

Design and Development of a Hybrid Portable Emergency Energy Box System Based on a Solar Panel and Hand-Crank Generator with GPS Location Tracking

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ABSTRACT

Keywords:

GPS Tracker
Hybrid Portable Energy
Hand-Crank Generator
Portable Solar Panel

The need for reliable portable power sources during emergencies continues to grow, particularly in disaster-affected areas and remote regions with limited access to the power grid. This study aims to design and implement a Hybrid Portable Emergency Energy Box based on a portable solar panel and a hand-crank generator as a lightweight, portable, and self-sufficient power source to support rescue team operations. The system uses a 40 Wp monocrystalline solar panel with a total weight of 9.6 kg and is capable of powering both AC and DC loads. Energy is stored in a 12 V 22 Ah LiFePO₄ battery and supported by a 50 W permanent magnet DC generator with a 6:1 pulley ratio. Test results showed that battery charging via the solar panel produced 225.28 Wh of energy after AC loading with a charging time of three days, as well as 109.67 Wh and 146.14 Wh after DC loading and combined AC-DC loading, respectively, with a charging time of two days each. In the hand-crank generator test, all subjects were able to generate power exceeding the GPS system's requirement of 1.19 W, with a peak power of 2.91 W at 308 RPM and a minimum of 1.22 W at 133 RPM. Load testing showed that the battery was capable of supplying 109.03 Wh under an AC load with an inverter loss of 0.85%, 93.2 Wh under a DC load, and 112.57 Wh under a combined AC-DC load. The ESP32- and Neo-6M GPS-based system demonstrates good accuracy, with a minimum error of 1.35–1.56 meters in open to semi-open conditions and a maximum error of 16.4 meters in densely built-up areas. These results indicate that the designed system is capable of independently providing emergency power with sufficiently reliable performance and is equipped with location-tracking features to support monitoring in disaster areas.

INTRODUCTION

Indonesia is one of the countries with the highest risk of natural disasters in the world. Its geographical location at the junction of three major tectonic plates and home to thousands of active volcanoes makes the region vulnerable to earthquakes, tsunamis, floods, and landslides, which can occur suddenly and spread across various areas (Syukri et al., 2025). One of the most critical issues that arises when a disaster strike is the interruption of the electricity supply due to damage to the distribution network or major power plants.

2023, there were 5,400 disaster incidents recorded across all provinces in Indonesia, a significant increase from the 3,544 incidents in the previous year. These incidents resulted in 8,491,288 people being displaced or affected, as well as damage to 47,214 homes and more than 1,291 public facilities (Ainun et al., 2023). Field operations generally still rely on emergency generators and tower lights provided by relevant agencies, so nearly every major disaster disrupts communication, lighting, and coordination due to the loss of power. This situation underscores the need for portable

energy sources that can operate independently without relying on the main power grid to support emergency response operations (Budhi Anto et al., 2024).

Previous research has developed a portable energy box based on a solar power plant (PLTS) as the primary energy source in post-disaster situations, using a conventional 30 Wp solar panel and a 12 V 70 Ah battery with a full charging time of 84 hours, capable of powering a 5 W DC LED light for 168 hours and charging a 10 W cell phone (Fitriyah et al., 2022). The system's performance is highly dependent on the intensity of sunlight, so it cannot operate optimally at night or on cloudy days a limitation that underscores the need for a backup energy source that does not rely directly on sunlight.

Based on these issues, this study designed a Hybrid Portable Emergency Energy Box that combines two energy sources: a 40 Wp solar power system consisting of foldable solar panels which are lightweight and easy to transport to disaster sites and a 50 W hand-crank generator that can be operated manually when the solar panels cannot generate power, such as at night. The hand-crank mechanism is equipped with a 1:6 pulley ratio to achieve a lower and more stable output speed (Santoso et al., 2023). The combination of these two energy sources allows the system to continue functioning under various environmental conditions with a compact design, unlike conventional power banks that rely on AC power from the national grid for charging, or mini generators, which are impractical to transport to disaster sites along with their fuel (Stanlee et al., 2024).

In addition to its energy-supply capabilities, this system is equipped with a Global Positioning System (GPS) module that enables real-time location tracking, making it easier for relief teams to locate users in disaster-affected areas. This feature is important because the duration of search and rescue operations is a crucial factor that affects the chances of survival and the number of victims successfully evacuated (Basarnas, 2024). Thus, the portable hybrid system is designed not only to provide reliable emergency power but also to serve as a strategic positioning and communication tool for trained rescue teams such as BASARNAS.

Based on the above description, this study aims to measure the time required for solar panels to charge a battery; analyze the effect of variations in hand-crank speed and rotation duration on the voltage, current, and power generated by the generator; evaluate the system's load performance; and determine the accuracy of the GPS module in providing location coordinates in the field.

RESEARCH METHOD

Type and Location of the Research

This study employs a quantitative approach using an experimental research design, as the entire process of testing and data analysis is conducted through numerical measurements, calculations, and direct observation of the performance of the developed system. This approach aligns with the study's objectives, which require testing of

technical variables, such as the power generated by solar panels under different irradiation conditions, the effect of the rotational speed of the hand-crank generator on the output voltage and current, the performance of the hybrid system under varying load conditions, and the accuracy of the GPS system. The design and testing were conducted at the D4 Electrical Engineering Laboratory, Vocational Faculty, Surabaya State University, during the even semester of the 2025/2026 academic year.

Hybrid System Workflow

Figure 1 illustrates the hybrid system operation method managing solar panels and a hand-crank generator. The solar source is prioritized at irradiance $\geq 100 \text{ W/m}^2$, while the generator serves as a backup. The output voltage is regulated to 14.4 V using converters before charging the battery until it reaches $\geq 13.2 \text{ V}$, indicating readiness for use.

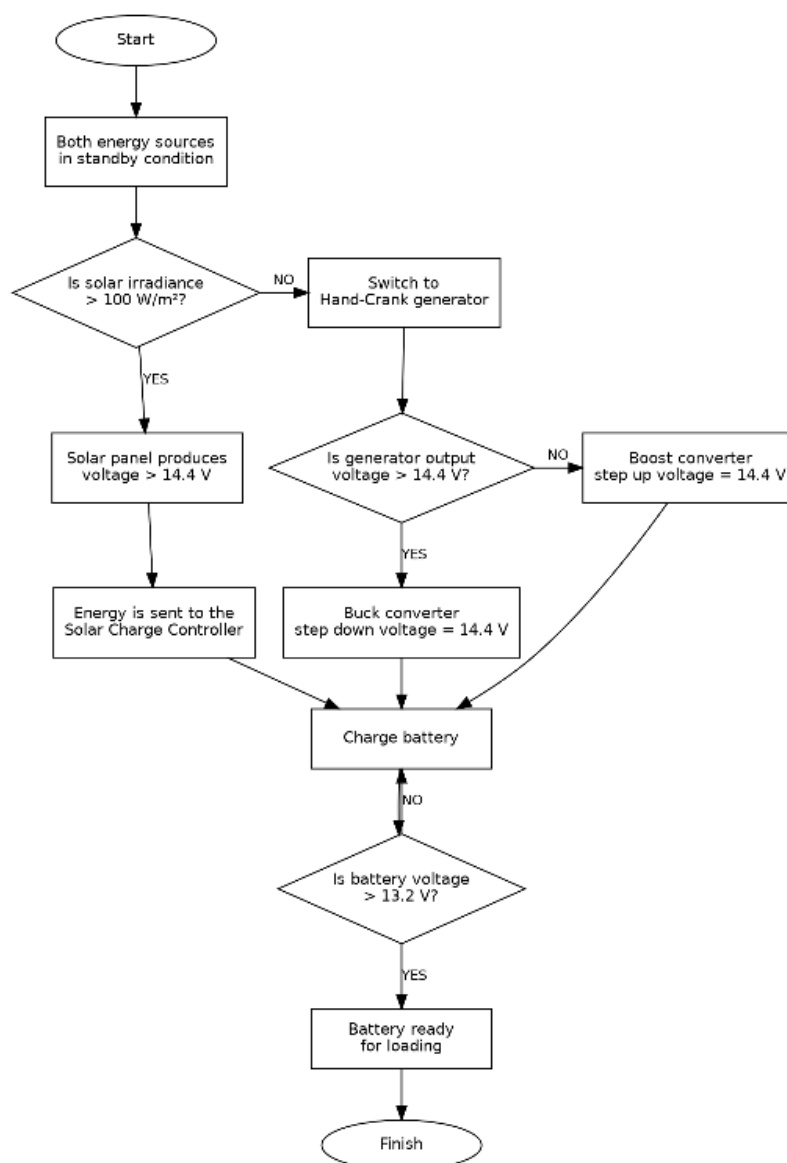


Fig. 1. Flowchart System

System Design Calculations

The determination of the main component specifications began with calculating the total energy requirements of the loads to be served by the system, including the ESP32, GPS Neo-6M, 4G modem, 5 W DC lamps (2pcs), and 40W cell phone charging, with a load duration of 10 hours to represent typical daily usage patterns. The total energy requirements of the loads are presented in Table 1.

Table 1. Power Requirements and Energy Consumption of Equipment

No	Components	Voltage (V)	Current (A)	Power (W)	Time (Hour)	Energy (Wh)
1	ESP32	5	0,25	1,25	10	12,5
2	GPS NEO-6M	5	0,06	0,3	10	3
3	4G Modem	5	0,06	0,3	10	3
4	DC Lamps 5 W (2pcs)	12	0,418	5,016	10	100,32
5	40 W Phone Charging	220	0,181	39,82	0,75	35,135
TOTAL						153,955

Based on a total energy requirement of 153,955 Wh, the specifications for the solar panels, battery capacity, and operating current of the solar charge controller (SCC) were calculated using the following equation, based on the formula used in previous research (Hariyanto, 2025):

$$\text{Energy (Wh)} = P \text{ (W)} \times t \text{ (h)} \dots\dots\dots(1)$$

Where Energy is the total energy (Wh), P is the load power (W), and t is the duration of the load (hours). The capacity of the solar panel is then calculated as follows:

$$\text{Solar Panel (Wp)} = \text{Total Energy (Wh)} / (\text{PSH} \times \text{Efficiency}) \dots\dots\dots (2)$$

Assuming a Peak Sun Hour (PSH) of 5 hours/day, based on the average solar radiation in Indonesia, and a conservative efficiency of 80%, the solar panel capacity is calculated as $153.955 / (5 \times 0.8) = 38.48$ Wp, rounded to 40 Wp. The battery capacity is calculated as follows:

$$\text{Battery (Ah)} = \text{Total Energy (Wh)} / (V.\text{bat (V)} \times \text{DoD} \times \text{Efficiency}) \dots\dots\dots(3)$$

With a battery voltage of 12 V and a Depth of Discharge (DoD) of 80% in accordance with LiFePO₄ battery standards, the battery capacity is calculated as $153.955 / (12 \times 0.8 \times 0.8) = 20.04$ Ah, rounded to 22 Ah. The SCC operating current is calculated as follows:

$$\text{SCC (A)} = (\text{Solar Panel (Wp)} + \text{Total Energy (Wh)}) / V.\text{bat (V)} \dots\dots\dots(4)$$

Which yields $(40 + 153.955) / 12 = 16.16$ A, so an SCC with a 20 rating was selected.

The results of these calculations serve as a reference for determining the specifications of the main components, as summarized in Table 2.

Table 2. Main System Component Specifications

Components	Key Parameters	Value
Solar Panel	Maximum power / Voltage / Current	40 W / 19 V / 2,1 A
Battery LifePo ₄	Rated Voltage / Capacity	12,8 V / 22 Ah
Generator DC Brush	Maximum power / No-load voltage	50 W / 12 V (150–200 RPM)
Solar Charge Controller	Voltage rating / Current rating	12/24 V / 20 A
Inverter	Type / Power / Efficiency	Pure sine wave / 1000 W / 85%

Testing Procedures

Testing of battery charging by solar panels was conducted over seven days from 7:00 a.m. to 5:00 p.m. to represent variations in weather conditions over a weekly cycle; the parameters measured included irradiance, battery voltage, panel voltage and current, and power output.

Testing of the hand-crank generator was conducted on ten subjects from various genders and age groups (junior high school students, senior high school students, college students, workers, and adults), each of whom cranked the generator for 5 minutes in three repetitions. The measured parameters included rotational speed (RPM), voltage, current, and the generator's output power after passing through a buck-boost converter, which were then compared to the minimum power requirements of the GPS system.

Load testing was conducted with a 40 W AC load, a 10 W DC load, and a combination of the two, by periodically measuring the output voltage, current, and power. The energy consumed during the load test was calculated by summing the energy at each measurement interval (Martyushev et al., 2025), (OpenStax, 2022):

$$E = \Sigma (P \times t) \dots\dots\dots(5)$$

Where E is the energy consumed (Wh), P is the load power at each interval (W), and t is the measurement interval (hour). The battery's energy capacity is calculated as follows:

$$E_{bat} = V_{bat} \times Ah_{bat} \dots\dots\dots(6)$$

Thus, the battery discharge level, or Depth of Discharge (DoD), can be determined by comparing the energy consumed to the battery's capacity (Martyushev et al., 2025):

$$DoD = (Energy\ Used / Battery\ Capacity) \times 100\% \dots\dots\dots(7)$$

GPS system accuracy testing was conducted at five locations with different environmental conditions by comparing the coordinates obtained from the GPS module with reference coordinates at the same locations. The distance difference between the two sets of coordinates was calculated using the Haversine method (Palupi et al., 2021):

$$d = 2R \arcsin(\sqrt{(\sin^2((\phi_2 - \phi_1)/2) + \cos\phi_1 \cos\phi_2 \sin^2((\lambda_2 - \lambda_1)/2))}) \dots\dots\dots(8)$$

Where d is the distance between two coordinate points (meters), R is the Earth's radius (6,371 km), ϕ_1 and λ_1 are the latitude and longitude of the reference point, and ϕ_2 and λ_2 are the latitude and longitude from the GPS reading. The distance values obtained are used as the GPS position error values in each test scenario.

RESULTS AND DISCUSSION

Implementation of Tools

This riset successfully developed a Hybrid Portable Emergency Energy Box that integrates a solar panel, a hand-crank generator, a battery, an inverter, and a GPS system into a single portable unit, as shown in Figure 2. The system architecture, which illustrates the energy flow from both power sources to the battery and on to AC and DC loads and the GPS system, is shown in Figure 3.



Fig. 2. Implementation of the Hybrid Portable Emergency Energy Box

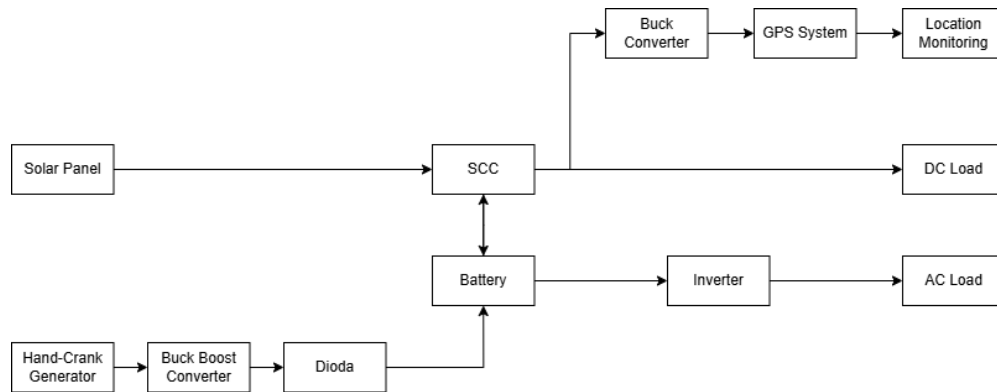


Fig. 3. Architecture of the Hybrid Portable Emergency Energy Box

The final results show a length of 40 cm, as per the initial design, while the width and height increased by approximately 3.7–3.8 cm and 5 cm, respectively, due to the need for additional space for the generator, pulley system, inverter, and wiring. The total weight of the device reached 9.6 kg, an increase from the initial target of less than 7 kg, with the largest contributions coming from the box (2,943 g), the battery (1,866 g), and the generator (1,495 g). This increase in weight is a result of the space required for assembling and maintaining components, but the device is still portable enough for rescue teams to carry.

Battery Charging Performance Using Solar Panel

The battery charging process using solar panels is greatly influenced by the level of solar irradiance and weather conditions during the testing period. The power output of the panels increases as irradiance rises and reaches its maximum value from morning through midday, whereas under cloudy conditions or in the late afternoon, the charging current and power output decrease accordingly. In the charging test following AC loading, the charging process took the longest three days with the total energy generated by the solar panels reaching 225.28 Wh. The charging process following DC loading was shorter, lasting two days with 109.67 Wh of energy, while under combined AC-DC conditions, the charging process also lasted two days with 146.14 Wh of energy. These differences in duration and energy levels indicate that charging requirements are heavily influenced by the amount of energy previously consumed. When the battery reaches full charge, the Solar Charge Controller (SCC) enters cut-off mode, reducing the charging current to 0 A, indicating that the system is ready to be used again as an emergency power source.

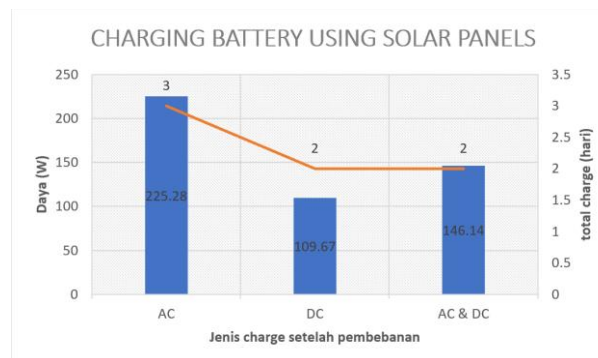


Fig. 4. Testing the Power Generated by Solar Panels for Charging Battery

Performance of Hand-Crank Generator as Backup Power Sources

The minimum power requirement for the GPS system was determined to be 1.19 W based on measurements of power consumption during operation. This value was used as a reference for the minimum power that the hand-crank generator must generate. The test results for ten subjects of varying genders and ages are presented in Table 3.

Table 3. Test Results for the Average Energy Output of a Hand-Crank Generator

Criteria	Gender	Age (th)	Rotation Speed (RPM)	Voltage (V)	Current (A)	Power (W)
Junior High School Student	Male	15	172,2	14,186	0,132	1,84
Junior High School Student	Female	14	133,1	14,168	0,09	1,22
Senior High School Student	Male	17	142,0	14,167	0,097	1,33
Senior High School Student	Female	18	149,2	14,173	0,107	1,46
College Student	Male	23	242,9	14,286	0,18	2,52
College Student	Female	23	186,5	14,158	0,147	2,04
Worker	Male	26	308,0	14,258	0,206	2,91
Worker	Female	28	182,0	14,204	0,141	1,95
Adult	Male	49	208,3	14,199	0,159	2,22
Adult	Female	46	162,4	14,149	0,125	1,72

All test subjects were able to generate power above the minimum GPS requirement of 1.19 W. The highest power output was recorded by a 26 years old male worker at 2.91 W at 308 RPM, while the lowest power output was recorded by a 14 years old female middle school student at 1.22 W at 133.1 RPM. The data in Table 3 show a positive correlation between rotational speed and power output, with subjects operating at higher RPMs tending to generate greater power. These results demonstrate that the designed hand-crank generator can serve as an adequate backup power source for operating a GPS system under various user conditions.

Performance of the Loading System Under Emergency Load Conditions

In AC loading, the power characteristics tend to be the most dynamic due to the energy conversion process in the inverter and the charging characteristics of the five different types of HP, with total energy consumed reaching 109.03 Wh in the 0.85% inverter loss scenario and 205.95 Wh in the 0.45% loss scenario. In DC loading, energy is delivered directly without passing through the inverter, resulting in smaller power fluctuations and a gradual drop in battery voltage, with a total energy consumption of 93.2 Wh, making the DC load the most stable condition. Under the combined AC and DC load, the system experienced a transitional state with a more significant voltage drop at the beginning of the test due to both loads operating simultaneously, with a total energy consumption of 112.57 Wh the highest value among the three load scenarios.

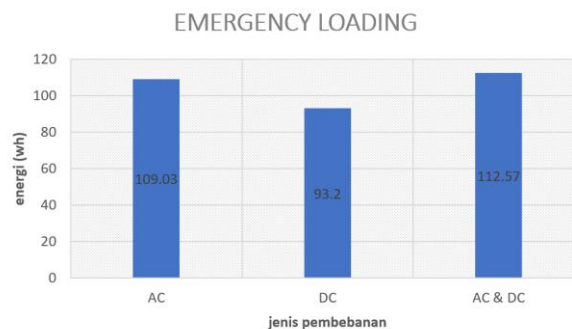


Fig. 5. Energy Released by the System during Load Testing

GPS System Accuracy Performance

GPS system accuracy testing was conducted at five locations with different environmental conditions; the results are presented in Table 4.

Table 4. Results of GPS System Accuracy Testing under Various Environmental Conditions

Testing Environmental Conditions	Distance Error (Meter)
Sparse buildings	1,56
Dense buildings without floors	4,89
Dense buildings with floors	16,4
1st floor of a 2 level building	5,63
2nd floor of a 2 level building	9,17 / 1,35

The Neo GPS system demonstrates a high level of accuracy in open areas with minimal obstructions, with a minimum error of 1.35–1.56 meters, because satellite signals can be received directly by the receiver. Conversely, in multi-story buildings with overhead obstructions and reflective materials such as steel plates, the error value increases significantly to 16.4 meters due to the multipath phenomenon, in which satellite signals bounce off building surfaces before being received by the receiver. A comparison between a two-story test site dominated by concrete (error of 1.35 meters) and a site with a large steel plate (error of 9.17 meters) confirms that reflective materials have a greater impact on accuracy than simply the number of obstacles or floor height. This finding is consistent with previous research indicating that GNSS accuracy can be limited to a few meters in open conditions, However, it increases to tens of meters in urban environments due to multipath effects and signal obstructions (Farjas-abadia, 2021). Overall, the error values obtained are still within a reasonable range for a Neo-6M module-based GPS system in an environment with many obstacles.

CONCLUSION

This riset successfully designed and developed a Hybrid Portable Emergency Energy Box based on a 40 Wp monocrystalline solar panel and a 50 W hand-crank generator equipped with a GPS locator. The energy and charging time of the battery via the solar panel were influenced by the type of previous load and weather conditions, with 225.28 Wh achieved in three days after an AC load, and 109.67 Wh and 146.14 Wh achieved in two days after a DC load and a combined AC-DC load, respectively. Testing of the hand-crank generator showed that all subjects were able to generate power exceeding the GPS system's requirements (1.19 W), with a range of 1.22–2.91 W at 133–308 RPM, indicating a positive correlation between rotational speed and power output. In load testing, the system was able to supply AC, DC, and combined loads with energy consumption of 109.03 Wh (inverter loss of 0.85%), 93.2 Wh, and 112.57 Wh, respectively, where DC loads are the most stable and AC-DC combinations consume the most energy. The Neo-6M-based GPS system demonstrated good accuracy in open to semi-open conditions (error of 1.35–1.56 m), but accuracy decreased to as much as 16.4 m in densely built-up environments due to signal obstruction and multipath. Overall, this hybrid system is capable of independently providing emergency power with reliable performance and location-tracking features that support disaster response operations, with potential for further development toward a lighter enclosure and improved efficiency of the hand-crank mechanism.

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REFERENCES

- Ainun, A. M., F. Y., S. T., P. K. P., & K. F. (2023). Buku Data Bencana Indonesia 2023. In *Buku Data Bencana Indonesia* (Vol. 3).
- Basarnas. (2024). *Basarnas Report 2024: Vol. IV*.
- Budhi Anto, Dahliyusmanto, D., Firdaus, F., & Jahrizal, J. (2024). Sistem Sumber Tenaga Listrik Berbasis Baterai Untuk Usaha Jajanan Kuliner Bergerak. *Prosiding Seminar Hasil Penelitian Dan Pengabdian Kepada Masyarakat*, 7(1), 306–316. https://doi.org/10.47767/sehati_abdimas.v7i1.936
- Farjas-abadia, M. (2021). *An Approach to Improving GNSS Positioning Accuracy Using Several GNSS Devices*. 1–27.
- Fitriyah, Q., Saragi, E. P., Nugroho, B. Y., Danatyosetyawan, A. A., & PrihadiEko W, M. (2022). Koper Portable Berbasis Sel Surya Sebagai Solusi Tanggap Bencana. *Eksergi*, 18(1), 77. <https://doi.org/10.32497/eksergi.v18i1.3219>
- Hariyanto, A. T. (2025). *Design and Construction of A Corn Sheller Powered By A Solar Power System With an ESP32 Based Control System in Sukosewu Village Gandusari Subdistrict Blitar Regency.pdf*. 1–22.
- Martyushev, N. V., Malozyomov, B. V., Demin, A. Y., Pogrebnoy, A. V., Efremenkov, E. A., Valuev, D. V., & Boltrushovich, A. E. (2025). *Modeling the Reliability of an Electric Car Battery While Changing Its Charging and Discharge Characteristics*. 1–24.
- OpenStax. (2022). *College Physics 2e*.
- Palupi, R., Ayuk, D., & Santi, S. M. (2021). Analisa Perbandingan Rumus Haversine dan Rumus Euclidean Menggunakan Metode Independent Sample t- Test. *Journal Informatic Technology And Communication*, 5(1), 40–47.
- Santoso, Q. A., Nisa, K., Abidin, Z., & Ilmi, U. (2023). An Analysis The Distinction of Generator and Efficiency Gear Ratio PLTMH Vortex Turbine in Reservoir at Bujel Village. *JEEMECS (Journal of Electrical Engineering, Mechatronic and Computer Science)*, 6(2), 122–128. <https://doi.org/10.26905/jeemecs.v6i2.8269>
- Stanlee, A. R., Saputri, F. R., & Linelson, R. (2024). Laboratory-Scale Testing of a Solar Panel-Based Portable Power Bank Design. *G-Tech: Jurnal Teknologi Terapan*, 8(4), 2651–2657. <https://doi.org/10.70609/gtech.v8i4.5412>
- Syukri, U., Deliarnoor, N. A., & Widianingsih, I. (2025). Comparison of disaster management practices in Indonesia: a study of resilience in Garut and Majene districts. *Discover Sustainability*, 6(1). <https://doi.org/10.1007/s43621-025-01526-w>