INNOVATIVE JOURNAL
OF INTELLIGENT CONTROL AND OPTIMIZATION FOR ELECTRICAL SYSTEM

Vol. 2 (2025) No. 2

Publisher by AITEKS : Aliansi ahlI TEKnologi dan Sains
https://ijcioes.org/index.php/ijcioes

Design of a Battery Pack for a Solar Power System at the Farmers Group Hut in Guo Village, Padang City

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***Abstract*— The utilization of lithium-ion batteries to store electrical energy generated from sunlight presents an effective solution due to its efficiency and reliability in supplying power from a Solar Power System (PLTS) to a farmers' group hut in Guo village, Padang. Lithium-ion batteries were selected as the storage medium because of their efficiency, longer lifespan, and environmentally friendly characteristics. However, these batteries require a meticulous protection management system to prevent damage from overcharging or over-discharging and to ensure that the voltage of each cell is balanced during the charging process. This research was conducted by designing and testing a lithium-ion battery pack composed of 48 INR 18650 cells. The system is integrated with a 3S 40A Battery Management System (BMS) to regulate the charging and discharging processes, along with an active balancer to equalize the battery cell voltages. Based on calculations, the required battery capacity was 96.42 Ah, which led to the assembly of a battery pack with a total capacity of 102.4 Ah. The results of the protection system testing indicate that the protection management system functions correctly. The BMS successfully cut off the charging current when the voltage reached 12.5V and stopped power delivery to the load when the voltage dropped to 7.9V, effectively preventing overcharge and over-discharge. Furthermore, the active balancer successfully equalized the voltage of each parallel cell group to 4.0V, ensuring optimal and uniform charging. This protection management system is expected to maintain the battery's health and extend its operational lifespan.**

***Keywords*— Battery, Lithium Ion, Solar Power Plant, Protection.**

Manuscript received 26 Oct. 2025; revised 6 Dec. 2025; accepted 7 Dec. 2025. Date of publication 31 Dec. 2025.

I. INTRODUCTION

The utilization of battery technology is currently being extensively developed to meet electrical energy demands on scales ranging from small to large. Batteries are the optimal medium for electrical energy storage. They can be utilized to store electrical energy generated from renewable energy sources such as biomass, water, wind, and sunlight.

In this project, batteries are used for a solar power system (PLTS) as a backup electrical energy source generated by sunlight. Storing energy in batteries will ensure a sufficient electricity supply, especially at night. Lithium-ion batteries are a type of rechargeable battery and are environmentally friendly because they do not contain hazardous materials, unlike older battery technologies such as Ni-Cd (Nickel-Cadmium) and Ni-MH (Nickel-Metal Hydride) batteries. Furthermore, these batteries are more durable and have a lifespan of approximately 10 years. This is why lithium-ion batteries are widely used in modern electronic devices [2].

According to Albright (2012), in his research comparing Lead Acid and Lithium-Ion in stationary storage applications, it is stated that lithium-ion batteries are currently the better battery to use in various situations. Despite having a higher initial cost, lithium-ion batteries possess a higher efficiency compared to Lead Acid batteries [3]. The use of a Battery Management System (BMS) for lithium-ion batteries is crucial for protection during battery operation. The BMS has specific functional advantages, including protecting individual cells from over-charging, protecting individual cells from over-discharging, temperature protection (Over-temperature and Under-temperature Protection), and overcurrent protection during charging and discharging.

This is because the protection system must be able to specifically secure the individual circuits of the lithium-ion battery. The BMS works to ensure the safety and reliability of the electrical system in the PLTS [5].

Not only the BMS, but an active balancer is also needed so that electrical energy can be distributed well to each individual lithium-ion battery cell. During the charging process, it is highly probable that one battery cell will become fully charged first, while the other cells are not yet full, and the charging process continues. An improper balancing process can cause damage to the battery's electrodes; therefore, the active balancer is designed to ensure that every battery cell can be fully charged simultaneously until the charging process is complete [6]

II. RESEARCH METHOD

A. Solar Power Plant

FIGURE 1. Guo Village Farmers Group

PLTS (Solar Power System) is a technology system that utilizes renewable energy from sunlight to produce electrical energy, which will later be implemented at a farmers' group hut. The research will be conducted in Guo Village, Kuranjii District, Padang City, West Sumatra Province. The research implementation time is planned to be from approximately May to August.

Guo Village is a strategic area that still holds significant potential for the utilization of new and renewable energy, particularly sunlight for Solar Power Systems (PLTS). Its geographical conditions, situated in the open, hilly areas of Padang city, combined with a tropical climate, strongly support the utilization of solar energy in this location. This region experiences a sufficiently high intensity of solar radiation throughout the year, making it a suitable location for installing solar panels as an inexhaustible renewable energy source.

Managing lithium-ion batteries integrated with a PLTS system requires control over the charging and discharging processes, as well as a proper balancing process during charging. This allows for monitoring, controlling the condition, and maintaining the performance of the batteries. Utilizing lithium-ion batteries for energy storage in a PLTS can reduce dependency on fossil fuel energy sources and contribute to carbon emission reductions and a lower environmental impact.

B. Battery Protection Circuit

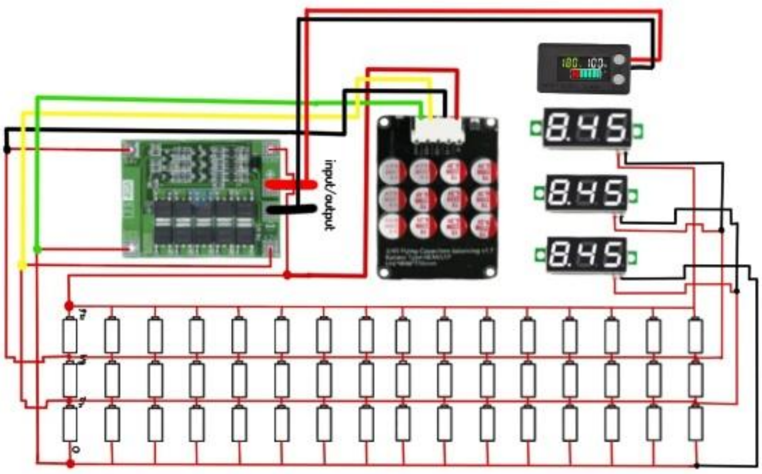

FIGURE 2. Wiring Diagram Sistem Manajemen Baterai Lithium Ion

C. Research Flowchart

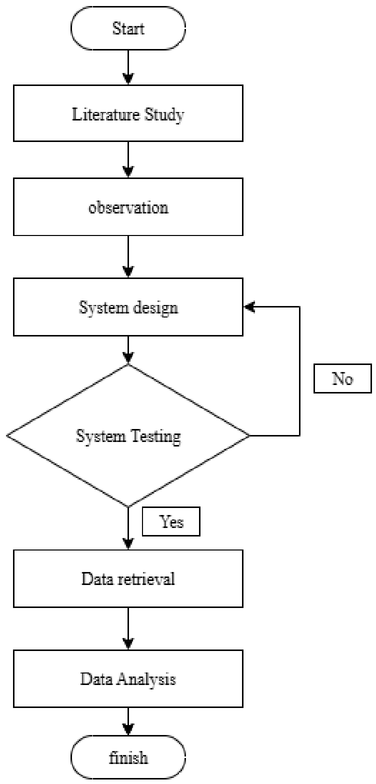

FIGURE 1. Research Flowchart

D. Block Diagram

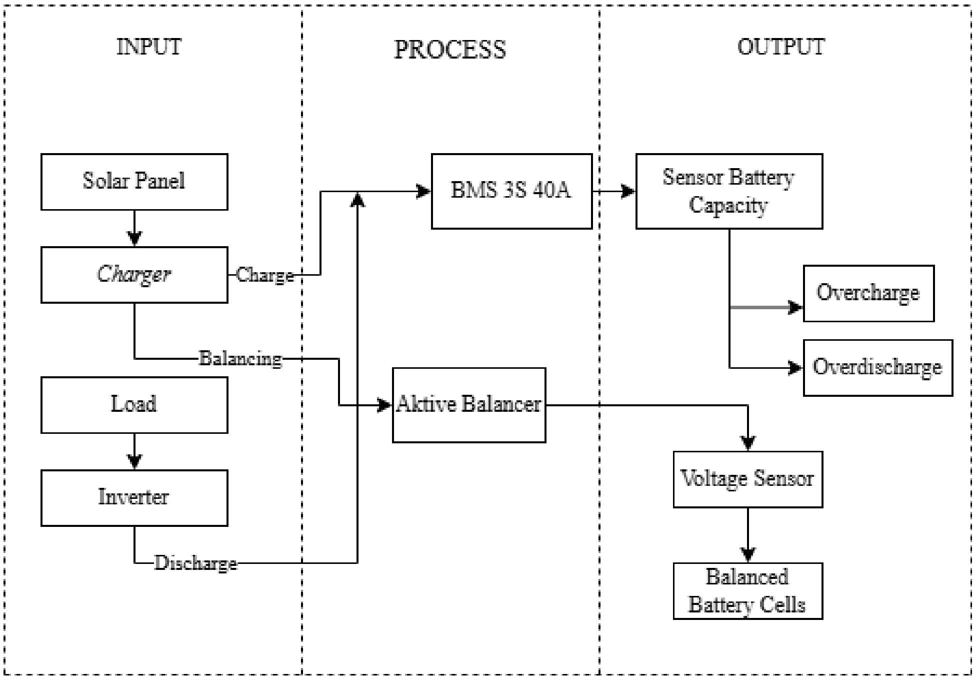

FIGURE 2 Block Diagram

E. Lithium Ion Battery Requirements Design

1. Determining the battery capacity used in a solar power plant. Determining the battery capacity required for a solar power plant system begins by calculating the total daily energy requirements of the load in watt-hours (Wh). Next, calculate the battery requirements by taking into account the efficiency of the inverter used and the battery's depth of discharge (DoD) limit.

2. Performing Battery Assembly

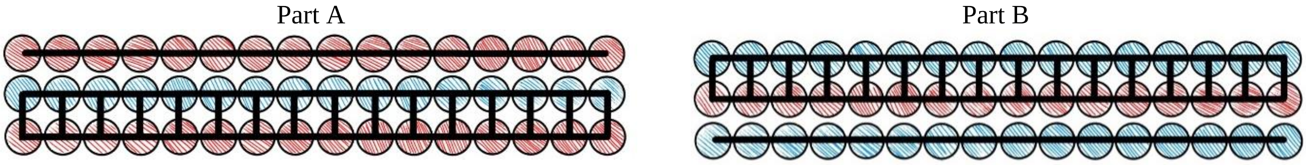

FIGURE 5. Battery Assembly

Description:
Red = Battery Positive Pole
Blue = Battery Negative Pole

F. Battery Pack 3D Design Shape

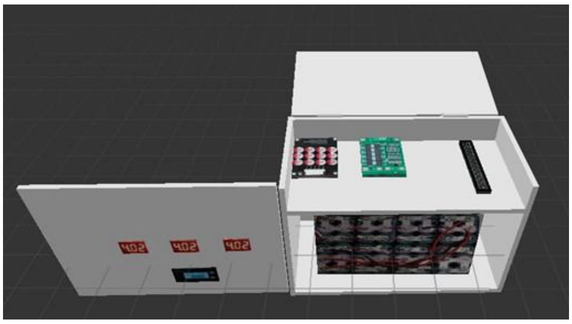

FIGURE 6. Battery Pack 3D Design

III. RESULTS AND DISCUSSION

A. Battery Pack Requirements Calculation Results

1. Analyzing Daily Load Requirements, the total daily power requirements can be described as follows:

TABLE I
Daily Load Requirements

No	Load Type	Load Amount	Length of Use	Power Capacity	Total Power Capacity
1	Led Lights18 Watt	2 pcs	12 Hours	36 Watt	432 Wh
2	Led Lights 6 Watt	1 pcs	12 Hours	6 Watt	72 Wh
3	Led Lights 12 Watt	1 pcs	12 Hours	12 Watt	144 Wh

Total Daily Power = 432W + 72W + 144W = 648W

2. Considering the Inverter Efficiency of 80%, it can be explained as follows:
   Battery requirement (DC) = Daily Energy (AC) / Inverter Efficiency
   Battery requirement (DC) = 648 Wh / 0.80 = 810 Wh
3. Calculate Battery capacity with DoD of 70%.
   - Battery capacity (Ah) = Daily energy (Wh) / Battery nominal voltage (V)
     Battery capacity (Ah) = 810 Wh / 12V = 67.5 Ah.
   - Battery capacity = 67.5 Ah / 70%
     Battery capacity = 96.42 Ah

B. Battery Pack Assembly Results

FIGURE 7. Lithium Ion Battery Assembly

The Lithium-Ion batteries utilized are of the INR 18650 type, with each cell possessing a capacity of 6,400 mAh and a nominal voltage range of 3.7V to 4.2V. This assembly uses 48 cells, configured in a 3-series and 16-parallel (3S16P) arrangement. This configuration yields a total voltage of 11.1V-12.6V and a total capacity of 102.4 Ah. The assembly employs a 3S 40A BMS (Battery Management System) and an active balancer for the battery protection system. The BMS serves to limit the charging and discharging processes, whereas the active balancer is responsible for balancing the voltage across each cell and maximizing battery utilization.

C. Overcharge Testing

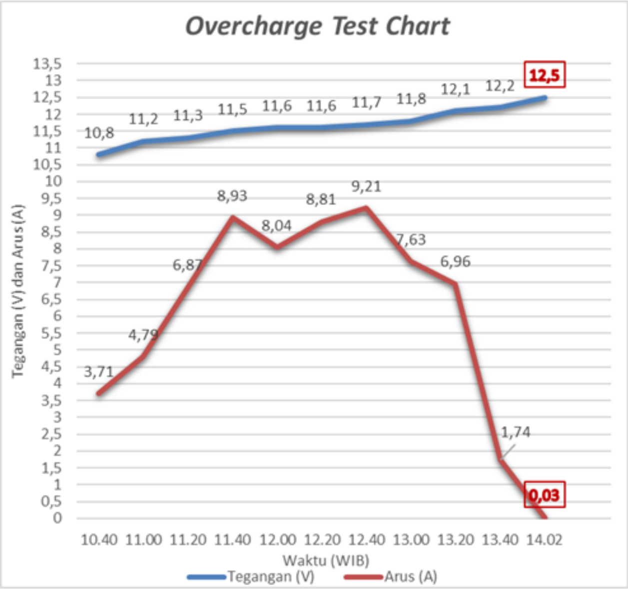

FIGURE 8. Overcharge Test Chart

The overcharging test process lasted for 3 hours and 22 minutes, starting from 10:40 WIB (Western Indonesia Time) until 14:02 WIB. The lithium-ion battery was charged using two 100WP (Watt-peak) solar panels connected to a charger, which functions to step down the voltage while simultaneously stabilizing the voltage entering the battery.

For the cut-off process, the BMS continuously monitors the voltage of each cell individually during charging. At 14:02 WIB, the BMS successfully activated overcharge protection at a voltage of 12.5V. From the testing conducted, and in accordance with the datasheet of the 3S 40A BMS used, the BMS will activate to cut off the electrical current from the charger to the battery if any single cell reaches 4.2V. This is indicated by the current flowing into the battery ceasing, measuring 0.03A.

D. Overdischarge Testing

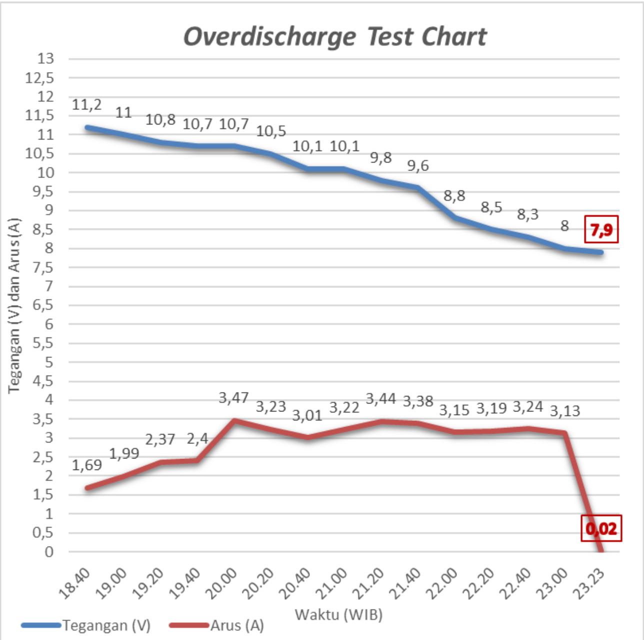

FIGURE 9. Overdischarge Test Chart

The over-discharging test in this study lasted for 4 hours and 43 minutes, using a 54-Watt load. The test began at 18:40 WIB with an initial voltage of 11.2V and concluded at 23:23 WIB, at which point the remaining battery voltage was 7.9V. The figure above illustrates the rate of voltage reduction and the current output from the battery. During this test, the voltage output from the battery decreased slowly until it reached 7.9V, at which point the BMS initiated the low-voltage cut-off. Meanwhile, the current supplied by the battery remained stable at 3A from 20:00 WIB until 23:00 WIB. At 23:23 WIB, the voltage reached 7.9V and the current dropped to 0.02A, causing the BMS to execute the low-voltage cut-off.

FIGURE 10. BMS Output Voltage

FIGURE 11 Battery Output Voltage

The figure above indicates a difference between the BMS output voltage and the battery's direct output voltage. When measured, the voltage directly from the battery showed a value of 8.0V, whereas the voltage at the BMS output terminals registered 0.9V. This difference proves that the BMS is working effectively to prevent over-discharging of the lithium-ion battery.

E. Battery Voltage Balancer Testing

TABLE II
Lithium Ion Battery Balancing Cell

No	Voltage Before Charge (V)			Voltage After Charge (V)		
	Group A	Group B	Group C	Group A	Group B	Group C
1	2,96	2,67	2,80	4.0	4.0	4.0
2	2,96	2,67	2,80	4.0	4.0	4.0
3	2,96	2,67	2,80	4.0	4.0	4.0
4	2,96	2,67	2,80	4.0	4.0	4.0
5	2,96	2,67	2,80	4.0	4.0	4.0
6	2,96	2,67	2,80	4.0	4.0	4.0
7	2,96	2,67	2,80	4.0	4.0	4.0
8	2,96	2,67	2,80	4.0	4.0	4.0
9	2,96	2,67	2,80	4.0	4.0	4.0
10	2,96	2,67	2,80	4.0	4.0	4.0
11	2,96	2,67	2,80	4.0	4.0	4.0
12	2,96	2,67	2,80	4.0	4.0	4.0
13	2,96	2,67	2,80	4.0	4.0	4.0
14	2,96	2,67	2,80	4.0	4.0	4.0
16	2,96	2,67	2,80	4.0	4.0	4.0

The table above presents the observation results from the voltage balancing process for the INR 18650 lithium-ion battery cells. This process was conducted with a low voltage value of 8.5V and a high voltage value of 12V. Before charging, the voltage for each parallel group was different: Group A was 2.96V, Group B was 2.67V, and Group C was 2.80V. After balancing was performed, the lithium-ion battery voltage was equalized to 4.0V across each parallel group.

In this process, the active balancer plays an active role in distributing energy from the battery evenly to every cell in one battery pack; this process ensures each battery [cell] receives sufficient energy to be supplied to the load. From the balancing test conducted, it was shown that monitoring the voltage of each battery cell can maintain and extend the battery's lifespan. This occurs because the active balancer ensures that the entire energy capacity stored in the battery pack can be accessed and utilized, no longer being limited by the weakest cell. This research proves that voltage balancing during charging is very influential, because the high-voltage cut-off process occurs when every battery cell has received the same voltage of 4.0V.

IV. CONCLUSION

From the calculation results, the battery assembly for the PLTS system is adequate for a 54-Watt load that will be operated for 12 hours. This load will be supplied by a 12V lithium-ion battery pack, configured in a 3-Series 16-Parallel (3S16P) arrangement, with a capacity of 102Ah.

Based on the design and testing results, the implemented lithium-ion battery protection management system demonstrates that the charging and discharging processes of the lithium-ion battery can be limited. This limitation is achieved not only by monitoring the total voltage of the battery pack, but also by monitoring the voltage of each individual cell within the battery. The battery voltage balancing process in this research ensures that each battery cell receives an equal voltage value and maximizes the charging process for the lithium-ion battery pack.

ACKNOWLEDGMENT

The author expresses gratitude to the Department of Electrical Engineering at Politeknik Negeri Padang for the facility support, as well as to all parties who provided assistance and input, enabling this research to be completed successfully.

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