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Design of Charger Controller on Wind Energy Power Plant with Arduino Uno Based on Pi Controller

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ABSTRACT Technological developments are increasing every day. Most human activities do not escape the use of electrical energy. The increase in world fuel oil and its scarcity has led to many new innovations, one of which is the use of renewable energy. The most widely used renewable energy is solar, wind, and hydro energy. In order to support the effectiveness of the generator, a charger controller is needed to maintain battery performance. In this accumulator, the maximum voltage required to charge is 14.4 Volts. The problem that arises is how the voltage generated from the generator does not match the voltage required in the battery charging process. From this problem, a charger controller with a buck converter circuit with the PI method was made to stabilize the output voltage for charging. The aim o this study is to make a battery charger that can stabilize the level voltage of the battery charger. From the research, it was found that the efficiency value of the charger controller is 83-95%, and the average error percentage is 1.373%. For this reason, it can be concluded that the charge controller has good performance in terms of efficiency and percentage of output voltage error. The charger controller is expected to maintain battery performance and the lifetime of the battery.

INDEX TERMS Electrical, Wind, Turbine, Battery.

I. INTRODUCTION

The source of electrical energy is the most needed resource for humans [1]. Electricity is very important for humans today; almost all equipment used uses electrical energy. However, from the increasing number of consumers of electrical energy, the availability of electrical energy is running low because electrical energy in Indonesia is produced by fossil energy [2]. For this reason, Indonesia needs new energy sources to meet its growing electricity needs [3]. The utilization of solar energy as an alternative energy source to overcome the energy crisis, especially petroleum, which has occurred since the 1970s, has received considerable attention from many countries in the world. The most widely used renewable energy is solar, wind, and hydro energy [4]. In order to support the effectiveness of the generator, a charger controller is needed to maintain battery performance [5]. In this accumulator, the maximum voltage required to charge is 14.4 Volts. The problem that arises is how the voltage generated from the generator does not match the voltage required in the battery charging process [6]. From this problem, a charger controller with a buck converter circuit with the PI method was made to stabilize the output voltage for charging [7].

In another study conducted by Jamal in 2020, research was carried out on the angle of the vertical wind turbine blade placement, which was carried out with four variations [8]. From the research conducted, it was found that the highest power coefficient that can be produced by wind turbines is in wind turbine research with a pitch angle of 45° Cp max 7.39% with a TSR of 0.422. This research was conducted using a vertical wind turbine with three blades [9]. Furthermore, one of the important components in a power plant is a battery. The process of recharging the battery that is not suitable can cause a decrease in battery performance. In a previous study conducted by Robiansyah in 2017, a study was conducted on charger controllers using a buck converter [10]. The purpose of this research is to design a charge controller for small-scale utilization [11]. Wherefrom the research conducted, it was found that the output voltage value of the charger controller was a maximum of 13.5 V with a maximum current output of 3 A [12]. For this reason, in this study, a charge controller was designed using a PI controller [13].

In the manufacture of charge controllers, a PI controller is used, which aims to stabilize the output voltage [14]. This is because the input of the charge controller has a varying voltage level. This PI controller will be carried out by Arduino Uno, where the setpoint is 144 V at the output voltage obtained from measurements made by the voltage sensor on the output side of the system [15].

In this study, the design of a tool consisting of the calculation of the buck converter component, the calculation of the values of Kp and Ki on the PI controller used, and also the manufacture of an open-loop transfer function used in the simulation before the tool is used in testing with input in the form of a power plant. Furthermore, testing was carried out on all sensors that had previously been calibrated, then tested the power output of each power plant used and also tested the charge controller with input from renewable energy hybrid power plants. From the whole series of tests, conclusions will be drawn, and it is hoped that the tool can overcome the problems that exist in the renewable energy power generation system in Indonesia.

II. MATERIALS AND METHODS

A. MATERIALS AND TOOL

In this study, the input voltage value from the power plant is used in the range of 15v to 25v. This tool uses two current sensors and also two voltage sensors that will be installed on the input side and the output side of the buck converter. It aims to calculate the efficiency value of the charger controller that is made. In addition, the Arduino Uno R3 microcontroller is also used as a data processor for measuring the magnitude of current and voltage in the charge controller system that is made. Arduino also functions as a PI controller data processor, which aims to stabilize the output voltage value of the buck converter. Furthermore, when the battery is full, charging will be cut off by a charging module to avoid overcharging. All measured values in the system will be displayed on a 16x2 LCD as an interface.

In this research, several sensor modules and a microcontroller are used, which have technical specifications. The first is the INA219 current sensor which is a current sensor used for DC electric current. The INA219 sensor can be used to measure the voltage, current, and power of a circuit. In operation, an I2C connection is used so that 16 sensor units can be used simultaneously. In addition, this sensor has an accuracy of 0.5%. This sensor uses the SOT23-8 and SOIC-8 packages and is also equipped with a filtering option and also with a calibration register.

While in this study used an Arduino Uno R3 microcontroller board with the following specifications.

The microcontroller used in this study has dimensions of 68.6 x 53.4 mm with a weight of 25 grams using an Atmega328P IC with an operating voltage of 5V, but a voltage of 7-12V can be used because this microcontroller uses a regulator IC so that it can reduce the voltage entered in the jack power in this microcontroller. This microcontroller has 14 digital pins where there are six pins that can be used as PWM outputs. In addition, this micro-controller also has six analog pins. This microcontroller has a memory capacity of 32 kb, of which 0.5 kb is used as a bootloader, and there is also 2 kb of SRAM and 1 kb of EEPROM.

Data from the measurement of the voltage sensor and current sensor will be displayed on a 16x2 LCD with the following specifications. The LCD used consists of 16 columns and two rows; besides that, this LCD is also equipped with a backlight. Regarding the display of the LCD itself has 192 characters stored. In operation, it can be addressed in 4-bit and 8-bit modes. And lastly, there is also a programmable character generator. This study also used two voltage sensors where the voltage sensor used applies the principle of voltage divider where the voltage sensor design process can be seen in the next section.

B. THE DIAGRAM BLOCK

The working system of the charge controller in this study can be seen in FIGURE 1.

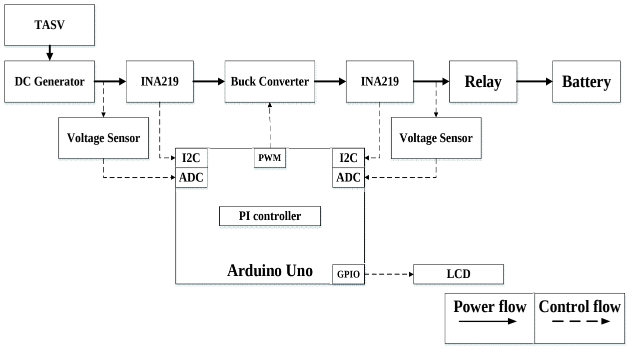

FIGURE 1 The working system of the charge controller

The chart is divided into three parts which consist of input, process and output. In the input section there is a voltage sensor, an INA219 current sensor and the power output from the turbine which is an electrical power source. Furthermore, the process section consists of the Arduino Uno microcontroller board as a PWM producer and the part that processes input data from the voltage sensor and current sensor. In addition, there is also a buck converter which is useful for maintaining the power output that enters the battery to be constant and in accordance with the planning that has been done. Furthermore, the output section consists of a battery and also an LCD as a display of current and voltage output. For a more detailed circuit, see the wiring diagram FIGURE 2.

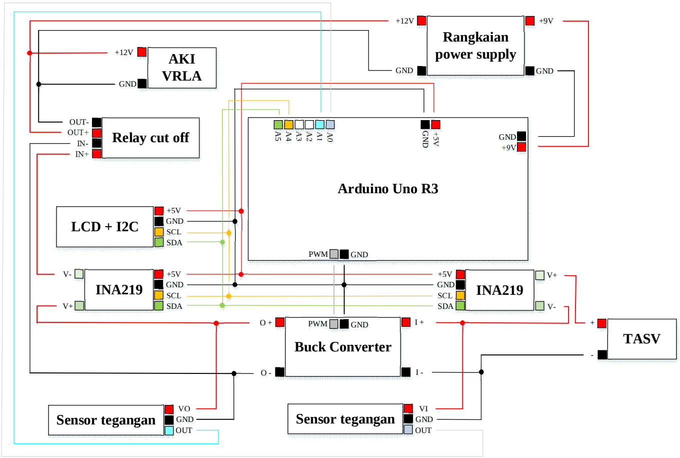

FIGURE 2 System wiring diagram

C. DESIGN OF CHARGE CONTROLLER SYSTEM

From the circuit that has been made, run simulation is carried out, and the output voltage waveform of the buck converter is known as below. From the simulation results of the open-loop buck converter, as shown in the picture above, it is found that the response wave of the output voltage at a steady-state is 14.26 V with a steady-state time of 66.89 ms. Based on the waves obtained in the above test, the following data were obtained:

Steady state time (T) = 66.89 ms
Steady state voltage (Y) = 14.26 volts
Target voltage (X) = 14.4 volts

From the experiments conducted, data was obtained in the form of steady-state time (T) of 0.06 s, in addition to the steady-state voltage (Y) of 14.26 volts, and the target voltage (X) of 14.4 volts.

$$K = \frac{Y_S}{X_S} \quad [25] \tag{1}$$

Where K is the gain, Yss is the crest of the wave, and Xss is the setpoint. Next is the determination of the value of the time constant (τ) [26]

$$t_s = 5\tau \tag{2}$$

Where is the time constant, ts is the settling time. Next, calculate the value of ts*:

$$t_s{}^* = 5\tau \tag{3}$$

$$t_s{}^* = \frac{1}{n^*} x t_s \tag{4}$$

Where ts* is the settling time after being controlled, ts is the settling time before being controlled. So:

$$\tau^* = \frac{t_s{}^*}{n} = \frac{0{,}012}{5} = 0{,}024 \tag{5}$$

Dimana τ^* merupakan time constant setelah dikontrol, $t_s{}^*$ merupakan settling time setelah di control, dan n merupakan jumlah pembagian section pada setiap time constant. So for the values of Kp and Ki in this system are as follows:

$$K = \frac{\tau}{k\ *} = \frac{0{,}012}{0{,}99\ x\ 0{,}024} = 0{,}5050 \tag{6}$$

$$K = \frac{K}{\tau} = \frac{42{,}087}{13{,}378} = 42{,}087 \tag{7}$$

Where Kp is a proportional constant value, is a time constant, k is a gain, * is a time constant after controlling, and Ki is an integral constant value. Before carrying out the design process, wind speed data was collected where data collection was carried out by measuring wind speed using an anemometer. From the data collection of wind speed characteristics that have been carried out, the calculation of the blades of the vertical wind turbine is carried out. Wind speed testing data can be seen in the research results section.After that, to perform tests on mathlab, calculations must be carried out to obtain the transfer function of the open loop buck converter circuit. From the waves generated from the experiment using the PSIM application, the following data were obtained:

Yss (setpoint) = 14.4 V
Yp (peak wave) = 23.47 V
t(Yp) (t reaches gel peak) = 0.0115 s

$$K = \frac{V}{D \quad C} [23] = \frac{14.4}{0.8} = 18 \tag{8}$$

$$\zeta = \frac{1}{\sqrt{1 + \left(\frac{\pi}{ln\left(\frac{Y \quad - Y}{Y}\right)}\right)}} [24] \tag{9}$$

$$\zeta = \frac{1}{\sqrt{1 + \left(\frac{3.14}{ln\left(\frac{23.47 - 14.4}{14.4}\right)}\right)}} \tag{10}$$

$$\zeta = 0.2523 \tag{11}$$

$$\omega = \frac{\pi}{t(Y \quad)\sqrt{1-\zeta^2}} \quad [25] \tag{12}$$

$$\omega = \frac{3.14}{0.0115\sqrt{1 - 0.2523^2}} \tag{13}$$

$$\omega = 316.0577 \tag{14}$$

So that the open-loop transfer function of the buck converter circuit is obtained as follows:

$$O \quad = \frac{1798064{,}644}{s^2 + 159{,}489s + 99892{,}48} \tag{15}$$

IV. RESULT

A. COMPARISON OF TESTING WITHOUT METHODS AND USING METHODS P AND PI

This comparison of the use of control methods in this plan has the aim of clearly knowing the difference between each control method when applied to the plan. The figure below is a comparison of the system response from the circuit with feedback without the method and the use of the P and PI methods (FIGURE 3).

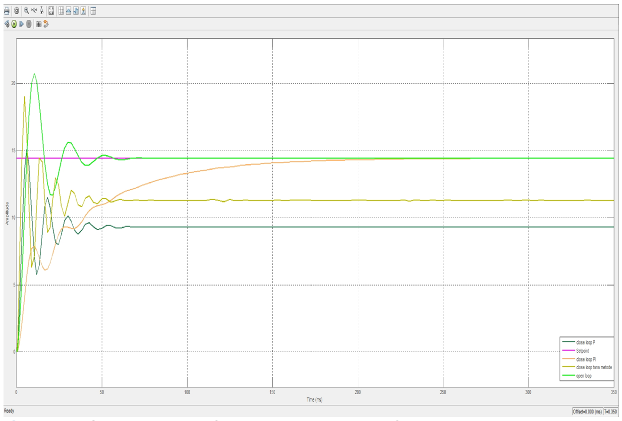

FIGURE 3 **Comparison of system response of each circuit**

The characteristics of the system response in each experiment can be seen in TABLE 1.

TABLE 1
COMPARISON OF SYSTEM RESPONSE OF EACH CIRCUIT

Characteristics	Open-loop	Close loop without method	Close loop with P	Close loop with PI
Td (delay time) (s)	0,037	0,0016	0,0028	0,009
Tr (Rise time) (s)	0,0055	0,0023	0,003	0,09
Tp (peak time) (s)	0,010	0,0046	0,0059	0,028
Ts (settling time) (s)	0,088	0,087	0,0893	0,33
Mp (maximum overshoot)(V)	20,075	19,037	15,051	7,76
Ess (error steady state) (%)	0,069	21,69	35,45	0,069

From the characteristics of the system response obtained, it is found that the PI method has a low overshoot and reaches the setpoint. For this reason, the PI method is used in this research.

B. TESTING BUCK CONVERTER IN OPENLOOP

This test is conducted to determine the output of the buck converter when the system is not subjected to the PI method. Open-loop testing on the system integration of this converter is to use a resistive load at the output of the buck converter. This test is carried out using a duty cycle value of 80%. From the tests carried out, the data obtained are as follows.

TABLE 2
BUCK CONVERTER TEST DATA IN OPEN LOOP

Vin (V)	Vout (V)	Iin (mA)	Iout (mA)	D (%)	*Error* Vout (%)
19	15,05	15,3	17,1	79	4,514
18,5	13,57	15,2	17	73	5,764
18	14,32	15,4	17,4	80	0,556
17,5	13,95	15,4	17,1	80	3,125
17	13,57	15,5	17,1	80	5,764
16,5	13,2	15,3	17	80	8,333
17,5	13,95	15,4	17,1	80	3,125
Average					4,676

From the test data that has been carried out, it can be presented in a graph as shown in FIGURE 4.

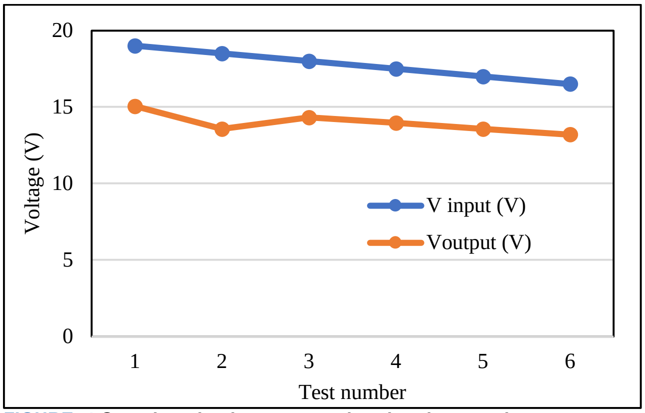

FIGURE 4 **Open loop buck converter charging data graph**

FIGURE 5 **Open-loop buck converter test**

From the tests carried out, it was found that the output voltage value of the buck converter in the test with an input voltage of 18.5 volts to 16.5 volts was below the setpoint (FIGURE 5). As for the input voltage of 19 V, the output voltage of the buck converter is above the setpoint. For this reason, it is necessary to use a method to improve the output voltage of the buck converter.

C. BUCK CONVERTER TEST IN CLOSE LOOP WITHOUT PI METHOD

This test is carried out by applying the duty cycle value where the duty cycle is obtained from reducing the setpoint value with the sensor reading value. The output voltage sensor in the circuit will be used as feedback which gives the reading of the voltage value in the system (TABLE 3).

TABLE 3
BUCK CONVERTER TEST DATA WITH METHODLESS CLOSE LOOP

Vin (V)	Vout (V)	Iin (mA)	Iout (mA)	D (%)	*Error* Vout (%)
19	15,31	13,9	27,4	80,6	6,319
18,5	14,91	14,1	28,1	80,6	3,542
18	14,72	14,3	30,7	81,8	2,222
17,5	14,31	14,2	30,6	81,8	0,625
17	13,92	14,4	29,9	81,9	3,333
Average					3,541

The output voltage of the system test using closed control without any method can be presented in the form of a graph in FIGURE 6.

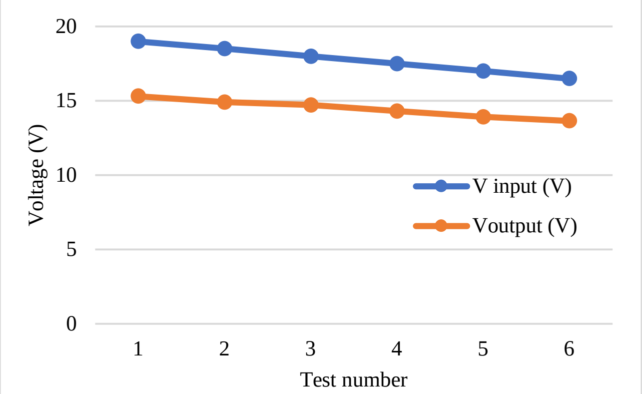

FIGURE 6 **Methodless close loop buck converter test data graph**

FIGURE 7 **Methodless close loop buck converter test**

From the tests that have been carried out, it is found that the output value of the buck converter is unstable. This is because the duty cycle of the buck converter only depends on feedback and is not processed by a method (FIGURE 7).

D. CLOSE LOOP BUCK CONVERTER TEST USING P . METHOD

The next buck converter test is to use the P method. Where the Kp value used is 278. This value is obtained from the test in section 4.8.3. The results of the tests carried out can be seen in TABLE 4.

TABLE 4
BUCK CONVERTER TEST WITH P . METHOD

Vin (V)	Vout (V)	Iin (mA)	Iout (mA)	D(%)	*Error* V out (%)
19	6,905	6,9	11,1	36,3	52,049
18,5	6,813	6,8	11,7	36,8	52,688
18	6,718	6,9	11,2	37,3	53,347
17,5	6,622	7,1	11,3	37,8	54,014
17	6,524	7	11,2	38,4	54,694
16,5	6,425	6,9	11,4	38,9	55,382
Average					53,69

Based on the tests carried out, the output voltage of the buck converter is unstable. This is because the greater the value of Kp given, the system will work unstable, or the system response will be isolated.

FIGURE 8 is a graph of the output voltage of the buck converter in the close loop test using the P method.

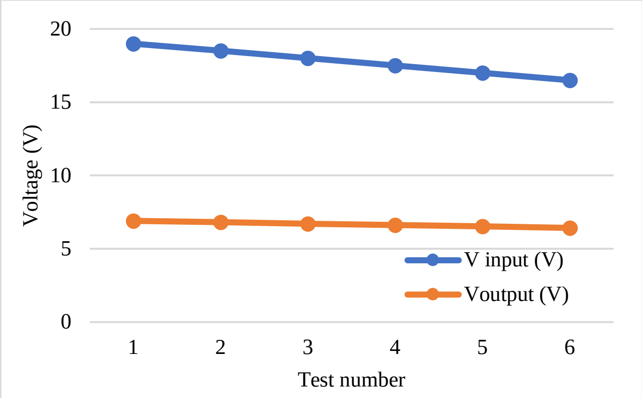

FIGURE 8 **Graph of close loop buck converter test data with P . method**

FIGURE 9 **Buck converter test with P . method**

Based on the graph above, which is a graph of the output voltage of the system, the % error value is quite large (FIGURE 9). This is because the small value of Kp makes the output of the buck converter unable to reach the set point.

E. TESTING CHARGER CONTROLLER IN CLOSE LOOP WITH PI

The PI Control Test aims to determine whether the system can maintain a constant voltage according to the design and compare the system when it is without control and when it is given control. The test is carried out using the input from the DC power supply, which is then inserted into the input of the buck converter. The load used during the simulation is a resistive load of 1 kOhm. This test is carried out using a random input voltage.

Meanwhile, when testing using the value of Kp = 0.5050 and Ki = 42.087, where the determination to get the value using analytical methods. Below is the buck converter simulation test data with open loop and close loop (TABLE 5).

TABLE 5
CLOSE LOOP BUCK CONVERTER TEST DATA

Vin (V)	Vout (V)	Iin (mA)	Iout (mA)	D(%)	Efficiency (%)	Error (%)
18,94	14,49	1,8	2,1	77	89	0,625
18,87	14,49	2,1	2,3	77	84	0,625
19,09	14,37	2,2	2,3	75	79	0,208
19,84	14,47	1,9	2,3	73	88	0,486
21,02	14,3	2,1	2,4	68	78	0,694
20,14	14,32	2	2,1	71	75	0,556
19,89	14,32	2,1	2,6	72	89	0,556
17,43	14,15	1,9	2,3	81	98	1,736
18,62	14,35	2	2,5	77	96	0,347
22,68	14,54	1,6	2	64	80	0,972
22,92	14,54	2	2,7	63	86	0,972
21,48	14,66	1,8	2,4	68	91	1,806
19,97	14,39	2,2	2,6	72	85	0,069
22,92	14,54	2	2,9	63	92	0,972
21,31	14,35	2	2,8	67	94	0,347
19,97	14,39	2	2,3	72	83	0,069
20,06	14,39	1,9	2,6	72	98	0,069
20,81	14,37	1,8	2,1	69	81	0,208
24,51	14,32	2	2,4	58	70	0,556
23,15	14,44	1,8	2,2	62	76	0,278
19,09	14,64	1,9	2,5	77	101	1,667
22,32	14,34	2,1	2,4	64	73	0,417
18,94	14,49	1,8	2,1	77	89	0,625
18,87	14,49	2,1	2,3	77	84	0,625
19,09	14,37	2,2	2,3	75	79	0,208
Average				70	85,77	0,647

This data was created from experimental on the PI control, which is done by varying the input voltage to find out how the response of the PI control is. These data prove that the use of PI control on the system is able to maintain the output voltage. The input and output voltage data on this buck converter test can be presented in FIGURE 10.

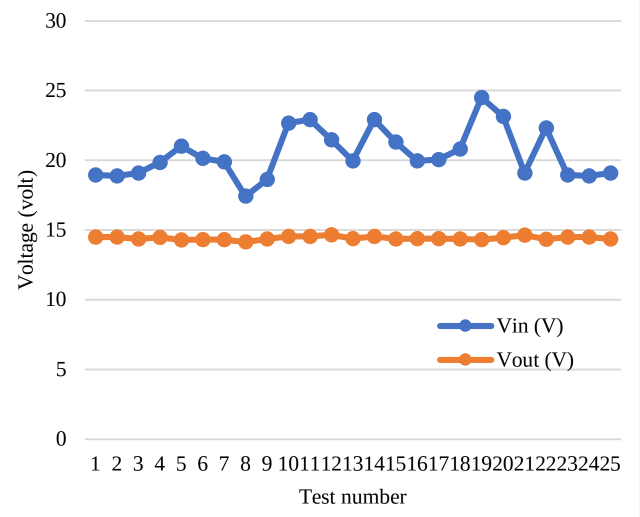

FIGURE 10 Buck converter test chart

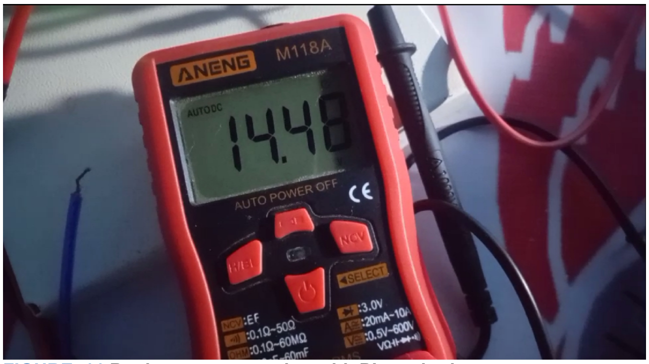

FIGURE 11 Buck converter testing with PI. method

Based on the graph above, which is a graph of the output voltage of the system when the condition is closed, it is found that the average output voltage value is 14.46 V which is close to the value of the charging voltage on the planned battery, which is 14.4 V (FIGURE 11). From the tests that have been carried out, it is found that The buck converter can maintain the output voltage value in accordance with the constant voltage condition with an average error percentage of 0.446 %.

F. BATTERY CHARGING TEST

System testing with a battery load is carried out with the aim of knowing how long it takes to fully charge the battery, as well as to test the cut-off module installed at the output of the charger controller, which is used to disconnect the circuit when the battery is full. In this charging simulation, a 7.2Ah VRLA LC-R127R2CH battery is used. When testing the battery charging process, what must be considered is the initial SOC of the battery, and in this test, the initial SOC is used at the time of charging, which is 12.3 V. For this reason, relay settings are made to charge when the battery voltage is 12 volts. Below is the test data of the buck converter with battery load.

TABLE 6
BUCK CONVERTER TEST DATA WITH BATTERY LOAD

Time (minute)	V in (volt)	I in (A)	V out (volt)	I out (A)	Relay condition
0	18,33	0,949	12,3	1,146	On
3	18,46	0,89	12,4	1,139	On
7	18,69	0,824	12,5	1,074	On
12	18,53	0,739	12,6	0,957	On
18	18,43	0,635	12,7	0,814	On
23	18,32	0,618	12,8	0,780	Off

From TABLE 6, it is found that the system is capable of charging the battery. In this test, it can be seen that the system has been able to carry out the charging process on a battery. When the system is charging, the measured voltage will follow the measured voltage on the cut-off relay. FIGURE 12 is a graph of the relationship between the output voltage of the buck converter and the charging time.

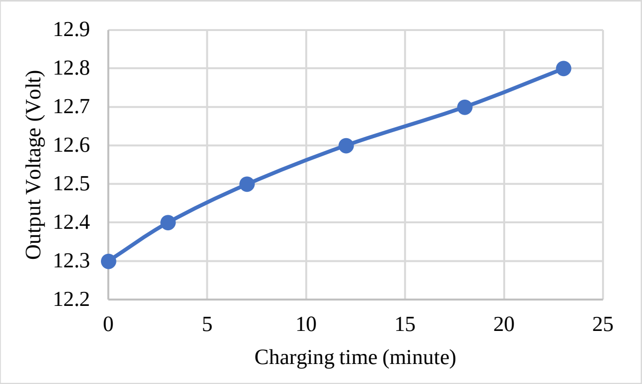

FIGURE 12 Battery charge test chart

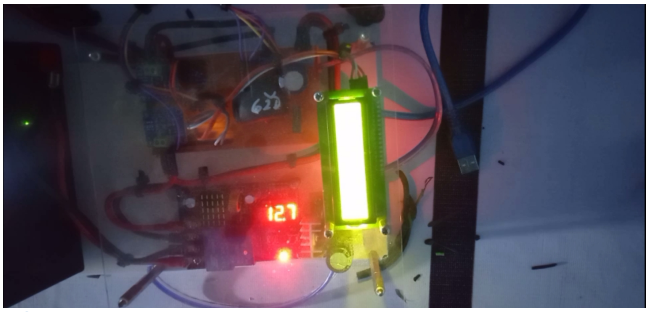

FIGURE 13 Buck converter test with a battery load

From this test, it is known that to charge the battery from 50% to 100% SOC condition takes 23 minutes (FIGURE 13).

G. INTEGRATION TESTING

This test was carried out at Kenjeran Beach Surabaya, where this test was carried out by applying power input to the charger controller using a vertical wind turbine. On the other hand, observations were also made regarding the wind speed at Kenjeran Beach when this integration test was carried out. In this system, the input value of the buck converter from the vertical wind turbine will be measured, and the value of the power output coming out of the buck converter will also be observed. The value of the input and output of the charger controller will be observed through the value displayed by the LCD, where what will be displayed by the LCD is the amount of voltage and current at the input and output of the charger controller. The test data that has been carried out can be seen in TABLE 7.

TABLE 7
DATA INTEGRATION TEST WITH WIND TURBINE

Time (menit)	Wind velocity	V in (volt)	I in (A)	V out (volt)	I out (A)
0	4,2	17,63	1,23	12,3	1,25
4	4,3	17,81	1,32	12,4	1,36
8	4,1	17,51	1,27	12,5	1,35
12	4,2	17,71	1,38	12,6	1,41
16	3,9	17,49	0,95	12,7	1,14
20	3,9	17,52	0,79	12,7	0,84
24	3,6	16,43	0,72	12,7	0,81
28	3,7	16,71	0,64	12,8	0,72
31	3,7	16,38	0,05	12,8	0,002

The data in the table above can be made in FIGURE 14.

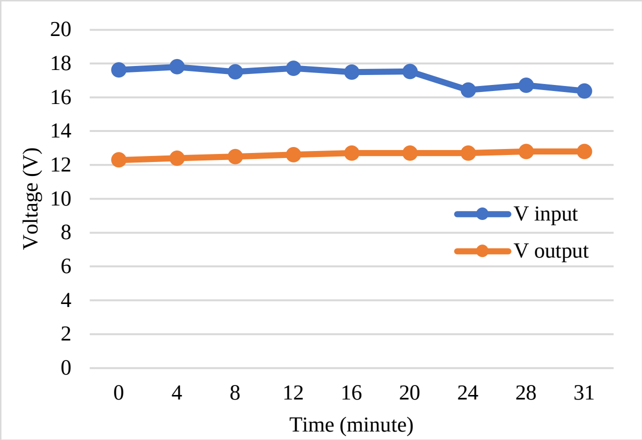

FIGURE 14 Charger controller integration test chart

FIGURE 15 Charge controller integration test

From the tests carried out, it was found that to charge the battery with an initial voltage of 12.3 V to 12.8 V it takes 31 minutes, and the relay will turn off when the battery is full (FIGURE 15).

V. DISCUSSION

The design of the charge controller that has been made has been tested in this study. Based on the tests that have been carried out, the system response obtained is that the PI method has a low overshoot and reaches the setpoint. For this reason, the PI method was used in this study.By comparing the system response output from the charge controller in the open-loop and closed-loop circuits without using the PI method, it was found that the best system response in the closed-loop circuit experiment using the PI method, the overshoot of the system was quite small. In addition, the error percentage of the circuit is in the closed-loop circuit with the method that is equal to 0.069%.

The performance of this work is also compared with other works. In previous research conducted by Robiansyah, it was found that the system made in this study worked more optimally, as evidenced by the output of the response not having oscillations and also with a fairly small percentage of output voltage error. The limit voltage of the input of the battery charger is under 15 V and bigger than 25V.

VI. CONCLUSION

This research aims to support the renewable energy utilization program by making one of the important components in power plants, namely the charge controller. From the tests that have been carried out, it is found that the efficiency of the buck converter system is 85.60-95.7%, so that the buck converter is expected to extend the life and maintain battery performance. Further research can be carried out on the manufacture of windings in the inductor and the effect of the cross-sectional area used in it.

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