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Design and Analysis of a Battery Charging System for a Pico-Hydro Power Plant

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Abstract

Pico-Hydro Power Plant (PLTPH) is very dependent on the received water energy, therefore a storage medium is needed to store electrical energy by using a battery and DC-DC Buck Converter as a regulator of the output voltage of the generator to charging the battery. In addition, it is necessary to design equipment in battery charging system. At PLTPH to adjust the generator voltage using a DC-DC Buck Converter 30A with an input voltage rating of 20V-70V and an output voltage of 2.5V-50V can be set for charging the battery. The battery capacity of this PLTPH uses 4 VRLA 12V 100Ah batteries which are arranged in 2 series and 1 parallel so that the battery capacity becomes 24V 200Ah with a load of the main PPYD Al-Ikhlas building with 4.2kWh of energy consumed. In testing the performance of the battery the battery is in accordance with the characteristics of the battery and the voltage is inversely proportional to the current, while the DC-DC Buck Converter has a large efficiency of 85% which shows the performance of the DC-DC Buck Converter is very good.

Keywords : Pico-Hydro Power Plant, Energy, Battery, Charging, DC-DC Buck Converter

1 Introduction

The increasing population in Indonesia from year to year causes energy needs to increase every year, especially electrical energy. Electrical energy is so important for human life that it requires an electrical system that is reliable from a technical and cost perspective that can serve and meet needs well. Electrical energy generation in Indonesia is still very dependent on fossil fuels, where fossil fuels are predicted to run out at any time. So alternative energy is needed as a substitute for fossil fuels [1][2]. Indonesia is rich in natural resources because it has a tropical climate. One of them is water which can be used as a renewable energy source, such as used in hydroelectric power plants (PLTA). Hydroelectric power plants have several differences based on the output produced, one of which is the pico-hydro scale. Pico-Hydro Power Plant (PLTPH) is a plant that converts water power to drive turbines and generators that convert water motion energy into electrical energy with a resulting power capacity ranging from hundreds of Watts to 5 kW so that it can only be used for lighting loads [3]. Pico-Hydro Power Plants (PLTPH) are very dependent on the water energy received, therefore a storage medium is needed to store electrical energy so that when repairs or damage to the turbine or generator load on the PLTPH can still be turned on [4][5]. Batteries are electrical devices that can convert chemical energy by using active materials directly to convert electrical energy through reduction-oxidation (redox) electrochemical reactions. And conversely, batteries can also convert electrical energy into chemical energy. The energy in batteries can be easily converted into light energy, heat or mechanical energy. However, batteries are not capable of storing relatively large amounts of energy [6]. The aim of this research is to test the DC-DC Buck Converter module on the effectiveness and efficiency of the battery charging system in the vortex type PLTPH. The DC-DC Buck converter is a step down type DC-DC converter that can work as a voltage reducer that can be adapted to other applications that require varying output voltages such as when charging batteries and can also function to improve power quality and efficiency [7].

2 Method

This research began by collecting and studying theories related to battery charging systems in Pico-Hydro Power Plants (PLTPH) from journals and previous research. Next, observations, interviews and literature studies are needed with the person in charge of the Al-Ikhlas Yatim Dhuafa Islamic Boarding School (PPYD) and then holding discussions with the team and supervisor. After collecting data for designing the battery charging system, it is necessary to know the loading data and carry out calculations to determine the battery capacity for the load that will be supplied and know the specifications and working principles and carry out tests on the generator output that will be used on the vortex type PTLPH to make it easier to select DC-DC. Buck Converter. After carrying out the design, performance testing was carried out on the DC-DC Buck Converter when charging the battery, testing for charging and discharging the battery, testing the voltage and current produced by the battery to the inverter with load. After obtaining test results with maximum system performance results, conclusions can be drawn from this research.

2.1 Battery Capacity Design

Before determining the battery capacity to be used, data on the load that will be supplied by the vortex and cross-flow type Pico-Hydro Power Plant (PLTPH) and Solar Power Plant (PLTS) is required. Data is taken by measuring voltage, current and energy used in a day. The following is data on the loading on buildings at PPYD Al-Ikhlas. [8]

Table 1: Ppyd Al-Ikhlas Building Load Data

Room	Load	Load Specification		Total Load (W)	Time (h)	Energy (Wh)
		Power (W)	Amount			
Room	Lamp	12	6	72	24	1728
	Contact Box (Fan)	64	1	64	24	1536
	Contact Box (Electric Charger)	50	3	150	6	900
	Total Load			286		4164

In table 2.1 the loading data with the total load obtained is 4.2 kWh, then it is substituted into the formula with system voltage planning for 24V generation as follows.

$$TotalBatteryCapacity = \frac{TotalEnergy(Wh)}{BatteryVoltage(V)} \tag{1}$$

Calculation :

$$TotalBatteryCapacity = \frac{4.2x1000}{24}$$

$$TotalBatteryCapacity = 175Ah$$

In this research, the battery used is a Valve Regulated Lead Acid (VRLA) battery because it is based on the factor that the VRLA battery charging process is faster than other types of batteries even though it runs out more quickly in use, this is not a problem because the battery will continue to be charged, so the battery is charged. until it's full can be faster. And maintenance of VRLA type batteries does not require checking and adding battery water, thereby saving time and maintenance costs [9]. The battery used is a Solana Brand VRLA 12V 100Ah which will be connected in 2 series to get a voltage of 24V and 1 in parallel to get a battery capacity of 200Ah so that the total battery capacity is 24V 200Ah with a total priority load of 4200 Watts.

Table 2: Specifications Of Solana Brand Vrla Batteries

Specification	
Voltage	12 V
Capacity	100 Ah
Length	395 mm
Width	110 mm
Heights	286 mm
Weight	31 Kg

2.2 Design of DC-DC Buck Converter

The power generated from the permanent magnet generator with the resulting power is 1000W and the efficiency is >75%. This permanent magnet generator produces a 3 phase AC voltage which is then rectified using a rectifier. The voltage produced by the generator tends to be large and not constant because it depends on the existing water flow, so a voltage reduction and stabilizer is needed, namely a DC-DC Buck Converter so that the resulting voltage can be adjusted for battery charging. In designing a DC-DC Buck Converter, it is necessary to consider the output current from the generator and also the voltage produced by the generator. And here are the specifications of the permanent magnet generator used in PLTPH with Vortex turbines. [10]

Table 3: Permanent Magnet Generator Specifications

Model	PMG-M-1000W
Rated Power	1000W
Max Power	1050W
Rated Speed	500rpm
Rated Voltage	12V/24V/48V
Start Torque	0,2Nm
Rate Torque	8,0Nm
Output Currrent	AC
Efficiency	>75%
Service life	More than 20 Years
Insulation Class	F
Bearing	HRB of for your order
Generator	3 Phase Permanent Magnet Synchronous Generator
Shaft Material	Stainless Steel
Shell Material	Aluminium Alloy
Material	Rare Earth NdFeB

Because in the specifications of the permanent magnet generator the voltage produced is AC voltage, it is necessary to test the generator when it is connected to the rectifier to determine the DC voltage rating that can be produced by the permanent magnet generator. Testing was carried out in the field, and the generator test data was obtained as follows.

Table 4: Generator No-Load Testing Data In The Field

No	No Load		
	Shaft Speed (rpm)	Voltage AC (V)	Voltage DC (V)
1	96.8	38.12	52.5
2	96.6	37.25	51,5
3	95.9	37.04	51
4	92.8	36.85	50.9
5	92.5	36.72	50.6
6	103	49.7	56.1
7	103.4	49.82	55.4
8	104.8	49.9	57
9	103.9	49.85	54
10	104.5	49.91	57.5
Average	99.42	49.836	55.16

It is necessary to calculate the current that a permanent magnet generator can produce from the permanent magnet generator specifications using the following formula.

$$I = \frac{P}{V} \tag{2}$$

Calculation :

$$I = \frac{1000Watt}{\sqrt{3}x48V}$$
$$I = 12.02A$$

To design a DC-DC Buck Converter, a DC-DC Buck Converter current of 12A is required. After making observations, the appropriate DC-DC Buck Converter specifications were obtained. This DC-DC Buck Converter can reduce the voltage from the generator to the setting voltage rating by using the potentiometer on the output side of the DC-DC Buck Converter for battery charging. with the following DC-DC Buck Converter specifications.

Table 5: Dc-Dc Buck Converter Specifications

Specification	
Input Voltage	DC 20V-70V
Input Current	20A max
Output Voltage	2.5V-58V (Adjustable)
Output Current	0.1A-30A (Adjustable)
Output Power	800W max
Conversion Efficiency	93-97 %
Circuit Structure	Non isolated (Buck)
Working Temperature	-20 to 60

2.3 Wiring the Vortex Type PLTPH Battery Charging System Circuit

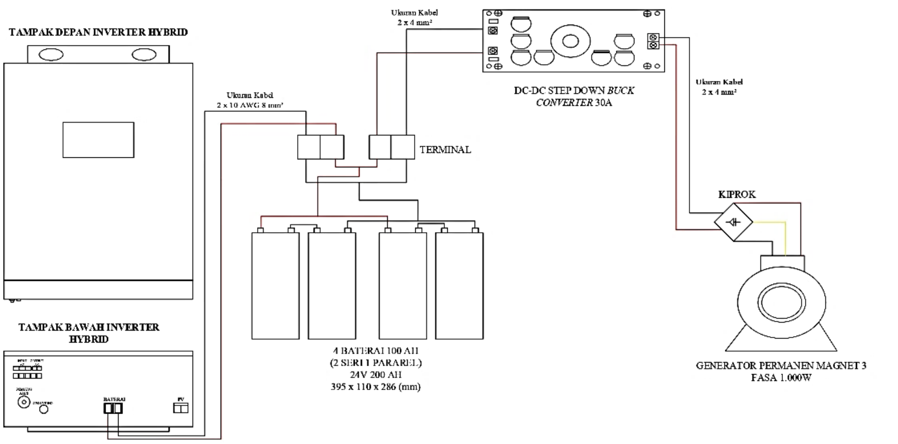

Figure 1: The Circuit of Battery Charging System

The battery charging system is installed close to river water in the PPYD Al-Ikhlas yard. For the permanent magnet generator located in the turbine body, the DC-DC Buck Converter is installed on the panel on the north outer side of the main PPYD Al-Ikhlas building using 2 x 4mm2 NYAF conductors. The battery is installed in the battery rack located below the panel using AWG conductors 8, and the Hybrid inverter is installed in the main PPYD Al-Ikhlas building with conductors connected to the battery using AWG 8.

3 Results and Discussion

3.1 Charging Test

In the battery charging test using generator sources from vortex and cross-flow turbines, however, the data listed only focuses on generators with vortex turbines only. This test was carried out directly at PPYD Al-ikhlas with the aim of obtaining data in real time. When testing the battery when it is not connected to a load. Testing is carried out by measuring the voltage and current on the DC-DC Buck Converter and battery. To get efficiency on the DC-DC Buck Converter and capacity on the battery. After testing, data was obtained on the DC-DC Buck Converter as follows.

Table 6: DC-DC BUCK CONVERTER DATA BATTERY CHARGING TESTING

Time Minutes	V_{in} (V)	I_{in} (A)	P_{in} (Watt)	V_{out} (V)	I_{out} (A)	P_{out} (Watt)	η (%)
5	31.3	0.8	25.04	25.97	0.9	23.37	93.3
10	31.14	0.8	24.91	25.99	0.84	21.83	87.6
15	31.4	0.7	21.98	26.04	0.8	20.83	94.8
20	31.01	0.6	18.61	26.06	0.68	17.72	95.2
25	31.25	0.6	18.75	26.06	0.67	17.46	93.1
30	31.2	0.6	18.72	26.06	0.64	16.68	89.1
35	31.08	0.5	15.54	26.07	0.56	14.60	93.9
40	31.51	0.5	15.76	26.11	0.55	14.36	91.1
45	31.33	0.5	15.67	26.11	0.54	14.10	90.0
50	31.13	0.5	15.57	26.11	0.54	14.10	90.6
55	31.3	0.47	14.71	26.13	0.51	13.33	90.6
60	31.5	0.45	14.18	26.14	0.5	13.07	92.2
65	31.36	0.3	9.41	26.15	0.34	8.89	94.5
70	31.03	0.2	6.21	26.17	0.22	5.76	92.8

From the efficiency test data on the DC-DC Buck Converter, the lowest efficiency is 87.6%, indicating that the performance of the DC-DC Buck Converter is good so not much power is wasted. In the charging test, the power from the generator to the battery decreased. This can be seen from the graph in Figure 3.1 below.

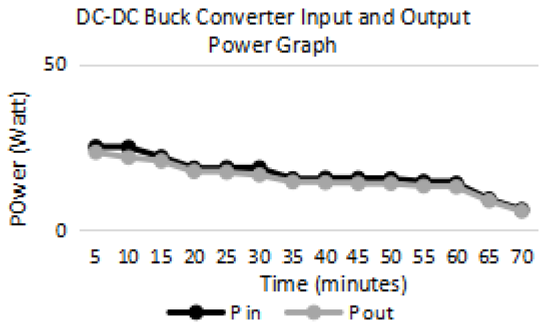

Figure 2: Power Graph Dc-Dc Buck Converter Charging Testing

The following is battery data from battery charging testing to find out the performance of the battery

Table 7: BATTERY DATA DURING CHARGING TESTING

Time (Minutes)	Battery	
	V_{batt} (V)	I_{batt} (A)
5	25.6	2.13
10	25.6	2.03
15	25.7	2.01
20	25.7	1.83
25	25.7	1.8
30	25.7	1.71
35	25.7	1.67
40	25.7	1.6
45	25.7	1.55
50	25.7	1.52
55	25.7	1.44
60	25.8	1.42
65	25.8	1.39
70	25.8	1.3

From the test results, the battery voltage has increased gradually while the current in the battery has decreased, this shows the battery charging characteristics where the battery voltage will increase and the current will decrease to 0 amperes, which indicates full battery capacity. The graph in Figure 3.2 shows the charging characteristics of battery testing, namely voltage is inversely proportional to current.

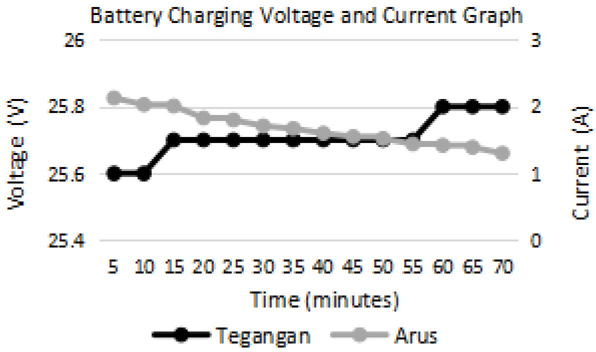

Figure 3: Charging Battery Voltage And Current Graph

3.2 Discharge Test

Testing battery discharge with the load of the main PPYD Al-Ikhlas building. The battery is not supplied by any generator so the battery is full and overloads the PPYD Al-Ikhlas building. This test aims to determine the performance of the battery when supplying a load, to find out how long the battery capacity will decrease in real time if the battery supplies a load, and to determine the amount of input and output power on the hybrid inverter. In the battery discharge test, the voltage and current on the battery are measured and the input and output voltage and current of the hybrid inverter are measured. This test only uses voltmeter and ampere meter measuring instruments, measurements are carried out with an estimated time of 5 minutes. After the discharge test was carried out, the following data was obtained.

Table 8: DISCHARGE TEST DATA

Time (Minutes)	V_{batt} (V)	Inverter Hybrid					
		Input DC			Output AC		
		V_{in} (V)	I_{in} (A)	P_{in} (Watt)	V_{out} (V)	I_{out} (A)	P_{out} (Watt)
5	24.7	24.2	45	1089	228	4.09	932.52
10	24.5	24.1	45	1084.5	228	4.05	923.4
15	24.2	23.9	47	1123.3	228	4.03	918.84
20	24.1	23.8	47	1118.6	228	4.19	955.32
25	24	23.3	47	1095.1	228	4.19	955.32
30	23.9	23.8	35	833	228	3.3	752.4
35	23.9	22.7	36	817.2	228	3.4	775.2
40	23.8	22.1	48	1060.8	228	4.28	975.84
45	23.7	22.1	48	1060.8	228	4.28	975.84
50	23.6	22	48	1056	228	4.28	975.84
55	23.6	22	48	1056	228	4.27	973.56
60	23.3	22.2	48	1065.6	228	4.26	971.28
65	23.1	22.1	48	1060.8	228	4.27	973.56

From the battery discharge test with the main PPYD Al-Ikhlas building load, the battery voltage continued to decrease gradually with an average load of 927.61Watts. The battery voltage dropped from 24.7V to 23.1V, which shows the battery capacity was reduced, but with the PPYD Al-Ikhlas building load which decreases causes the hybrid inverter input current to decrease and the hybrid inverter input voltage to increase and the input power to decrease as well. The input power to the hybrid inverter is greater than the output power, but the difference is not large, indicating good hybrid inverter efficiency. Figure 3.3 and Figure 3.4 show the results of the discharge test.

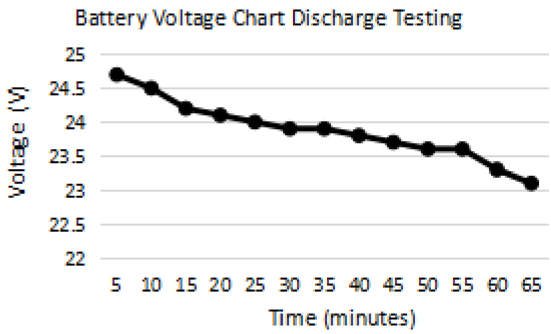

Figure 4: Battery Voltage Graph For Discharge Testing

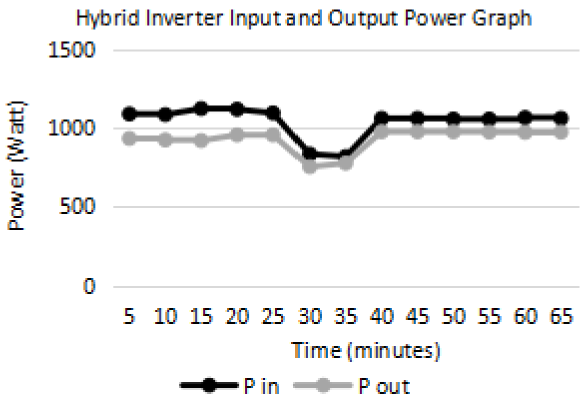

Figure 5: Hybrid Inverter Power Graph Discharge Testing

3.3 Battery Charging System Testing

Testing of the battery charging system was carried out by connecting the vortex type Pico-Hydro Power Plant (PLTPH) and crossflow from the turbine to the load of the Al-Ikhlas PPYD building, but the test only focused on the vortex type PLTPH. The purpose of this test is to find out especially the battery charging system such as the efficiency of the DC-DC Buck Converter and battery performance in real time. This test was carried out with an estimated data collection time of 5 minutes. In testing this battery charging system, data is taken by measuring the voltage and current at the input and output of the DC-DC Buck Converter, measuring the voltage and current on the battery and measuring the input voltage and current on the hybrid inverter. After the test was carried out, the DC-DC Buck Converter test data was obtained as follows.

Table 9: DC-DC BUCK CONVERTER DATA BATTERY CHARGING SYSTEM TESTING

Time (Minutes)	V_{in} (V)	I_{in} (A)	P_{in} (Watt)	V_{out} (V)	I_{out} (A)	P_{out} (Watt)	η (%)
5	30.04	2	60.08	24.79	2.3	57.02	94.90
10	30.16	2.35	70.88	24.79	2.7	66.93	94.44
15	30.14	2.3	69.32	24.76	2.5	61.90	89.29
20	30.9	2.2	67.98	24.75	2.57	63.61	93.57
25	30.99	2	61.98	24.81	2.4	59.54	96.07
30	30.03	1.92	57.66	24.72	2.25	55.62	96.47
35	29.97	1.95	58.44	24.68	2.3	56.76	97.13
40	31.2	1.96	61.15	24.71	2.4	59.30	96.98
45	30.03	2.3	69.07	24.71	2.7	66.72	96.59
50	30.01	1.93	57.92	24.26	2.2	53.37	92.15
55	29.42	2	58.84	24.63	2.3	56.65	96.28
60	30.78	1.78	54.79	25.45	2.1	53.45	97.55
65	29.91	1.74	52.04	24.69	2.03	50.12	96.31

DC-DC Buck Converter can reduce the voltage from the generator stably following the output setting voltage. Based on table 3.4, the efficiency of the DC-DC Buck Converter shows good with the lowest efficiency of 89.29%. With good efficiency, you can maximize the power entering the battery from the generator. The following is a graph in Figure 3.5 from the DC-DC Buck Converter test.

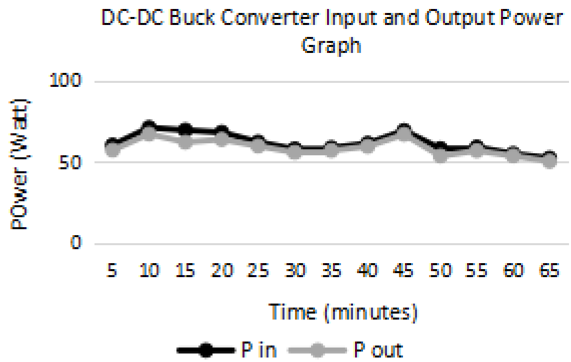

Figure 6: Dc-Dc Buck Converter Power Graph Battery Charging System Testing

The following is battery data when testing the battery charging system to determine the performance of the battery.

Table 10: BATTERY DATA DURING CHARGING TESTING

Time (Minutes)	Battery		Inverter	
	V_{batt} (V)	I_{batt} (A)	V_{in} (V)	I_{in} (A)
5	25.4	26.2	23.1	30
10	25.32	24.9	23.2	30
15	24.63	24.2	23.3	29
20	24.6	25.9	23.3	29
25	24.57	24.6	23.3	29
30	24.54	26.4	23.3	30
35	24.52	28.5	23	32
40	24.51	26.5	23	30
45	24.49	26.4	23	30
50	24.47	26.9	23	30
55	24.3	26.4	23	29
60	24.04	25.7	23.2	28
65	24.04	26.1	23.3	29

From testing the Vortex type PLTPH battery charging system based on table 3.5, the battery voltage decreased gradually, indicating that the battery capacity was decreasing. The battery experiences a voltage drop of 1.36V. The voltage at the hybrid inverter input experiences increases and decreases where the voltage is inversely proportional to the current, if the current increases then the voltage decreases and vice versa. Figure 3.6 shows the voltage drop on the battery when testing the battery charging system.

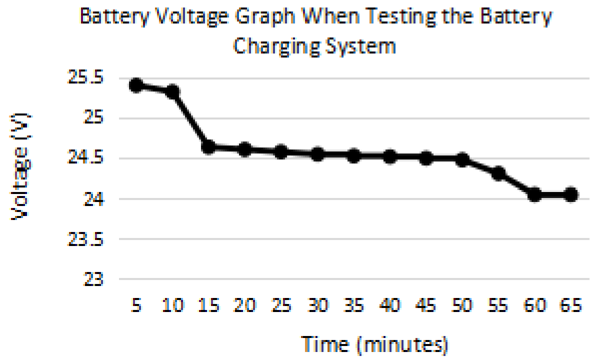

Figure 7: Battery Voltage Graph For Battery Charging System Testing

In testing the battery charging system, the battery capacity decreased because the load power was greater than the generating power from the vortex type PLTPH and cross-flow type PLTPH. This can cause the battery to become empty. If the battery is used continuously until it is empty, it can damage the battery and shorten the life of the battery. Therefore, it is necessary to set the hybrid inverter so that when the battery capacity shows low voltage or is almost empty, the hybrid inverter will switch to PLN so that the load will be supplied by PLN and the battery will be charged by the generator. And when the battery is full, the hybrid inverter will switch to the battery so that the load will be supplied again by the battery.

4 Conclusion

Based on the test results and analysis of the research obtained, several conclusions can be drawn, as follows: Designing a battery charging system in a vortex type PLTPH using a DC-DC Buck Converter as a battery charging voltage regulator, it is necessary to analyze the generator used before designing the DC-DC Buck Converter, such as the voltage and current that the generator can produce. So the specifications for the DC-DC Buck Converter used are obtained with an input voltage rating of 20V-70V, an output voltage rating of 2.5V-58V and a maximum input current of 20A with an average voltage produced by the generator during no-load testing of 55.16V. Designing the capacity of the battery used requires maintenance data to be supplied. The battery capacity used is 12V 100Ah, 4 batteries connected in 2 series and 1 parallel so that the battery capacity is 24V 200Ah with a total load of 4.2kWh. In testing the vortex type PLTPH battery charging system, the performance of the DC-DC Buck Converter has very good efficiency with an average of 85%, and can reduce the voltage stably from the generator which has been connected to the kiprok/rectifier to the battery with a voltage of 26V and can maximize performance when charging the battery. Battery performance when charging and discharging the battery voltage and current is in accordance with the characteristics in the Solana battery data sheet where when charging the voltage on the battery is inversely proportional to the current on the battery. When full the battery voltage reaches 27V and the lowest battery voltage during testing reaches 23V.

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