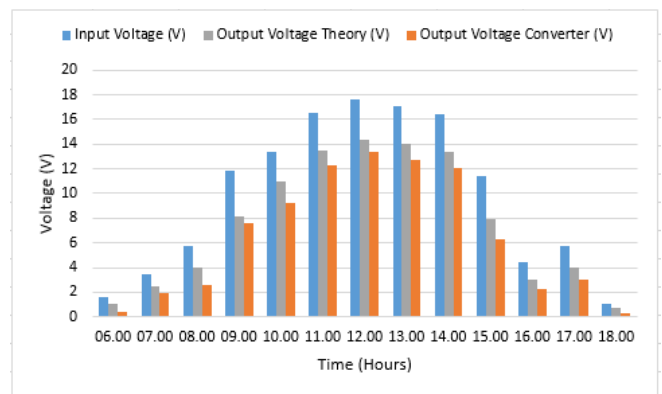


Fig. 12. Buck Boost Converter Voltage comparison

Based on the above calculations, the theoretical output voltage at 12.00 is 14.40 V, while the output voltage on the converter is 13.41 V. The graph of the voltage comparison between input voltage, theoretical output voltage, and converter output voltage against time is shown in Figure 12.

D. Current Testing of Implementation Tool

This test consists of measuring the input current and the output current. The input current is measured using a current sensor module, so that the reading of the current value is directly on the LCD. Meanwhile, the output current is measured using a digital multimeter. Table 7 shows the results of the current measurements in the design.

TABLE VII. CURRENT TESTING OF CONVERTER

Time (Hours)	Radiation (W/m ²)	Load (Ohm)	Input Voltage Converter (V)	Input Current Converter (A)	Output Current Theory (A)	Output Current Converter (A)
06:00	41	5	1.6	0.04	0.32	0.11
07:00	82	5	3.5	0.22	0.70	0.24
08:00	121	5	5.7	0.54	1.14	0.63
09:00	382	5	11.8	1.41	2.36	1.68
10:00	407	5	13.4	1.63	2.68	1.83
11:00	549	5	16.5	2.18	3.30	2.26
12:00	757	5	17.6	3.06	3.52	3.01
13:00	632	5	17.1	2.63	3.42	2.70
14:00	570	5	16.4	2.28	3.28	2.35
15:00	338	5	11.4	1.32	2.28	1.68
16:00	124	5	4.4	0.47	0.88	0.65
17:00	143	5	5.8	0.53	1.16	0.74
18:00	39	5	1.1	0.03	0.22	0.08

In Table 7, the theoretical calculation of the converter output current is analyzed, where the output current is equal to the input voltage divided by the load. For example, data is taken at 12.00 with 757 W / m² radiation and a voltage of 17.6 V, then the theoretical output current is as in equation 2.17.

$$I_{out} = \frac{V}{R} = \frac{17.6}{5} = 3.52 \text{ A}$$

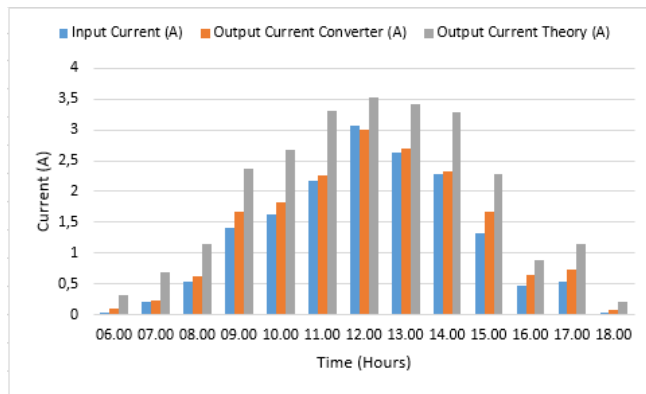


Fig. 13. Buck Boost Converter Current comparison

Based on the above calculations, the theoretical output current at 12.00 is 3.52 A, while the converter output current is 3.01 A. The graph of the current ratio between the input current, the theoretical output current, and the converter output current against time is shown in Figure 15.

E. Power Testing Implementation Tool with Constant Load

The power test in this study is the result of the multiplication of voltage and current. The input power is measured using calculations on the algorithm on the Arduino and the reading results directly on the LCD, while the output power is measured by theoretical multiplication based on the voltage and current that has been tested. Table 8 is a data presentation of input power and output power.

TABLE VIII. POWER OF BUCK-BOOST CONVERTER

Time (Hours)	Radiation (W/m ²)	Input Power (W)	Output Power Theory (W)	Output Power Converter (W)
06:00	41	0.06	0.35	0.04
07:00	82	0.77	1.70	0.47
08:00	121	3.07	4.51	1.60
09:00	382	16.63	19.35	12.78
10:00	407	21.84	29.37	16.90
11:00	549	35.97	44.55	27.82
12:00	757	53.85	50.68	40.36
13:00	632	4.97	47.84	34.39
14:00	570	37.39	43.98	28.02
15:00	338	15.04	18.05	10.60
16:00	124	2.06	2.68	1.49
17:00	143	3.07	4.67	2.22
18:00	39	0.03	0.16	0.02

In Table 8, an analysis of the calculation of power both the input power, the converter output power, and the theoretical converter output power is carried out, where the calculation of the power is equal to the voltage multiplied by the current. For example, the data is taken at 12.00 with 757 W / m² radiation, then the power is:

$$P_{input} = 17.6 \times 3.06 = 53.85 \text{ Wp}$$

$$P_{output (T)} = 14.40 \times 3.52 = 50.68 \text{ Wp}$$

$$P_{output (C)} = 13.41 \times 3.01 = 40.36 \text{ Wp}$$

Based on the above calculations, the input power, converter output power, and converter output power can theoretically be known, where the input power is 53.85 Wp, the converter output power is 50.68 Wp, and the converter output power is theoretically 40.36 Wp. Based on these data, it can be seen that the converter output power and the output power are theoretically smaller than the input power. This comparison can be seen in Figure 14.

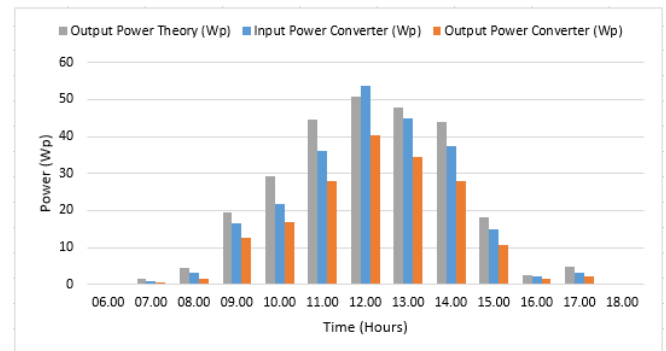


Fig. 14. Buck Boost Converter Power

F. Power Testing Implementation Tool For Battery Charging

This design uses a load for charging the 12 Vdc battery. Rload is replaced with a battery and then connected to a buck-boost converter circuit. This is done when the output voltage exceeds the nominal battery charge voltage from 10:00 to

14:00 in order to anticipate that the input voltage is lower than the battery voltage. When it is below 10:00 AM or above 14:00 PM, the voltage is below the battery charging range, so that in anticipation of the PV generator becoming a load, a blocking diode is given at the converter output. Table 9 shows the measurement data of the buck-boost converter output for battery charging.

TABLE IX. POWER CURVE IS CHARGING A BATTERY

Time (Jam)	Radiation (W/m ²)	Charging Voltage (V)	Charging Current (A)	Charging Power (W)
06:00	44	0	0	0
07:00	85	0	0	0
08:00	132	0	0	0
09:00	386	0	0	0
10:00	587	13.5	2.10	28.35
11:00	641	13.8	2.23	30.77
12:00	772	14.7	2.64	38.80
13:00	642	13	1.22	13.12
14:00	575	12.5	0.20	2.5
15:00	325	0	0	0
16:00	172	0	0	0
17:00	152	0	0	0
18:00	31	0	0	0

From the data in Table 9, a power change curve can be made when charging the battery. Figure 17 shows the power movement curve when charging the battery. In Figure 17 you can see the change in power during the charging process. The power curve is close to zero at 14:00 p.m. This state indicates that the battery charging process is complete.

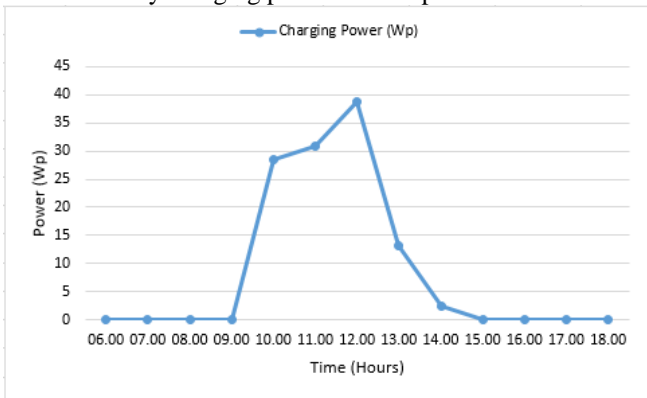


Fig. 15. Buck Boost Converter Power

G. Efficiency

To determine the efficiency of the buck-boost converter, a calculation is performed as in Equation 6. The calculated efficiency is the input power efficiency parameter and the output power efficiency. The results of the efficiency calculations are presented in Table 10. In Table 10, it can be seen that the efficiency of the buck-boost converter is in the range 51.99 - 77.42 with an average efficiency of 71.41%. This efficiency depends on the power ratio, the greater the difference between the input power and the output power, the lower the buck-boost efficiency of the converter.

TABLE X. POWER EFFICIENCY OF BUCK-BOOST CONVERTER

Time (Hours)	Radiation (W/m ²)	Input Power (Wp)	Output Power (Wp)	Efficiency (%)
06:00	41	0.06	0.04	68.75
07:00	82	0.77	0.47	61.71
08:00	121	3.07	1.60	51.99
09:00	382	16.63	12.78	76.84
10:00	407	21.84	16.90	77.42
11:00	549	35.97	27.82	77.34
12:00	757	53.5	40.36	74.95
13:00	632	44.97	34.39	76.49
14:00	570	37.39	28.02	74.95
15:00	338	15.04	10.60	70.45
16:00	124	2.06	1.49	72.29
17:00	143	3.07	2.22	72.46
18:00	39	0.03	0.02	72.73

H. Validation of Implementation Tool With Simulation

Tests carried out on the entire PV generator system to buck-boost converter by implementing the tool will be validated by simulation. The simulation in this study used supporting software, namely Matlab R2016a. This is to prove that the tools that have been made have a relatively similar working pattern to the simulation. All constituent components are made in simulink so that they can run and produce voltage, current, and output power. Appendix E shows the simulation circuit on the Matlab R2016a software. The simulation results can be seen in Table 11.

TABLE XI. RESULT OF VALIDATION ON MATLAB R2016 SIMULATION

Radiation (W/m ²)	Input Voltage (V)	Input Current (A)	Input power (Wp)	Output Voltage (V)	Output Current (A)	Output Power (Wp)
41	2.776	0.1968	0.5464	1.179	0.2358	0.2779
82	4.713	0.3936	1.855	2.339	0.4678	1.094
121	6.57	0.5807	3.815	3.391	0.6915	3.458
382	16.78	1.685	28.27	10.59	2.118	22.43
407	16.88	1.794	30.29	11.01	2.203	24.26
549	17.34	2.416	41.89	13.06	2.612	34.11
757	18.02	3.281	59.12	15.62	3.123	48.78
632	17.48	2.79	48.78	14.1	2.82	39.76
570	17.39	2.509	43.62	13.33	2.666	35.54
338	16.54	1.496	24.75	9.725	1.945	18.92
124	6.541	0.5951	3.892	3.549	0.7097	2.518
143	7.431	0.6861	5.098	4.093	0.8186	3.351
39	2.682	0.1872	0.502	1.121	0.2241	0.2512

The curve of the change in the output voltage value in the design and simulation is shown in Figure 16.

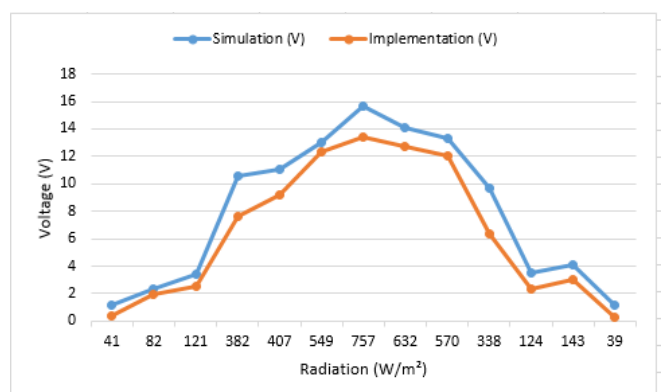


Fig. 16. Buck Boost Converter Voltage Validation

The following is the pattern of change in the output current shown in Figure 17.

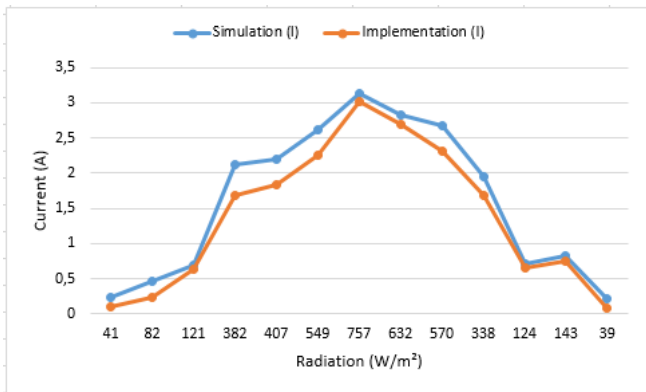


Fig. 17. Buck Boost Converter Current Validation

The curve of the change in power to radiation is shown in Figure 18.

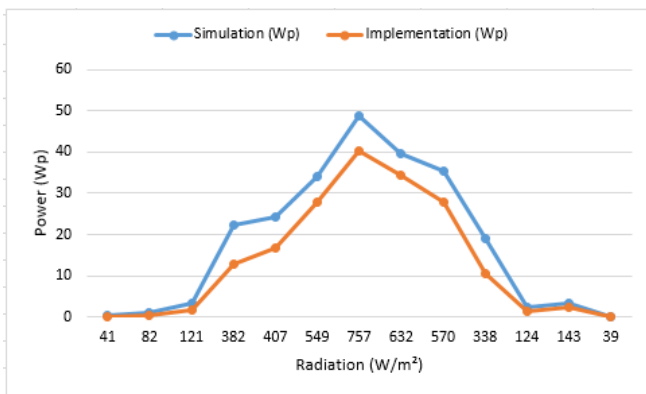


Fig. 18. Buck Boost Converter Power Validation

Table 12 is the power efficiency data in the Matlab/R2016 simulation. Table 12 shows the power efficiency validation data in the simulation. Based on the data in the table, the highest efficiency reaches 90.64% with an average power efficiency of 81.68%. Based on the simulation series, the duty cycle value can be taken to see the change in the buck-boost voltage of the converter due to changes in radiation received by the PV generator. The varying radiation changes are taken based on the results of the design stress test, namely the lowest radiation value of 41 W/m² and the highest of 757 W/m² with R load. W/m² and 757 W/m² with R load.

TABLE XII. RESULT POWER EFFICIENCY VALIDATION IN SIMULATION

Radiation (W/m ²)	Input Power (Wp)	Output Power (Wp)	Simulation Efficiency (%)	Implementation Efficiency (%)
121	3.81	3.45	90.64	51.99
382	28.27	22.43	79.34	76.84
407	30.29	24.26	80.09	77.42
549	41.89	34.11	81.42	77.34
757	59.12	48.78	82.51	74.95
632	48.78	39.76	81.50	76.49
570	43.62	35.54	81.47	74.95
338	24.75	18.92	76.44	70.45

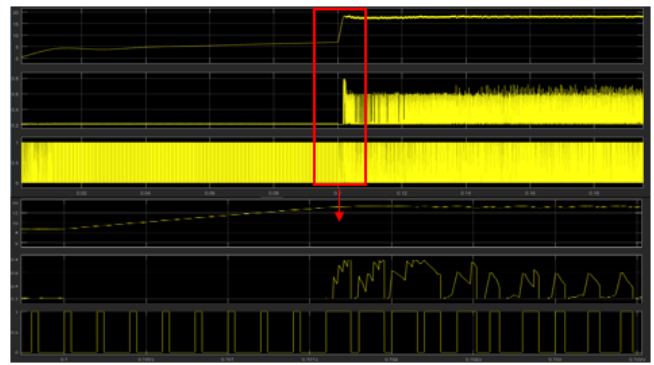


Fig. 19. Buck Boost Converter Power

Based on Figure 19, when the radiation is 41 W/m², the resulting voltage is 5 V with a duty cycle of 0.2 or 20%. Then when the radiation changes up to 757 W/m², the resulting voltage is 17 V with a duty cycle of 0.7 or 70%. It can be seen that when the duty cycle is less than 50%, the converter works as a buck, while when the duty cycle is greater than 50%, the converter works as a boost converter.

IV. CONCLUSION

The voltage and current generated by a PV generator is affected by changes in radiation, the greater the radiation received by the PV generator, the greater the resulting voltage and current. Based on the test results, the highest output power is generated when the radiation is 757 W/m² which is 40.36 Wp. For power testing with battery load, battery charging takes 4 hours (10:00-14:00). The average power consumed by the battery is 28.38 W with an average charge voltage of 13.5 V and a charging current of 1.678 A. The design efficiency of the buck-boost converter obtained from this study reached an average of 71.41%. The curve of change in the parameters of voltage, current and power has a pattern that is relatively the same as the curve obtained from the design test results.

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