ATCSJ
Applied Technology and Computing Science Journal
Open Access **p-ISSN 2621-4458 | e-ISSN 2621-4474**
UNUSA
Available online to journal2.unusa.ac.id
UNUSA
S4-Accredited – SK No.200/M/KPT/2021
Journal Page is available to https://journal2.unusa.ac.id/index.php/ATCSJ

Battery Charger Design with PI Control Based on Arduino Uno R3

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Article history:

Received 29 September 2021
Revised 29 April 2022
Accepted 12 May 2022
Available online 30 May 2022

Keywords:

Electrification
Energy
Battery
PI control
Efficiency

Abstract

In line with the increase in the electrification ratio target to 100% in 2025, the electricity demand is projected to increase more than 7 times to 1,611 TWh in 2050. the share reached 58% or about 50 GW. On the other hand, the current energy diversification carried out by the government is directed at the utilization of renewable energy that exists in nature. One of the important components in this power plant is the battery. This is because the battery functions as a store of energy generated from the vertical wind turbine. After use, the battery needs to be recharged. The process of recharging the battery that is not suitable can cause a decrease in battery performance. Therefore, in the process of charging this battery, a safe battery charging system is needed for the battery to maintain battery performance and extend battery lifetime. This battery charging system uses a PI control system. From the research that has been done, it was found that. From the research that has been done, it is found that the output voltage value of the battery charger that is made has an average error percentage of 1.373% and the power output efficiency of the battery charger is 83-95%.

I. INTRODUCTION

In line with the increase in the electrification ratio target to 100% in 2025, the electricity demand is projected to increase more than 7 times to 1,611 TWh in 2050 [1]. Taking into account various factors, additional power generation capacity during the period 2015 s.d. 2019 is estimated at only 12 GW. Currently, power plants that have COD (Commercial Operation Date) only operate about 4% (± 1.5GW). Under these conditions, the implementation of the 35 GW program is estimated to be achieved in 2025 – 2026 [2]. In 2025 coal-fired power plants are estimated to continue to dominate with a share of 58% or around 50 GW [3]. According to BPPT in 2018, coal reserves will run out within 68 years. One of the largest electricity users in Indonesia is the household sector [4]. During January-July 2020, the largest electricity consumption from the household sector was 42.25% or reached 47.5 TWh.

One way that can be done is by utilizing renewable energy that is so abundantly available in nature [5]. On

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the other hand, the current energy diversification carried out by the government is directed at the utilization of renewable energy that exists in nature. As a solution to the high consumption of household electricity and to take advantage of the potential of wind and water as a manifestation of energy diversification, a portable power plant design was created [6]. One of the important components in this power plant is the battery.

In another study conducted by Jamal in 2019, research was carried out on the angle of the vertical wind turbine blade placement which was carried out with 4 angle variations, namely 22.5°, 45°, -22.5°, and -45°. Where the purpose of this study is to find out how the position of the most efficient wind turbine blades. 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 [7]. Furthermore, one of the important components in this power plant is the battery. This is because the battery functions as a store of energy generated from a vertical wind turbine. After use, the battery needs to be recharged [8].

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. The purpose of this research is to design a charge controller for small scale utilization. Where from 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.

This is because the battery functions as a store of energy generated from the vertical wind turbine. After use, the battery needs to be recharged [9]. The process of recharging the battery that is not suitable can cause a decrease in battery performance [10]. Therefore, in the process of charging this battery, a safe battery charging system is needed for the battery to maintain battery performance and extend battery lifetime. This battery charging system uses a PI control system.

II. METHODS

After taking data and studying literature, then the turbine design and charge controller will be made, this activity is useful to provide an overview of the tool to be made. Where in the picture below is a block diagram of the charge controller system that will be made.

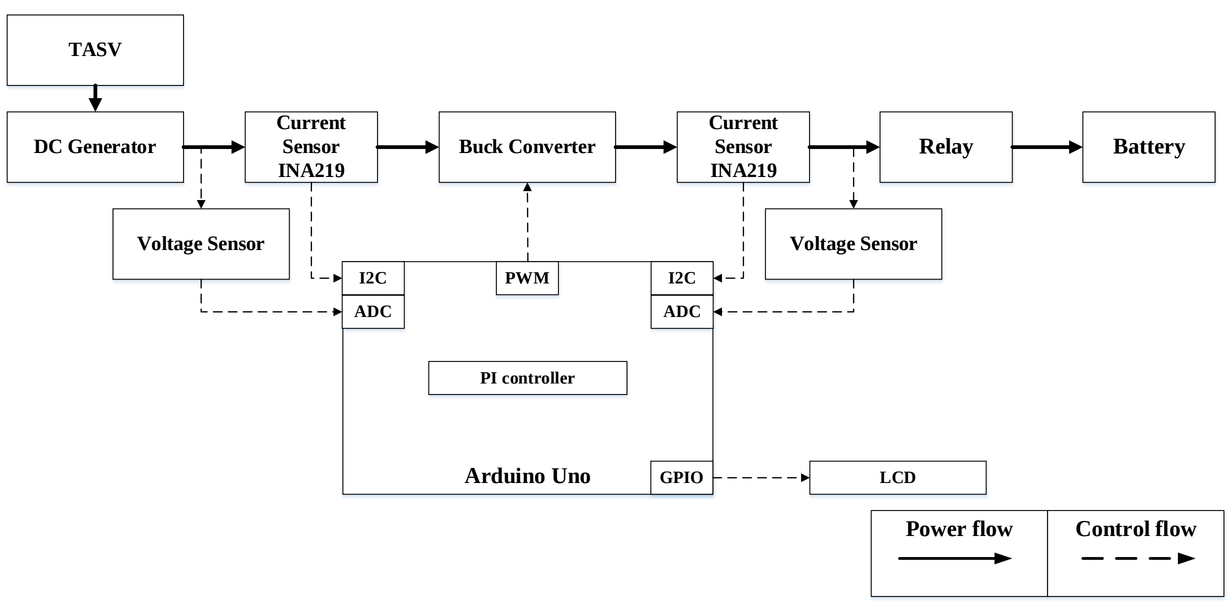

Figure 1. Block diagram of design concept system

The working system of this tool is that the mechanical energy from the wind turbine will be converted into electrical energy [11]. where the output of the generator will be measured by the voltage and current values by the voltage sensor and the input current sensor. Furthermore, the output from the generator goes to the input buck converter where after that the output from the buck converter will be measured again for the voltage and current values, then the voltage value from the output buck converter will be processed by the PI controller and the output from the PI controller is the PWM duty cycle which is used to regulate the output. from the buck converter [12]. After that the output of the buck converter passes through the relay and is used to charge the battery. where when the battery is full then the relay will be disconnected [13].

After that, proceed with making a wiring diagram of the charge controller system in this study where in the picture below is a wiring diagram of the system that will be made.

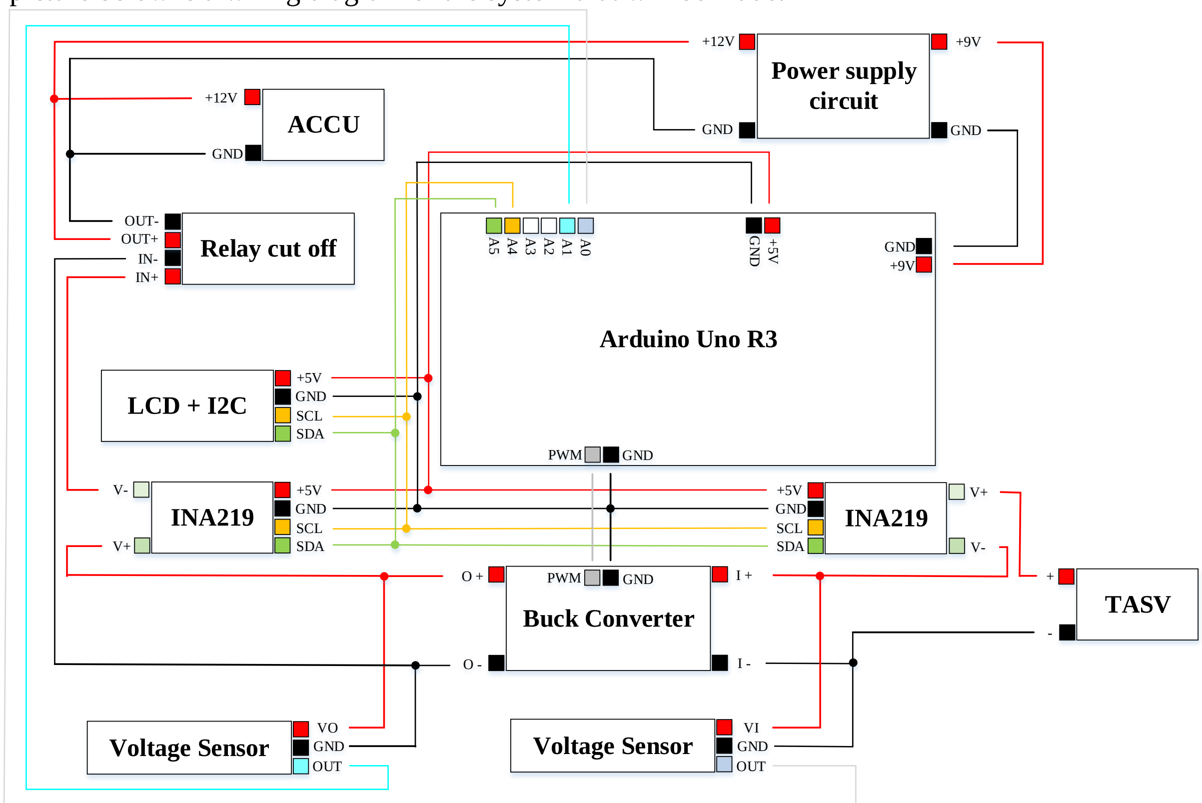

Figure 2. Wiring diagram of charge controller

At this stage, it is done by making a chart containing the components used. This stage aims to support the performance of the tool made. After that, the planning stage of the component quantities that compose the buck converter circuit is carried out.

Input Voltage (Vin) = 18 V

Switching Frequency (fs) = 0.98 Khz

Resistive Load (R) = 560 Ohm

Ripple Voltage (Vs) = 2 Volt

Next, determine the values of Kp and Ki used for PI control on the buck converter, where this stage is done by observing the output voltage wave on the buck converter circuit made on the PSIM application. Below is a series made on the PSIM application.

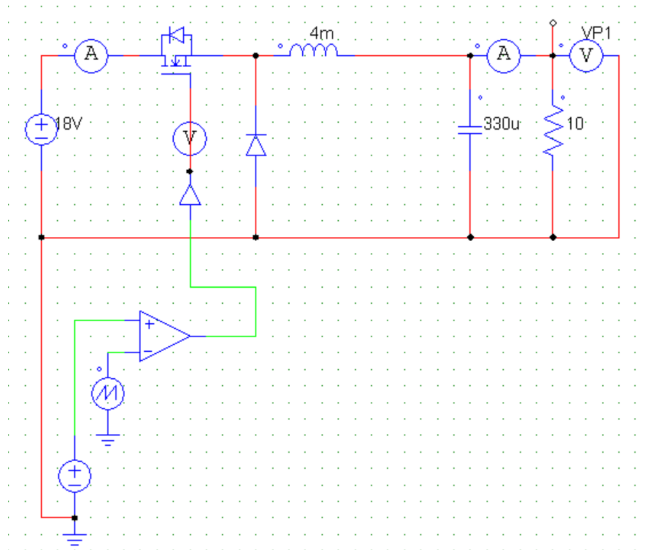

Figure 3. Buck converter circuit in PSIM application

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.

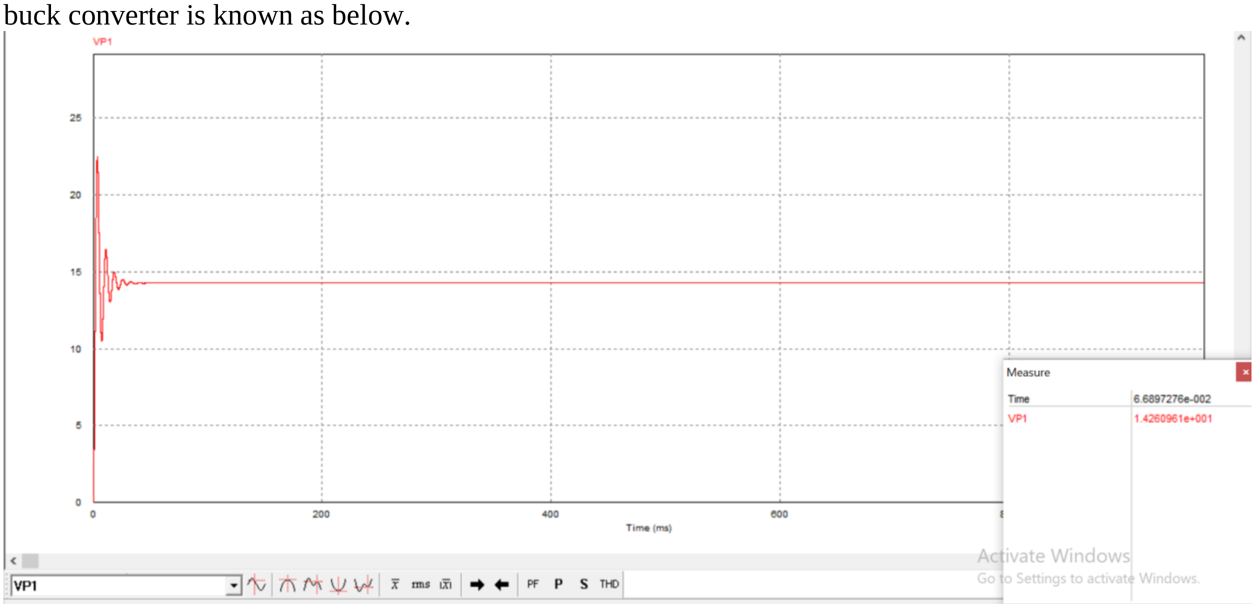

Figure 4. Voltage output waveform of PSIM simulation

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 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 (TS) = 66.89 ms
Steady state voltage (YSS) = 14.26 volts
Target voltage (XSS) = 14.4 volts
The first step is to determine the gain over all (K) value.

$$K = \frac{Y_{SS}}{X_{SS}} \quad [14] \tag{1}$$

$$= \frac{14,26}{14,4} \tag{2}$$

$$= 0,99 \tag{3}$$

Next is the determination of the value of the time constant (τ)

$$t_s = 5\tau \text{ [15]} \tag{4}$$

$$\tau = \frac{66,89\ ms}{5} \tag{5}$$

$$\tau = 13,378 \text{ ms} \tag{6}$$

So that the open loop transfer function can be determined as follows [16]:

$$OLTF = \frac{K}{\tau S + 1} \quad \text{[17]} \tag{7}$$

$$OLTF = \frac{0,99}{13,378\ S + 1} \tag{8}$$

As for the Close Loop Transfer function (CLTF) as follows [18]:

$$t_s{}^* = 5\tau \tag{9}$$

$$t_s{}^* = \frac{1}{n^*} x t_s \tag{10}$$

$$t_s{}^* = \frac{1}{5} x 66,89 \tag{11}$$

$$t_s{}^* = 13,378 \tag{12}$$

So:

$$\tau^* = \frac{t_s{}^*}{n} = \frac{13,378}{5} = 2,6756 \tag{13}$$

So that:

$$CLTF = \frac{1}{\tau^* s + 1} = \frac{1}{2,6756\ s + 1} \tag{14}$$

$$Kp = \frac{\tau}{k\tau^*} = \frac{13,378}{0,99\ x\ 2,6756} = 5,5050 \tag{15}$$

$$Ki = \frac{Kp}{\tau} = \frac{5,5050}{13,378} = 0,4114 \tag{16}$$

From the calculations that have been carried out, it is found that the values of Ki and Kp are as large as 0.4114 and 5.5050.

Below is a mechanical design of a portable power plant. Information can be seen in the image below.

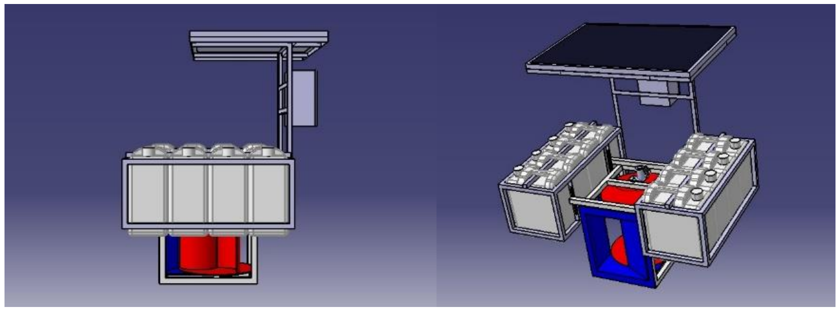

Figure 1. Prototype Design of hybrid power plant

In this design there is a solar panel that is useful as a hybrid of a savonious turbine in order to increase the output power of the power plant.

After getting data on wind speed characteristics testing, the next step is to design a vertical wind turbine blade. The first design stage is done by calculating the total area of the turbine blades (the area of the tube blanket).

$$P = Cpr\frac{1}{2}\rho A v^3 \quad (17)$$

Where :
P = power (Watts) [19]
Cpr = Rotor Power Coefficient (0.3) [20]
ρ = viscosity of air [21]
A = total area of all blades (m^2)
v = wind speed (m/s)

$$A = \frac{2P}{Cpr\rho v^3} \quad (18)$$

The average turbine Cpr value is 0.158 [21], so:

$$= \frac{2x15}{0{,}158\ x\ 40{,}75\ x\ 4{,}66} \quad (19)$$

$$= 1{,}9538\, m^2 \quad (20)$$

From the calculations that have been made, it is found that the total number of turbine blades is 3 m^2. After that proceed with determining the size of each blade [22]. In this study, a vertical axis wind turbine with 3 blades was used.

$$A = K\ x\ L \quad (21)$$

Where:
A = area of the entire blade (m^2) [23]
L = blade length (m)
K = circumference of circle/ width of blade (m)

$$K = \frac{A}{L} \quad (22)$$

$$= \frac{1{,}9538\, m^2}{0{,}04\, m} \quad (23)$$

$$= 44{,}406\ cm \tag{24}$$

After obtaining the length and width of the blade, the next calculation will be on the length of the bowstring of the blade [24]. This is used to find out how big the curvature of the blade is. This calculation technique is done by using the formula for a triangle in a circle with an equilateral triangle shape.

$$D = \frac{K}{\pi} \tag{25}$$

$$D = \frac{44{,}406}{3{,}14} \tag{26}$$

$$D = \ 14{,}142\ cm \tag{27}$$

After that, the length of the bowstring for each blade is determined. This is done to determine the curvature of the turbine blades that are designed.

$$\mathrm{r} = \frac{axbxc}{4xLabc} \quad [25] \tag{28}$$

$$7{,}07 = \frac{axbxc}{4x\frac{1}{2}xaxa\sqrt{2}} \tag{29}$$

Because a = b = c [26], so:

$$7{,}07 = \frac{a}{2x\sqrt{2}} \tag{30}$$

$$a = 24{,}15\ \mathrm{cm} \tag{31}$$

The following is a detail of the size of the turbine that has been carried out in the design process:

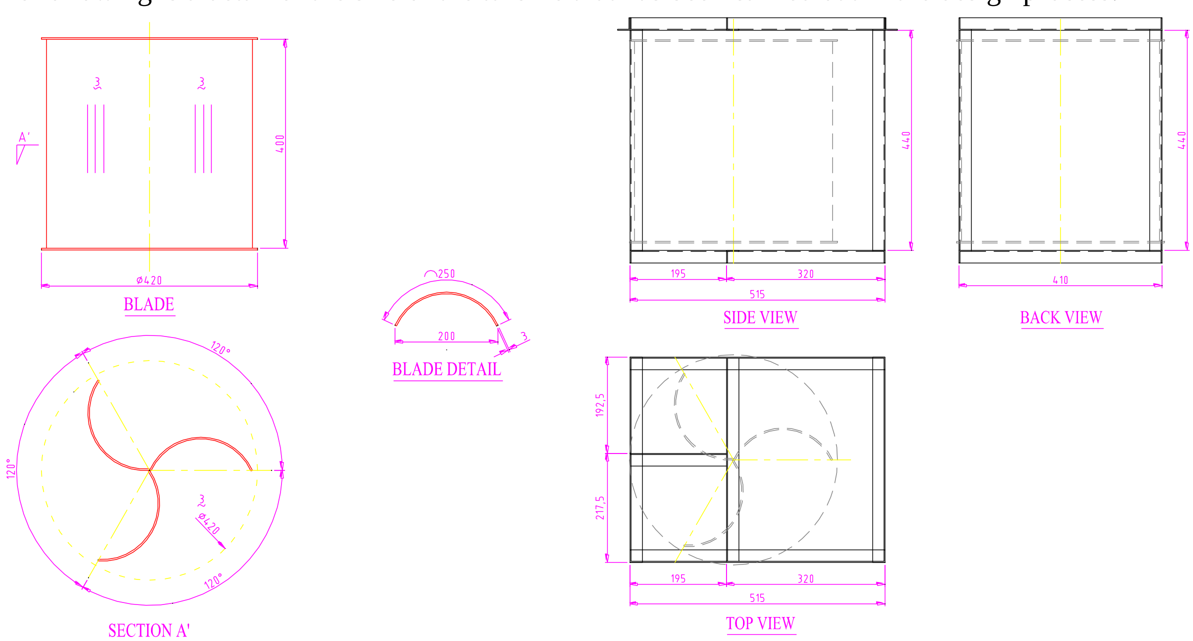

Figure 2. Blade dimension of TASV

III. RESULTS AND DISCUSSIONS

A. Turbine Testing on Hydro Energy

This test was conducted to determine the power generated by the turbine to hydro energy. This test was conducted in Singopadu Village, Tulangan District, Sidoarjo. The test data can be seen in table below.

Table 1. Test Results of the Effect of River Water Flow Velocity on the Power Produced

No.	**Velocity of water flow 0,42 m/s**	
	Voltage (V)	**Current (A)**
1.	16,66	0,57
2.	16,61	0,48
3.	17,9	0,47
4.	16,864	0,55
Average	17,01	0,52

From the tests that have been carried out, a graph can be made as below.

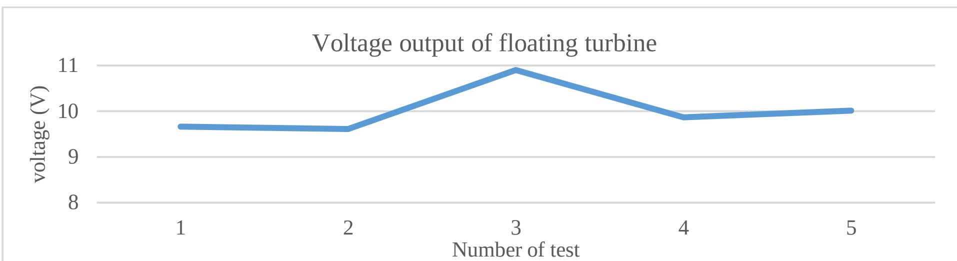

Figure 7. Turbine voltage output graph (hydro)

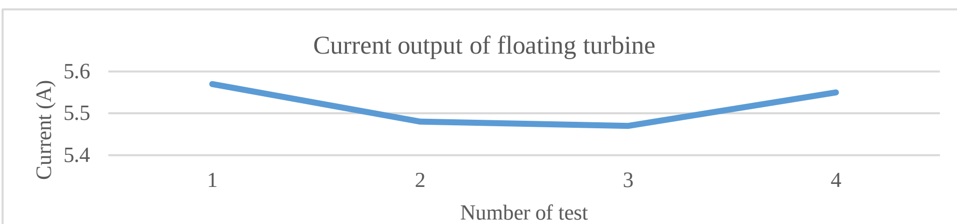

Figure 3. Turbine current output graph (hydro)

Based on the tests that have been carried out, it is known that the higher the speed of the water flow, the greater the power generated and vice versa. From the data obtained, each rotation, the turbine can produce a power of 55.2 W.

B. Turbine Testing on Wind Energy

This test aims to determine the amount of electrical power produced by wind energy with a power plant prototype. The test was carried out on July 14, 2020 at Kenjeran Beach with 4 variations of speed. The test result data can be seen in the following table.

Table 2. Table of wind turbine test results

Wind velocity variations	**Variable testing**	
	Voltage (v)	**Current (A)**
4	17,1	0,287
5	17,3	0,387
4,5	17,2	0,287
4.3	17,4	0,287
Average	17,25	0,31

From the tests that have been carried out, a graph can be made as below.

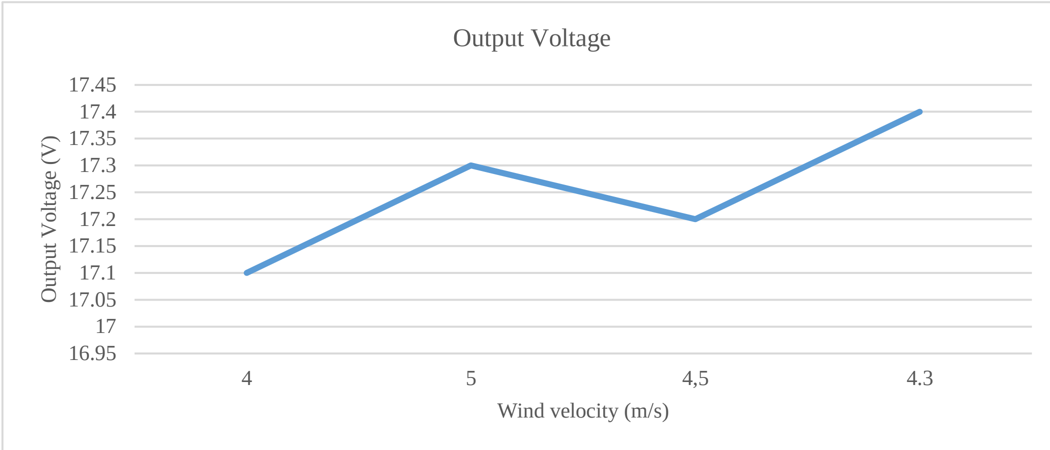

Figure 9. Turbine voltage output graph (wind)

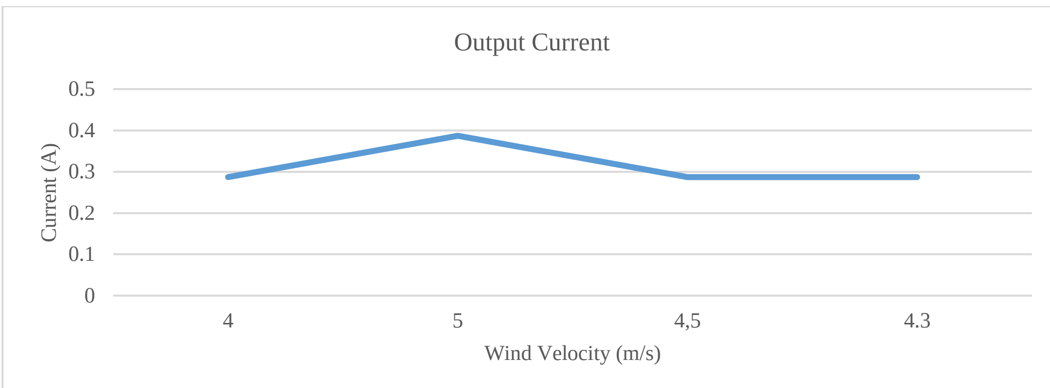

Figure 10. Turbine current output graph (wind)

Based on the test data obtained, the average output voltage is 17.25 volts. In this test, a good wind speed was taken for this savonious turbine, this is because previously the savonious turbine was designed for wind with a speed of 4 m/s. The faster the wind speed, the greater the power generated.

C. Solar Panel Test

This test is carried out with the aim of knowing the maximum power that can be produced by solar panels. The test was carried out at 9:00 to 15:00 WIB. The test is carried out using a 120 ohm load resistor and measured using a multimeter to determine the amount of voltage and current output from the solar panel. The data can be seen in the table below.

Table 3. Solar Panel Power Test

Time	Voltage (V)	Current (A)	Temperature (˚C)
9:00	18,79	0,153	49
9:30	18,88	0,156	54
10:00	18,75	0,337	56
10:30	18,93	0,107	62
11:00	18,44	0,287	58
11:30	18,53	0,115	59

12:00	18,5	0,107	58
12:30	18,5	0,127	58.2
13:00	18,12	0,287	60.2
13:30	17,95	0,387	58
14:00	18,36	0,287	56.6
14:30	18,32	0,287	53.2
15:00	18,59	0,112	50.6
Average	18,51	0,210	34,9231

From the tests that have been carried out, a graph can be made as below.

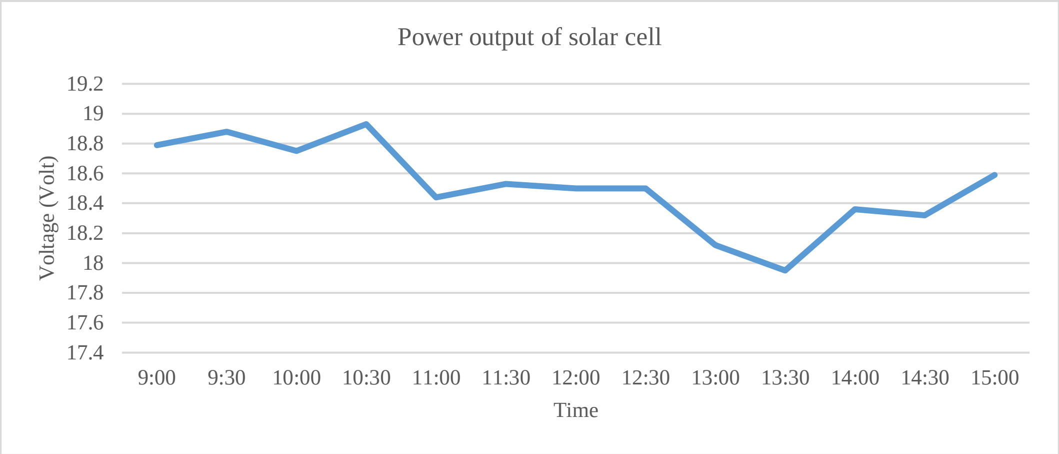

Figure 11. Solar cell voltage output graph

From these data, it can be explained that testing solar panels for one day can produce a voltage of 18.12 to 18.95 volts.

D. Open Loop and Close Loop Buck Converter Test

System integration testing without control aims to determine the output voltage generated from the system when it has not yet received control. The test is carried out with the source of the power supply where the output voltage is 15-19 volts. The test was carried out on August 1, 2021. The data below is the data obtained from the open loop buck converter test.

Table 4. Buck converter output test

D (%)	Vin (V)	Iin (A)	Vout (V)	Iout (A)	Vo theory (V)	Error (%)
10	18,5	0,115	2,05	0,315	1,85	10,811
20	18,5	0,107	4,01	0,317	3,7	8,378
30	18,12	0,127	5,696	0,347	5,436	4,783
40	17,95	0,287	7,4	0,499	7,18	3,064
50	18,36	0,387	9,49	0,627	9,18	3,377
60	18,32	0,287	11,412	0,477	10,992	3,821
70	18,59	0,287	13,423	0,487	13,013	3,151

Next, a close loop test was conducted on the buck converter circuit during charging with the aim of finding out whether the system can maintain a constant voltage according to the design and comparing the system when it is without control and when it is given control. Below is a comparison of data on the results of the open loop and close loop tests of the buck converter circuit.

Table 5. Comparison of open loop and closed loop buck converter tests

R (Ohm)	Vin (volt)	I in (A)		Vout (V)		I out (A)		Error (%)	
		Open loop	Close loop	Open loop	Close loop	Open loop	Close loop	Open loop	Close loop
200	18	1,51	1,63	16,21	14,55	1,74	1,86	12,569	1,042
180	18	1,49	1,61	15,99	14,52	1,72	1,84	11,042	0,833
160	18	1,44	1,56	15,70	14,53	1,67	1,79	9,028	0,903
140	18	1,38	1,50	15,52	14,44	1,61	1,73	7,778	0,278
120	18	1,34	1,46	15,11	13,99	1,57	1,69	4,931	2,847
100	18	1,29	1,41	14,98	14,12	1,52	1,64	4,028	1,944

From the data from experiments conducted by varying the input voltage, it is known how the response of the given control is. From these data it proves that the use of PI control in the system is able to maintain the output voltage. The error comparison between the openloop and closeloop test results will be displayed in the graph shown in the image below.

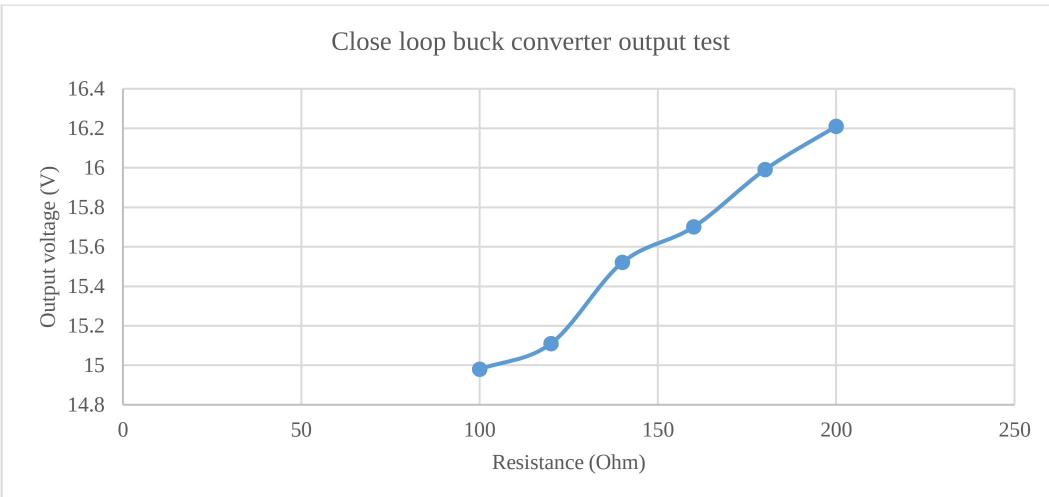

Figure 12. Voltage graph on buck converter test in close loop

Based on the picture above which is a graph of the comparison of the output voltage response of the system when the open-loop and closed-loop conditions are found, the average value of the output voltage when open-loop is 15.1 V which exceeds the maximum charging voltage limit on the battery, which is 14.4 V, whereas when the condition is closeloop obtained a constant average output voltage of 14.32 V.

E. Hybrid System Test

This test is carried out using three hybrid power plants using a chargec controller that has been made. The output of the charger controller will be hybridized and used to charge the battery. The data obtained are as follows.

Table 6. Hybrid system test data

Time (minute)	V in (volt)	I in (A)	V out (volt)	I out (A)	Relay condition
0	17,63	1,23	12,3	1,25	On
4	17,81	1,32	12,4	1,36	On
8	17,51	1,27	12,5	1,35	On
12	17,71	1,38	12,6	1,41	On
16	17,49	0,95	12,7	1,14	On
20	17,52	0,79	12,7	0,84	On
24	16,43	0,72	12,7	0,81	On

28	16,71	0,64	12,8	0,72	On
31	16,38	0,05	12,8	0,002	Off

From the tests that have been carried out, a graph can be made as below.

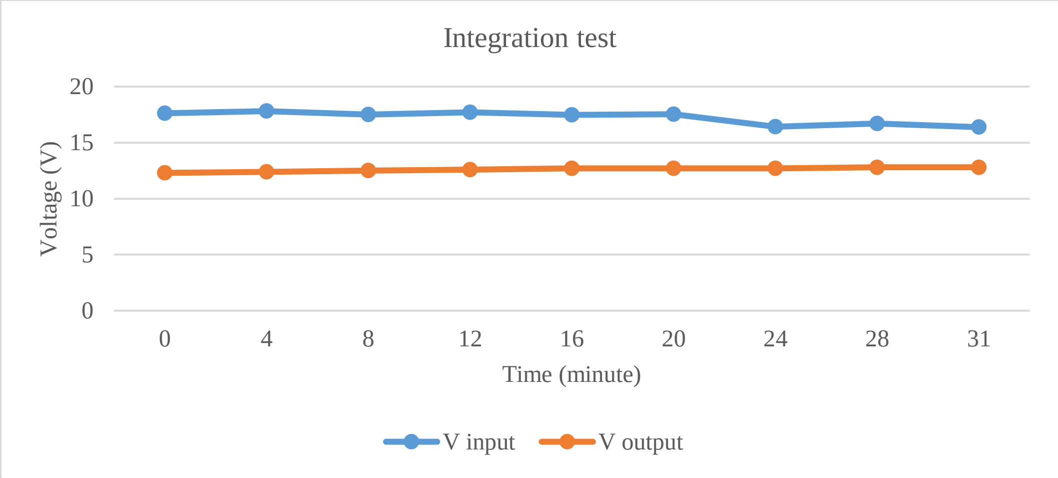

Figure 13. Charger controller integration test chart

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.

IV. CONCLUSIONS AND RECOMMENDATIONS

Some conclusions can be drawn from the previous discussion and suggestions regarding problems that can be discussed as a continuation of this research. The results of this study shown that from data collection characteristics of wind speed, data obtained wind speed of 3.66 m/s and air density of 1.2 kg/m3. It also shown that the power that can be generated by the hybrid power plant is 95.47-101.62 Watt. From the research that has been done, it is found that the output voltage value of the battery charger made has an average error percentage of 1.373% and the power output efficiency of the battery charger is 83-95%.

For the research's recommendation in this study that there is a need for research on the calculation of the type of ferrite material in the inductor and the magnitude of the switching frequency used in this charge controller in order to produce a more efficient output.

V. REFERENCES

[1] Dutta,A. 2012. Design of an Arduino Based MPPT Solar Charger Controller. Bangladesh: Brac University.
[2] Floyd, Thomas L. (2012). Electronic Devices (Electron Flow Version). New Jersey: Prentice Hall.
[3] Gautam, Aditya Raw., Deshpande, D.M., Suresh, Arisutha., & Mittal, Arvind. (2013). A Double Input DC to DC BuckBoost Converter for Low Voltage Fotovoltaic/Wind Systems. International Journal of ChemTech Reseach, 5: 1018-1020.
[4] Gurav,R. 2017. Paper of Implementasion of MPPT Charge Control Based BuckBost Converter.India: Maharasta.
[5] Kastha, Debaprasad, and Bimal K. Bose. "Fault mode single-phase operation of a variable frequency induction motor drive and improvement of pulsating torque characteristics." IEEE Transactions on Industrial Electronics 41.4 (1994): 426-433.
[6] Kazimierczuk, Marian K. (2015). Pulse-Width Modulated DCDC Power Converter. USA : John Wiley & Sons, Inc.
[7] Nugraha, Anggara Trisna, and Dadang Priyambodo. "Design of Pond Water Turbidity Monitoring System in Arduino-based Catfish Cultivation to Support Sustainable Development Goals 2030 No. 9 Industry, Innovation, and Infrastructure." Journal of Electronics, Electromedical Engineering, and Medical Informatics 2.3 (2020): 119-124.
[8] Nugraha, Anggara Trisna, and Dadang Priyambodo. "Design of a Monitoring System for Hydroganics based

on Arduino Uno R3 to Realize Sustainable Development Goals number 2 Zero Hunger." Journal of Electronics, Electromedical Engineering, and Medical Informatics 3.1 (2021): 50-56.
[9] Operate-motor-3-phase-with-electromagnetic-controlling-system / University of Sumatra.
[10] Pikatan, Sugata., 1999, Conversion of Wind Energy. Surabaya: Department of Mathematics and Natural Sciences, University of Surabaya.
[11] Priyambodo, Dadang. "Prototype Hybrid Power Plant of Solar Panel and Vertical Wind Turbine as a Provider of Alternative Electrical Energy at Kenjeran Beach Surabaya." Journal of Electronics, Electromedical Engineering, and Medical Informatics 2.3 (2020): 108-113.
[12] Priyambodo, Dadang. "Design and Build A Photovoltaic and Vertical Savonious Turbine Power Plant as an Alternative Power Supply to Help Save Energy in Skyscrapers." Journal of Electronics, Electromedical Engineering, and Medical Informatics 2.3 (2020): 57-63.
[13] Qazi, Salahuddin. (2017). Standalone Photovoltaik (PV)Systems for disaster relief and remote Areas. United State : Elsevier.
[14] Yahma Wisnani, 2004, Queri Ganda Pada Sistem Temu Kembali Informasi Berbasis Jaringan Inferensi, MAKARA SAINS, Vol.8 No.2, pp. 76-84.
[15] Juan Bernabe Moreno, 2004, Information Retrieval Meets Semantic Web, Content Management and Information Retrieval Converging.
[16] Christian Beecks and Thomas Seidl, 2009, Efficient Content-Based Information Retrieval: A New Similarity Measure for Multimedia Data, Symposium on Future Directions in Information Access.
[17] Margaret Anne Storey, 2006, Theories, Tools and Research Methods in Program Comprehension: Past, Present and Future, Springer, DOI 10. 1007/s11219-006-9216-4.
[18] Janet Feigenspan, 2011, Program Comprehension of Feature-Oriented Software Development, International Conference on Software Engineering.
[19] Seifedine Kadry, 2011, A New Proposed Technique to Improve Software Regression Testing Cost, International Journal of Security and Its Application, Vol.5, No.3.
[20] Sheo Kumar, Sugandha Chakraverti, S.C. Agarwal and Ashish Kumar Chakraverti, 2012, Modified COCOMO Model for Maintenance Cost Estimation of Real Time System Software, International Journal of Research In Engineering & Applied Sciences, Volume 2, Issue 3.
[21] Tara Kelly and Jim Buckley, 2009, Cognitive Levels and Software Maintenance Sub-Tasks, PPIG - Limerick.
[22] Sugumaran Nallusamy, Suhaimi Ibrahim and Mohd Naz'ri Mahrin, 2011, A Software Redocumentation Proses Using Ontology Based Approach in Software Maintenance, International Journal of Information and Electronics Engineering, Vol.1, No.2.
[23] Manjot Signh Ahuja, Surender Dhaiya and Neha Sadana, 2014, A Metric Mased Approach to Measure the Quality of Inline Comments in Source Code, International Journal of Computer Application, Volumen 1, Issue 4.
[24] Amandeep Kaur and Balraj Singh, 2014, Study on Metrics Based Approach for Detection Software Code Clones, International Journal of Advanced Research in Computer Science and Software Engineering, Volume 4, Issue 1, pp. 601 - 603.
[25] Michael P. O'Brien, 2003, Software Comprehension - A Review & Research Direction, Technical Report UL-CSIS-03-3.
[26] W. Meng, J. Rilling, Y. Zhang, R. Witte, and P. Charland,2006, An Ontological Software Comprehension Process Model.
http://users.encs.concordia.ca/~rilling/DRDC/Publications/ATEM_2006_Paper_15_Wen_Jun_Meng.pdf