

# Optimization of Battery Storage Systems in Solar Energy Application

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DOI: <https://doi.org/10.30880/peat.2025.06.02.018>

## Article Info

Received: 26 June 2025

Accepted: 11 August 2025

Available online: 30 October 2025

## Keywords

Battery storage, Solar grid, lithium-ion, optimization, Battery Management system (BMS).

## Abstract

This study presents a prototype of an optimized Battery Energy Storage System (BESS) for Malaysian solar grids. The system improves energy utilization, battery lifespan, and grid stability through advanced control strategies and optimized charging. Simulation and testing results show better charge-discharge efficiency and effective battery health management. The prototype also considers Battery Management System (BMS) integration, battery recycling, and environmental and economic impacts.

## 1. Introduction

Renewable energy integration in Malaysia demands reliable energy storage due to solar energy's variability. The inefficiencies caused by mismatches between solar generation and demand necessitate intelligent battery systems. This paper aims to optimize the battery storage performance through improved control strategies, lifecycle management, and sustainable practices.

The increasing reliance on renewable energy sources, such as solar and wind, has introduced challenges due to their intermittent and unpredictable nature. Traditional energy grids, designed for consistent power generation, often struggle to accommodate the variability inherent in renewable energy, leading to potential grid instability and inefficiencies. In Malaysia, the push for increased renewable energy integration necessitates effective solutions to manage these challenges and ensure a stable and reliable power supply.

Battery Energy Storage Systems (BESS) have emerged as a pivotal technology in addressing the intermittency of renewable energy sources. By storing excess energy during periods of high generation and releasing it during peak demand, BESS can balance supply and demand, enhance grid stability, and improve energy utilization efficiency. Recent advancements in BESS technologies have further solidified their role in modern energy systems. Studies highlight the critical role of optimization techniques in improving the efficiency of BESS, such as genetic algorithms and machine learning, which are now widely adopted to enhance their functionality. A study by Tan et al. (2023) in [1] indicates reviewed state of the art BESS optimization techniques.

In Malaysia, the integration of renewable energy into the national grid presents unique challenges, including inconsistent solar energy availability due to weather variability and limited infrastructure for energy storage. Addressing these challenges requires not only the deployment of BESS but also the implementation of advanced optimization techniques to ensure their efficient operation. For instance, real-time scheduling systems have demonstrated significant improvements in balancing grid demand and supply while optimizing energy usage. A study by Ali et al., (2022) in [2] indicates Real time scheduling significantly enhances grid stability. Furthermore, the development of sophisticated Battery Management Systems (BMS) tailored for renewable

energy applications is essential. Advanced BMS technologies ensure safety, prolong battery life, and optimize performance, enabling the effective use of renewable energy. Advanced BMS ensures battery safety and performance (Nguyen et al., 2021) [3].

By leveraging these advancements, this project aims to develop a scalable and adaptable BESS framework tailored to Malaysia's renewable energy landscape. The focus would be on optimizing charging and discharging processes, addressing issues such as battery degradation, and enhancing grid reliability. The anticipated outcomes include significant energy cost savings, improved integration of renewable resources, and a more resilient energy grid, contributing substantially to Malaysia's energy sustainability goals.

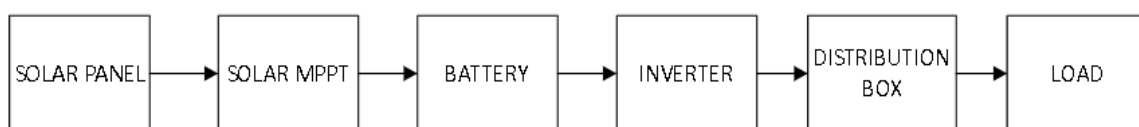
This study focuses on the development of a prototype Battery Energy Storage System (BESS) designed to address the intermittency of solar energy in localized settings. While not grid-scale, the prototype reflects the same vision by demonstrating how optimized control strategies and charging methods can improve energy utilization, extend battery lifespan, and enhance stability. Testing results show improved charge-discharge efficiency and battery health management. The prototype also incorporates key considerations such as BMS integration and battery recycling, supporting future scalability toward broader renewable energy goals.

Current BSS technologies lack advanced control strategies to effectively regulate charge-discharge cycles. Although basic protections like overcharge and overvoltage safeguards exist, they do not sufficiently mitigate the long-term wear caused by frequent cycling. This issue is particularly critical for lithium-ion batteries, which are widely used but often fail to meet a 10-year lifespan target. Lithium-ion batteries still face lifespan limitations (Chen et al., 2015) [4]. Additionally, the environmental burden of battery disposal is growing, as recycling processes for lithium-ion batteries remain inefficient and underutilized. Battery recycling processes remain underdeveloped (Melin et al., 2018) [5].

To address these issues, the project proposes an optimized battery storage framework that incorporates advanced monitoring and control mechanisms. The goal is to enhance battery lifespan, reduce environmental impact, and ensure more stable integration of renewable energy into the national grid, supporting Malaysia's shift toward sustainable energy solutions.

## 2 Methodology

This chapter outlines the methodology employed to design, develop, and validate the proposed optimized battery storage system for solar energy applications. The methodology provides a systematic approach to achieving the project's objectives, from conceptualizing the system design to constructing and testing the prototype. It begins by describing the project framework and major components, highlighting how each element contributes to the system's overall functionality. The chapter then details the development process, including hardware integration, software programming, and subsystem testing. Finally, it discusses the validation and verification protocols, specifying the performance metrics and testing procedures to ensure the system meets the desired efficiency, reliability, and sustainability standards. This structured approach ensures the proposed solution aligns with real world renewable energy requirements.

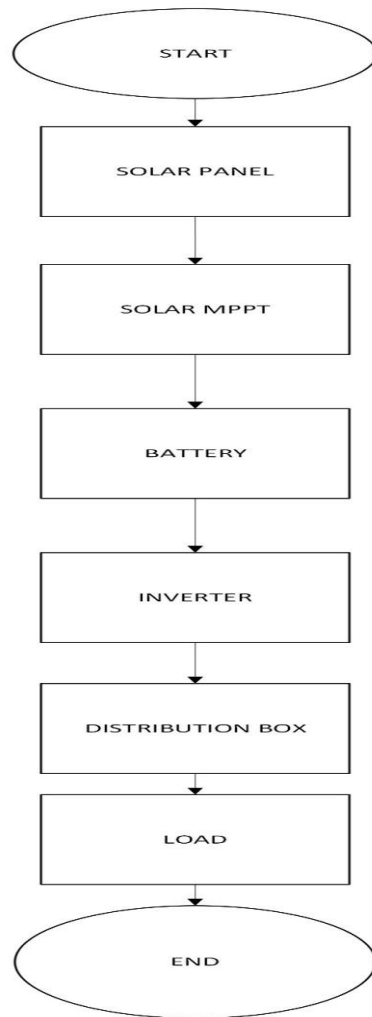


**Figure 1** The block diagram of the project

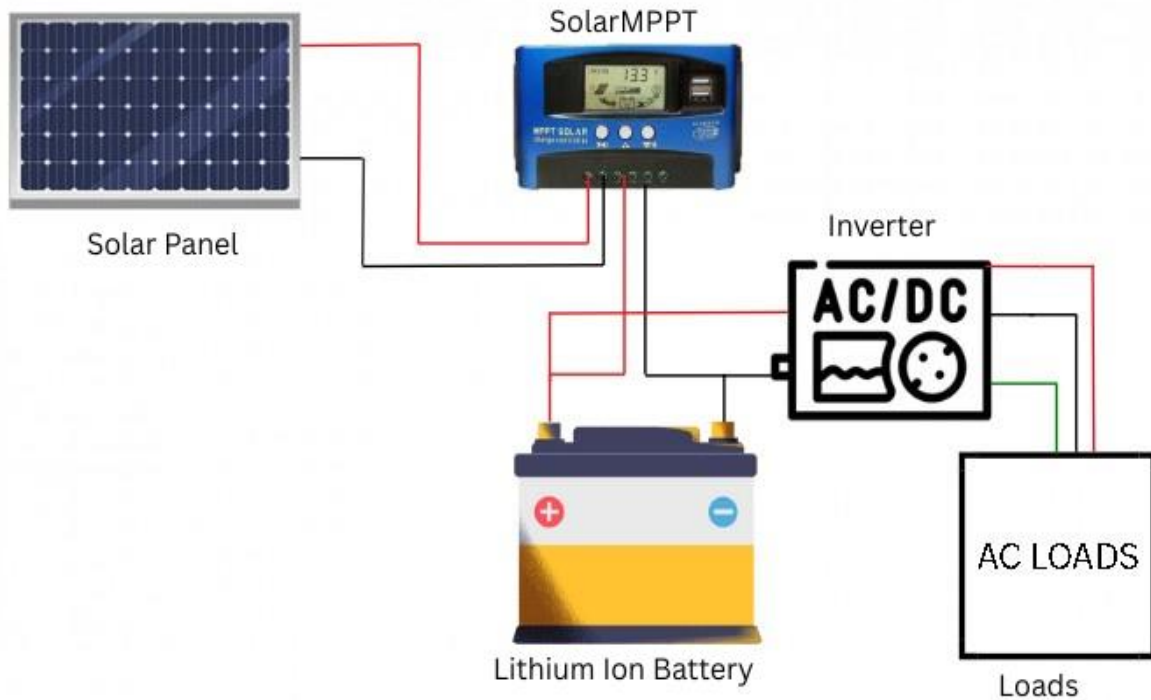
Based on Figure 1, the process begins with the solar panel, which is the major energy source. This panel, composed of several photovoltaic cells, converts sunlight into direct current (DC) electricity. The amount of electricity generated depends on sunlight intensity, panel surface area, and efficiency. However, the raw DC output is not directly suitable for most household appliances.

A critical component in optimizing this energy is the Maximum Power Point Tracker (MPPT). The MPPT continuously adjusts the voltage and current from the solar panel to ensure it operates at its most efficient point, even as sunlight conditions fluctuate. By tracking the maximum power point in real time, it prevents energy loss caused by shading, partial sunlight, or temperature variations. This allows the system to harvest the maximum possible energy from the panel throughout the day. In this prototype, setting and tuning the MPPT correctly is essential, as it directly impacts charging efficiency, battery health, and system reliability. The optimized DC output from the MPPT is then passed to the battery for storage.

The battery stores the DC electricity and supplies it during periods of low or no sunlight, such as at night or during cloudy weather. Its capacity determines the system's autonomy and reliability. The stored DC electricity is then converted into alternating current (AC) by the inverter, making it usable for standard household devices. The distribution box then routes this AC power to connected loads, ensuring safety through circuit breakers and proper load management.



**Figure 2 Flowchart of Optimization of Battery Storage Systems in Solar Renewable Energy Grids**



**Figure 3 The circuit of the project**

The figure above illustrates an off-grid solar energy system that converts solar energy into usable AC electricity. The system begins with a 40W polycrystalline solar panel, which generates direct current (DC) electricity when exposed to sunlight. This DC output is regulated by an MPPT (Maximum Power Point Tracking) charge controller, rated at 12V/24V and 20A, which continuously adjusts the panel's operating point to ensure maximum energy harvesting under varying light conditions. The MPPT also provides essential protection against overcharging and over-discharging, ensuring safe and efficient energy transfer to the battery.

### 3 Results and Discussion



Figure 4 Hardware Prototype of solar application system

#### 3.1 Data Collections

Table 1 Charging Pattern

Time (min)	Irradiance (W/m <sup>2</sup> )	Vcharge (V)	Icharge (A)	Vpv (V)	Ipv (A)	Vbat (V)
0	215	11.60	0.47	14.25	0.48	10.25
5	445	13.72	0.92	20.10	0.63	10.87
10	610	14.05	0.93	20.40	0.60	11.04
15	730	14.20	0.91	20.60	0.70	11.15
20	280	12.05	0.41	17.70	0.47	11.21

Time (min)	Irradiance (W/m <sup>2</sup> )	Vcharge (V)	Icharge (A)	Vpv (V)	Ipv (A)	Vbat (V)
25	560	13.35	0.79	20.00	0.85	11.30
30	580	14.22	0.84	20.01	0.63	11.37

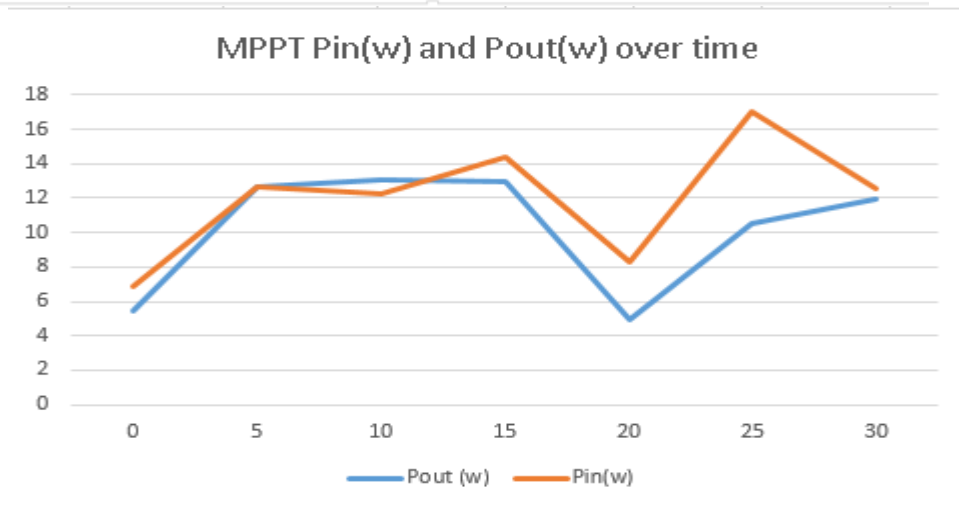
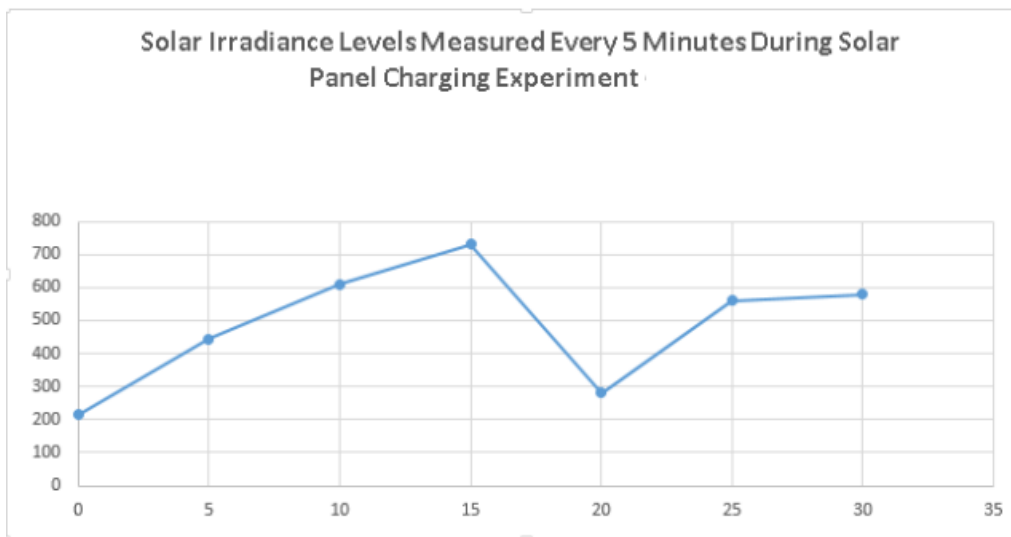


Figure 5 Graph for Battery Charging Pattern

### 3.2 Discussion

During the solar charging observation in Pagoh, Johor, the weather was partially bright with occasional dense cloud cover, causing substantial variations in solar irradiance. The irradiance pattern changed quickly, about every five minutes, due to fluctuating cloud movement. Irradiance peaked at  $730 \text{ W/m}^2$  when clouds lifted, allowing solar panels to receive maximum sunshine. This rise in irradiance resulted in a commensurate increase in both charging voltage ( $V_{\text{charge}}$ ) and current ( $I_{\text{charge}}$ ), demonstrating that solar production is extremely responsive to real time conditions.

The Maximum Power Point Tracking (MPPT) charge controller performed especially well, with changing efficiency during the session depending on irradiance stability. During periods of steady and intense sunlight, the MPPT performed well, with numerous instances where its efficiency exceeded 90%. However, a large reduction in irradiance later in the session resulted in a steep decrease in MPPT efficiency to 59.4%. This decline was attributable to an abrupt fall in input power produced by dense cloud cover.

The data demonstrated both the strengths and limits of MPPT devices under changing weather conditions. While the controller responded well to adjustments, fast irradiance decreases hampered its capacity to maintain optimal performance. These findings highlighted the difficulty of collecting solar energy in tropical locations as well as the significance of designing battery systems that can adjust to changing weather conditions for best performance and longevity.

### 4 Conclusion

In conclusion, this study found that optimizing battery storage systems in solar energy networks considerably increased sustainability and efficiency. The study's novel float charging procedure significantly minimized battery degradation, increased energy storage efficiency, and ensured long-term reliability. The strategy reduced internal battery stress during charging, enhancing the lifespan and performance of lithium-ion batteries. It also addressed the issues provided by intermittent renewable energy sources, resulting in improved grid stability and energy use. The study emphasized the necessity of sophisticated battery management systems in terms of both environmental sustainability and operational efficiencies. Overall, the study made a significant contribution to the development of dependable and efficient energy storage solutions, hence promoting the widespread adoption of renewable energy technologies in power systems.

### Acknowledgement

The authors gratefully acknowledge the support of the Universiti Tun Hussein Onn Malaysia.

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