Study of Hybrid Wind and Solar Energy Power Plants: An Analysis of the Battery Charging and Discharging System

F Gatot Sumarno(1), Bah Evan*(1), Vita Ayu Aspriyanti(2), Muhammad Alwi(1)
1*Department of Mechanical Engineering*, *Politeknik Negeri Semarang*, Semarang, Indonesia
2*National Taipei University of Technology,* Taipei, Taiwan
Email address : ***bah.evan@polines.ac.id**

Abstract— Alternative energy can address the issue of PLN electricity supply, which is not available in all regions of Indonesia. The hybrid system of solar cells and wind turbines is a clean and environmentally friendly energy source because it does not produce carbon dioxide (CO_2) or other gases that play a role in global warming. The purpose of this final project is to analyze the length of time needed by a hybrid generator to charge and discharge the battery using load variations. This test was conducted in the Energy Conversion Laboratory using a unit of hybrid system equipment produced by KTENG (Korea Technology). The method employed involves charging the battery with energy generated from the hybrid system and discharging it using variations in lamp load. The results of this study indicate that the time needed to charge the battery is 21.28 hours in slightly cloudy weather with a total current of 4.7 amperes, and the battery discharge reaches 200 hours using a 10-watt load.

Keywords— Hybrid Generator, Battery Charging, and Discharging

I. INTRODUCTION

Hybrid power plants may solve the nonrenewable energy shortage[1][2]. Using many energy sources, this system generates power sustainably[3]. This hybrid system combines a solar power plant with a wind turbine[4]. Renewable solar and wind energy are plentiful and eco-friendly[5]. Wind turbines collect wind energy, whereas photovoltaic systems convert solar energy into electricity[6]. Integrating these two energy sources should increase power-generating dependability and maximize energy supply in different weather circumstances[7].

Solar cells and wind power plants provide renewable energy in this analysis. Wind energy is a competitive renewable. Commercial solar cells convert 15% of solar light into electricity[8][9]. If solar collector systems were widely installed and managed, 1% of crop and grazing land could supply world energy demands[10][11]. Deserts like the Gobi Desert have the solar energy capacity to supply practically all of the world's energy[12].

A hybrid wind-solar power generating system was employed in this investigation. The hybrid power generation system was built with accompanying equipment for power conversion and regulation. This system uses AC load, while the generation system generates DC power, necessitating an inverter to convert DC voltage to AC. Three 200, 400, and 600 watt inverters convert 24 V DC to 220 V AC in the hybrid power generating system. This analysis uses a 600-watt inverter. The generating system's DC voltage output is unpredictable owing to weather, requiring a battery energy storage device. The battery is charged by a charge controller to stabilize voltage before being sent to the inverter for AC loads.

II. METHODS

This research utilized several key pieces of equipment to support the testing process of the hybrid power plant system. The tools used included the following:

1. 3-phase Step-Down transformer— used to reduce the voltage to meet system requirements.
2. Pyranometer – used to measure the intensity of solar radiation received by the solar panels.
3. Digital thermometer— used to measure the ambient temperature and the temperature of the system components.
4. Ampere Clamp and Battery – used to measure electric current and store the generated electrical energy.
5. Solar Panel Connecting Cable – used to transmit power from the solar panels to the system circuit.
6. Ammeter and Voltmeter – used to measure the current and voltage in the generating system.
7. Stopwatch – used to record test times and collect data.
8. Tachometer – used to measure the rotational speed of the wind turbine.
9. Cable Reel, Light Bulb, and Light Panel—used as loads and auxiliary devices in system testing.

The main materials used in this research are

a) One unit of the KTENG CP-520S Hybrid Power Plant (Hybrid System) test equipment.

This hybrid power generation system test equipment combines two types of renewable energy generators: a wind power plant and a solar power plant. The system's energy charges the battery, which is then used to supply the electrical load via an inverter. The light bulb and light panel serve as loads and auxiliary devices during system testing. The primary materials used in this research include one unit of the KTENG CP-520S Hybrid Power Plant test equipment. This hybrid power generation system test equipment integrates two types of renewable energy generators: a wind power plant and a solar power plant. The energy generated by these systems charges a battery, which subsequently supplies electrical power to the load through an inverter.

Figure 1. Hybrid Power Generation Equipment

III. RESULTS AND DISCUSSION

1. Battery Charging Process Analysis

Table 1 shows hybrid power generating system battery charging test results. The average wind turbine rotation speed was 688.46 rpm, with 25.56 V output and 0.3 A current. Since the wind speed was consistent during the test, the wind turbine's energy contribution was stable but did not considerably impact the total power output.

Average solar power system voltage was 28.99 V, and current was 2.66 A. As solar radiation intensity rose from morning to afternoon, these numbers changed dramatically. As radiation intensity rose from 385.26 W/m² at 9:30 AM to 496.20 W/m² at 1:30 PM, solar panel output current increased, suggesting quicker battery charging during daytime.

Solar generates more electricity than wind in sunny conditions. Wind turbines give additional energy to continue battery charging when solar radiation diminishes, such as in the morning or evening. The hybrid system uses these two energy sources to continuously power the battery, improving charging efficiency[13].

These results show that the hybrid power production system may function together, with solar power dominating during high light intensity and wind power supporting when wind speeds are appropriate[14] [15]. A reliable and efficient battery charging procedure with an average total voltage of 25–29 V DC shows that this integrated hybrid system provides sustainable electrical energy.

To find out the time required to charge the battery, you can use the formula below[16]:

$$\frac{\text{I battery}}{\text{I total}} = t \ldots\ldots\ldots\ldots\ldots (1)$$

I battery = Battery capacity current (Ah)

I total = Total generation current (A)

t = time (hour)

To find out how long the battery can power the load, use the formula below:

$$\frac{\text{P battery}}{\text{B}} = t \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

P battery= Battery Power (Watt)

B = Burden (Watt)

t = time (hour)

Table 1. Test data on the battery charging process

No	Hour	Wind Turbine			Solar Panel		
		Rotation (rpm)	V (volt)	I (A)	V (volt)	I (A)	I radiation (W/m^2)
1	09.30	675.83	25.6	0.3	25.1	0.9	385.26
2	10.00	677.4	25.2	0.3	25.4	1.3	402.07
3	10.30	710.63	25.2	0.3	25.8	2.2	415.57
4	11.00	685.63	25.8	0.3	30.57	3.4	431.46
5	11.30	692.06	25.7	0.3	38.06	4.4	441.16
6	12.00	690.86	25.7	0.3	33.66	3.6	464.40
7	12.30	684.06	25.7	0.3	33.67	3.4	470.6
8	13.00	688.53	25.6	0.3	26	2.8	479.63
9	13.30	690.90	25.7	0.3	26.1	3.2	496.2
10	14.00	688.7	25.4	0.3	25.6	1.4	488.53
Average		688.46	25.56	0.3	28.99	2.66	432.38

2. Battery Discharge Process Analysis

Testing the hybrid power generating system battery discharge process shows that system output voltage increases with load power, from 195 V to 237 V. This shows that the inverter converts battery DC power to AC according to load needs well.

At the start of the test (load of 10–50 W), the output current was 0.05 A to 0.28 A and the power was 0.025–0.073 kW. The output current climbed to 1.82 A as the load grew to 400 W, reaching 0.683 kW.

Battery current decrease increased from 0.083 A at mild load to 2.934 A at maximum load. This suggests that battery energy depletes quicker with higher load power. Battery storage capacity is inversely related to discharge current.

The battery-maintained energy delivery at 10-minute intervals for each load fluctuation during discharge without a substantial voltage reduction. Proper inverter settings and energy management allow the hybrid system to sustain power production.

These results reveal that the hybrid power generating system's output voltage is within the 220 V AC operational range, indicating that it can power low- to medium-power home appliances. Therefore, this hybrid solar and wind power system is effective at sustaining energy delivery from battery to load during discharge.

Table 2. Test data on the battery discharge process

No.	Generator Power (KW)	V out (Volt)	I out (Ampere)	Load (Watt)	Time (Menit)	Battery Current Drop (Ampere)
1	0.025	195	0.05	10	10	0.083
2	0.025	195	0.1	15	10	0125
3	0.035	195	0.19	25	10	0.202
4	0.04	195	0.24	40	10	0.325
5	0.073	207	0.28	50	10	0.408
6	0.06	207	0.31	60	10	0.475
7	0.085	207	0.34	75	10	0.558
8	0.135	207	0.46	85	10	0.638
9	0.135	207	0.46	100	10	0.783
10	0.21	216	0.64	140	10	1.034
11	0.245	222	0.73	160	10	1.182
12	0.275	225	0.79	175	10	1.302
13	0.325	231	0.92	200	10	1.523
14	0.393	228	1.09	240	10	1.734
15	0.44	234	1.26	260	10	1.834
16	0.466	234	1.32	275	10	1.991
17	0.52	237	1.42	300	10	2.252

18	0.595	237	1.58	340	10	2.434
19	0.623	234	1.66	360	10	2.550
20	0.646	228	1.72	375	10	2.680
21	0.683	222	1.82	400	10	2.934

3. Battery charging duration

The battery charging time is listed in Table 3:

T = (100 Ah) / (1.2 A) = 83.34 hour. The duration required to charge the battery The findings from the subsequent calculation will be organized and presented in Table 3 below.

Table 3. Battery charging duration

No	Jam	I angin (A)	I solar (A)	I total (A)	Waktu (Jam)
1	09.30	0.3	0.9	1.2	83.34
2	10.00	0.3	1.3	1.6	62.5
3	10.30	0.3	2.2	2.5	40
4	11.00	0.3	3.4	3.7	27.03
5	11.30	0.3	4.4	4.7	21.28
6	12.00	0.3	3.6	3.9	25.64
7	12.30	0.3	3.4	3.7	27.03
8	13.00	0.3	2.8	3.1	32.25
9	13.30	0.3	3.2	3.5	28.57
10	14.00	0.3	1.4	1.7	58.82

Over many periods, output voltage (V), output current (A), and total power (W) were monitored during battery charging. The output voltage and current grew with charging time, suggesting that the hybrid power system was progressively supplying energy to the battery.

Due to its poor charge capacity, the battery voltage started low. However, the voltage and charging power grew with time, showing that the solar panels and wind turbine were concurrently powering the batteries.

In addition, the hybrid system's charging power rise rate is constant, with tiny oscillations presumably driven by sunshine intensity and wind speed. The chart illustrates that the battery charging time is directly related to the rise in voltage and total power received until it reaches the maximum voltage, signifying that it is completely charged and ready for discharge.

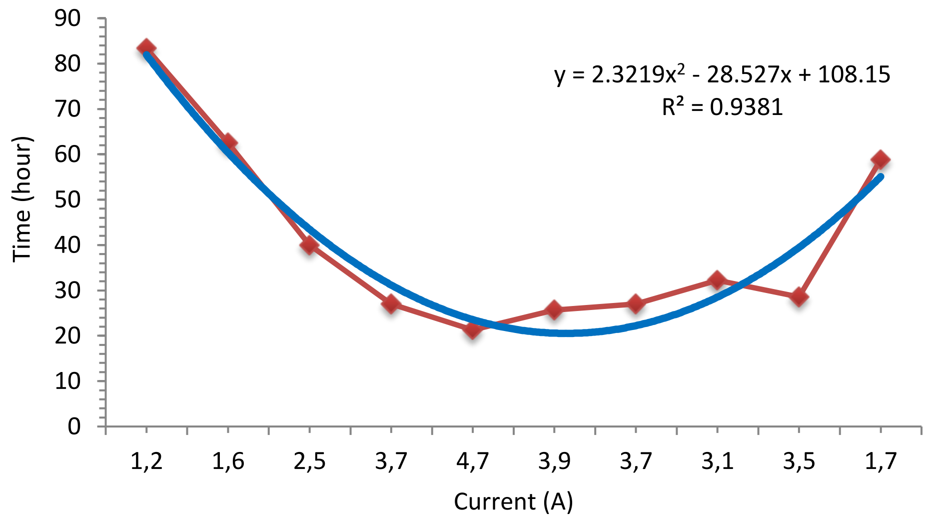

Figure 2. Graph of the relationship between current and battery charging process time

The graph demonstrates the relationship between charging current (Current, A) and battery charging time (Time, hour) in a wind-solar hybrid power generating system. Increasing current is inversely related to charging time until a certain threshold.

At modest currents (1.2 A–2.5 A), charging takes 60–80 hours. Battery charging is delayed owing to the modest current input. Most effective charging occurs between 3.7 A and 4.7 A, when charging time drops to 20 hours. However, when the current decreases again (3.1 A to 1.7 A), charging time increases, suggesting a drop in charging efficiency.

Overall, raising the charging current to the optimal point speeds up battery charging. However, if the current is too low or varies, charging time will rise, reducing the efficiency of the hybrid power production system.

4. Actual battery discharge analysis

The calculation of the battery discharge process using actual load variations in Table 4 data no. 1 is:

$$t = \frac{100}{0{,}498} = 200{,}8 \text{ hour}$$

Table 4. Actual battery discharge analysis calculation results

No	Battery Ampere (Ah)	Load (Watt)	Lowering Battery Ampere (Ampere)	Battery Discharge Time (hour)
1	100	10	0.498	200.803
2	100	15	0.750	113.334
3	100	25	1.20	83.334
4	100	40	1.950	52.083
5	100	50	2.448	40.849
6	100	60	2.85	35.087
7	100	75	3.348	29.868
8	100	85	3.828	26.123
9	100	100	4.698	21.285
10	100	140	6.204	16.118
11	100	160	7.092	14.1
12	100	175	7.812	12.08
13	100	200	9.138	10.943
14	100	240	10.404	9.611
15	100	260	11.004	9.087
16	100	275	11.946	8.371
17	100	300	13.512	7.4
18	100	340	14.604	6.847
19	100	360	15.3	6.535
20	100	375	16.08	6.218
21	100	400	17.604	5.68

The table shhow the battery discharge analysis of a wind-solar hybrid power system. The graph shows how output current, voltage, and discharge time relate during battery-to-load energy transfer. The battery voltage peaks at the start and drops as load current and running duration increase. This voltage drop shows how a battery's energy capacity declines during discharge. The graph also demonstrates that increasing output current accelerates battery drain to its minimal working voltage. Due to the lower energy release rate, smaller currents take longer to discharge, whereas high-current loads speed energy transfer. Thus, our research shows that load current and battery voltage during discharge greatly affect the efficiency of energy storage systems, which hybrid system designers must consider to ensure power supply stability.

5. Theoretical battery discharge analysis

The calculation of the battery life to power the load without any theoretical generation in Table 5 data no. 1 is:

$$\frac{2400}{10} = 240 \text{ hour}$$

Table 5. Theoretical battery discharge analysis calculation results

No	V Battery (Volt)	I Battery (Ampere)	Power Battery (Watt)	Load (Watt)	Time (hour)
1	24	100	2400	10	240
2	24	100	2400	15	160
3	24	100	2400	25	96
4	24	100	2400	40	60
5	24	100	2400	50	48
6	24	100	2400	60	40
7	24	100	2400	75	32
8	24	100	2400	85	28.24
9	24	100	2400	100	24
10	24	100	2400	140	17.14
11	24	100	2400	160	15
12	24	100	2400	175	13.71
13	24	100	2400	200	12
14	24	100	2400	240	10
15	24	100	2400	260	9.23
16	24	100	2400	275	8.73
17	24	100	2400	300	8
18	24	100	2400	340	7.05
19	24	100	2400	360	6.67
20	24	100	2400	375	6.4
21	24	100	2400	400	6

A theoretical analysis of battery discharge in a hybrid wind-solar power generating system is shown in the table. This research predicted the battery's energy discharge behavior using theoretical characteristics, including capacity, load current, and operation duration. The graph illustrates that battery voltage falls progressively with usage time, corresponding with battery degradation. Up to the minimal working limit, the linear voltage reduction indicates that the energy discharge process is steady before saturation. This theoretical research also shows that load current magnitude considerably affects voltage drop.

Higher load current reduces battery voltage faster and shortens discharge time. At smaller currents, energy release is slower, prolonging discharge. The balance between load current and battery capacity dictates the stability of the power supply in a hybrid system. These data help compare theoretical and real test outcomes in the hybrid power production system under test.

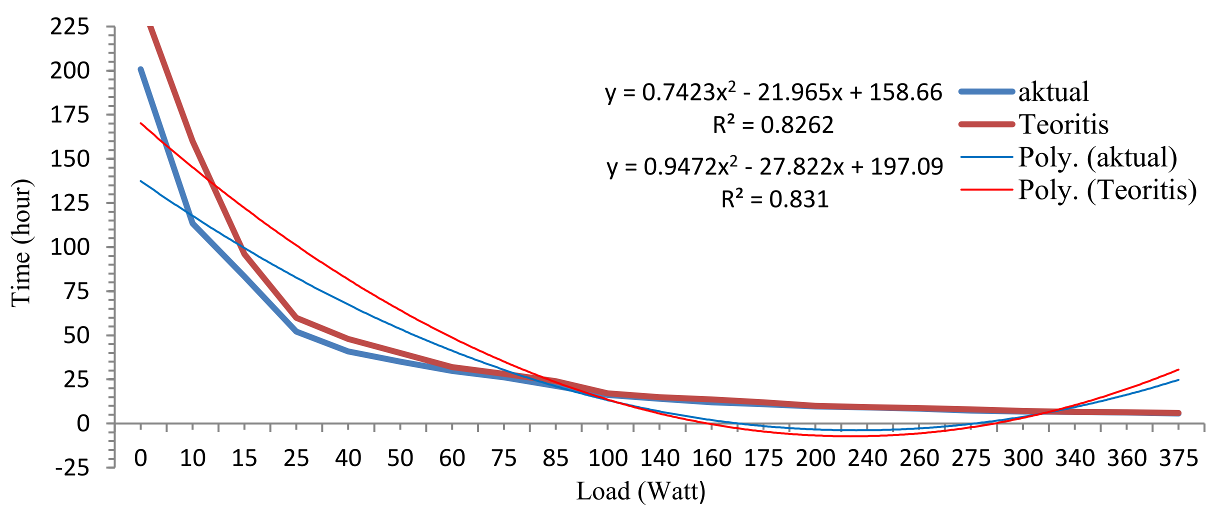

Figure 3. Graph of the relationship between load and usage time in the actual and theoretical battery discharge

IV. CONCLUSION

According to studies, solar panel output current greatly affects the battery charging time of the hybrid power generation system. According to test findings, the best overall generation current was 4.7 amperes at 11:30 a.m., which charged a 100 Ah battery in 21.28 hours. This suggests that strong sunshine intensity boosts battery charging efficiency. Battery quality and condition also help sustain energy storage capacity so electricity can be used properly for longer. Due to internal energy losses and system efficiency, real discharge time with the same load was less than predicted. The longest discharge period was 200.803 hours at a 10-watt load, while the quickest was 5.68 hours at 400 watts. The more load power, the faster the battery energy is transferred; hence, load control is crucial to hybrid system performance.

REFERENCES

[1] Q. Hassan, S. Algburi, A. Z. Sameen, H. M. Salman, and M. Jaszczur, "A review of hybrid renewable energy systems: Solar and wind-powered solutions: Challenges, opportunities, and policy implications," *Results in Engineering*, vol. 20, p. 101621, Dec. 2023, doi: 10.1016/j.rineng.2023.101621.

[2] Y. F. Nassar, H. J. El-Khozondar, and M. A. Fakher, "The role of hybrid renewable energy systems in covering power shortages in public electricity grid: An economic, environmental and technical optimization analysis," *J Energy Storage*, vol. 108, p. 115224, Feb. 2025, doi: 10.1016/j.est.2024.115224.

[3] F. Perdiansyah, E. T. N. Fitriana, N. Aziema, P. P. Maharani, F. Khoerunnisa, and N. Winarno, "The Efficient Implementation of Hybrid Power Plants in Indonesia," *ASEAN Journal of Science and Engineering*, vol. 1, no. 3, pp. 213–220, Aug. 2021, doi: 10.17509/ajse.v1i3.34226.

[4] A. Couto and A. Estanqueiro, "Wind power plants hybridised with solar power: A generation forecast perspective," *J Clean Prod*, vol. 423, p. 138793, Oct. 2023, doi: 10.1016/j.jclepro.2023.138793.

[5] K. K. Jaiswal *et al.*, "Renewable and sustainable clean energy development and impact on social, economic, and environmental health," *Energy Nexus*, vol. 7, p. 100118, Sep. 2022, doi: 10.1016/j.nexus.2022.100118.

[6] C. N. Nwagu, C. O. Ujah, D. V. V. Kallon, and V. S. Aigbodion, "Integrating solar and wind energy into the electricity grid for improved power accessibility," *Unconventional Resources*, vol. 5, p. 100129, Jan. 2025, doi: 10.1016/j.uncres.2024.100129.

[7] E. Ejuh Che, K. Roland Abeng, C. D. Iweh, G. J. Tsekouras, and A. Fopah-Lele, "The Impact of Integrating Variable Renewable Energy Sources into Grid-Connected Power Systems: Challenges, Mitigation Strategies, and Prospects," *Energies (Basel)*, vol. 18, no. 3, p. 689, Feb. 2025, doi: 10.3390/en18030689.

[8] A. A. Firoozi, A. A. Firoozi, and M. R. Maghami, "Harnessing photovoltaic innovation: Advancements, challenges, and strategic pathways for sustainable global development," *Energy Conversion and Management: X*, vol. 27, p. 101058, Jul. 2025, doi: 10.1016/j.ecmx.2025.101058.

[9] S. Wang, E. Tonge, I. Sekanyo, E. Portmann, and S. M. Azzouz, "On the State-of-the-Art of Solar, Wind, and Other Green Energy Resources and Their Respective Storage Systems," *Eng*, vol. 4, no. 1, pp. 857–883, Mar. 2023, doi: 10.3390/eng4010052.

[10] A. Ghosh, "Nexus between agriculture and photovoltaics (agrivoltaics, agriphotovoltaics) for sustainable development goal: A review," *Solar Energy*, vol. 266, p. 112146, Dec. 2023, doi: 10.1016/j.solener.2023.112146.

[11] H. H. Zeddies, M. Parlasca, and M. Qaim, "Agrivoltaics increases public acceptance of solar energy production on agricultural land," *Land use policy*, vol. 156, p. 107604, Sep. 2025, doi: 10.1016/j.landusepol.2025.107604.

[12] J. Wu, J. Xiao, J. Hou, and X. Lyu, "Development Potential Assessment for Wind and Photovoltaic Power Energy Resources in the Main Desert–Gobi–Wilderness Areas of China," *Energies (Basel)*, vol. 16, no. 12, p. 4559, Jun. 2023, doi: 10.3390/en16124559.

[13] A. Dascalu, S. Sharkh, A. Cruden, and P. Stevenson, "Performance of a hybrid battery energy storage system," *Energy Reports*, vol. 8, pp. 1–7, Nov. 2022, doi: 10.1016/j.egyr.2022.05.040.

[14] S. Algburi *et al.*, "Evaluating the Viability and Potential of Hybrid Solar-Wind Renewable Energy Systems in Relation to Geographical and Environmental Factors," *Results in Engineering*, p. 103473, Nov. 2024, doi: 10.1016/j.rineng.2024.103473.

[15] M. A. Russo, D. Carvalho, N. Martins, and A. Monteiro, "Future perspectives for wind and solar electricity production under high-resolution climate change scenarios," *J Clean Prod*, vol. 404, p. 136997, Jun. 2023, doi: 10.1016/j.jclepro.2023.136997.

[16] S. Piller, M. Perrin, and A. Jossen, “Methods for state-of-charge determination and their applications,” *J Power Sources*, vol. 96, no. 1, pp. 113–120, Jun. 2001, doi: 10.1016/S0378-7753(01)00560-2.