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Smart Cell Management of Solar-Powered Power Bank

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ABSTRACT

The project replicates a solar-powered power bank with a Smartcell management system. The objective is to improve the battery's efficiency, increase its lifespan, and enable the use of green energy. Solar power is used to charge the power bank, reducing grid electricity consumption. There is a balanced charge delivery mechanism with dynamic balancing between battery cells to prevent overcharging and enhance system performance. This MATLAB/Simulink simulation replicates solar energy harvesting, charging cycles, and cell balancing. The result provides enhanced energy efficiency, enhanced charging, and improved batteries. This system is a useful solution for off-grid power, renewable energy systems, and portable energy storage.

Keywords: *Active cell balancing, Battery efficiency, Pulse Width Modulation (PWM) controller, State of Charge (SOC)*

1. Introduction

Solar power is a widely used renewable energy source because it is readily available and eco-friendly. Solar power banks utilising solar panels to charge onboard batteries provide an effective and easy means of storing power, with application in remote locations and use in emergency rescue operations. The use of solar power reduces reliance on traditional electricity sources, enabling sustainability. However, their performance and longevity depend on good battery management, as a series of cells will accumulate imbalances over time due to differences in charge levels, internal resistance, and capacity. These imbalances will degrade performance, cause overheating, and shorten the battery's lifespan. To counteract this, cell-balancing processes equalise the charge across all cells. Adaptive cell balancing, in particular, redistributes excess energy from overcharged cells to undercharged cells, improving overall energy consumption and battery condition. While passive balancing dissipates excess energy as heat, active balancing maximises battery performance by preventing energy waste and capacity loss. By maximising efficiency and prolonging the lifespan of solar power banks, active balancing makes such systems more efficient and sustainable. This article discusses the importance of battery management and how active balancing methods significantly extend the lifespan and performance of solar power storage systems in the long term.

2. Research Methodology

This project is all about creating an easy-to-use, portable solar-powered power bank, making it an environmentally friendly way to power devices anywhere, anytime, most useful for outdoor activities or emergencies. It is designed to be compact and portable, with smart features such as foldable solar panels that enhance sunlight trapping. What elevates it to a new level is the addition of smart cell-optimisation technology within the power module, keeping all cells in the battery evenly charged. Not only does this prolong the battery's life, but it also provides more stable, safer operation. Real-time monitoring will also be there to assist consumers in monitoring battery health. Most of the time, the aim is to offer people a practical, sustainable charging solution while promoting the benefits of solar power and intelligent battery management**.**

3. Theory and Calculation

3.1 Existing System

Traditional power banks are commonly used for electrical energy storage to charge portable equipment and are a handy choice, but they come with several disadvantages. One disadvantage is that it is inefficient to charge, as unbalanced charge and discharge cycles cause energy loss and reduced efficiency. Another limitation is cell balancing, which leads to an uneven distribution of charges among battery cells. This uneven distribution also accelerates cell degradation, ultimately shortening the power bank's lifespan. Passive cell balancing, used to counteract charge imbalances, is commonly implemented by routing excess energy through resistors that dissipate it as heat. Though inexpensive and simple, this process has significant disadvantages, including energy waste and inefficiency in balancing large charge imbalances, resulting in slower charging times. While inexpensive, its drawbacks make it less ideal for applications that require long battery life and faster charging. Solar-Powered Backpacks are creative solutions that include solar panels to power electronic devices on the move. These backpacks, however, have some limitations too. The relatively low power output from the solar panels does not fully power larger devices like laptops, making them less useful for high-power requirements. Also, the efficiency of the solar panels depends heavily on the backpack's orientation, which must be set correctly, and this can be difficult in different environmental conditions. These constraints indicate the necessity for more effective energy storage and management systems in solar-powered systems

3.2 Proposed System

It involves creating an emulated model with solar energy harvesting and active cell balancing to improve battery efficiency management. The core purpose of the simulation is to replicate the charging and discharging cycles of a power bank powered by solar panels and to incorporate active cell balancing to maintain equal voltages across a group of battery cells. The simulation will model the solar panel energy capture process, the battery pack energy storage process, and energy distribution to cells to balance each cell efficiently, ensuring no overcharging or deep discharge. This system will mimic a battery optimisation system (BOS), continuously monitoring and balancing each battery's charge to make them more efficient and extend their lifespan. The BMS will also sense imbalances among cells and initiate active balancing, transferring energy to maintain balanced charge levels. The model will simulate different real-life conditions, e.g., solar intensity variations, energy losses due to inefficiencies, and balancing effects, to provide insight into the overall effectiveness and efficiency of solar-powered power banks and the impact of active cell balancing on battery health.

4. Modes of Operation

The power bank operates in multiple modes to regulate energy transfer between the solar panel, battery cells, and external load. The modes Charging, Discharging, and Idle ensure maximum energy storage, a steady power supply, and the conservation of battery health. The system regulates behaviour based on the cells' charge levels, thereby distributing energy evenly throughout the battery pack and maintaining each cell at an optimal charge level. To control the current distribution and ensure charge balance, the system utilises switches and pulse-width modulation (PWM) signals. Relying on the SOC values of the cells, it is in one of the modes below:

Mode1(s1=PWM,s2=0): This mode is activated when Cell 1 has a greater state of charge than Cell 2 (SOC1 > SOC2). Here, PWM controls the switch connected to Cell 1, diverting excess energy to charge Cell 2 or redistribute power within the circuit. This prevents Cell 1 from overcharging and maintains balance.

Mode 2 (s1 = 0, s2 = PWM): When Cell 2's SOC exceeds that of Cell 1 (SOC2 > SOC1), this mode is triggered.PWM regulates the switch for Cell2, allowing current to flow into the balancing circuit to equalise SOC levels and prevent overcharging.

Mode 3 (s1 = 0, s2 = 0): If both cells have nearly equal SOC levels, this mode is activated. All switches remain off, and no charge transfer takes place. The system stays in an idle state until an imbalance is detected

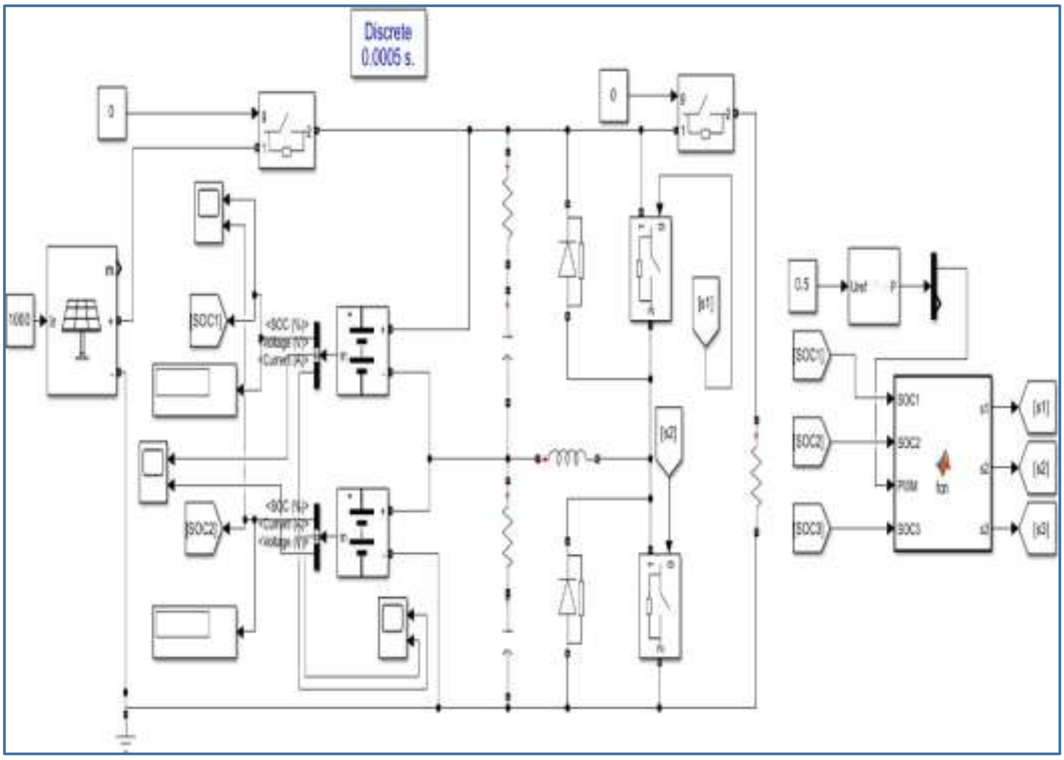

Figure 1: Solar power bank with active cell balancing

5. Results and Discussion

5.1 Charging State Analysis:

The graph illustrates the charging states of Cell1 and Cell2 over time during charging.

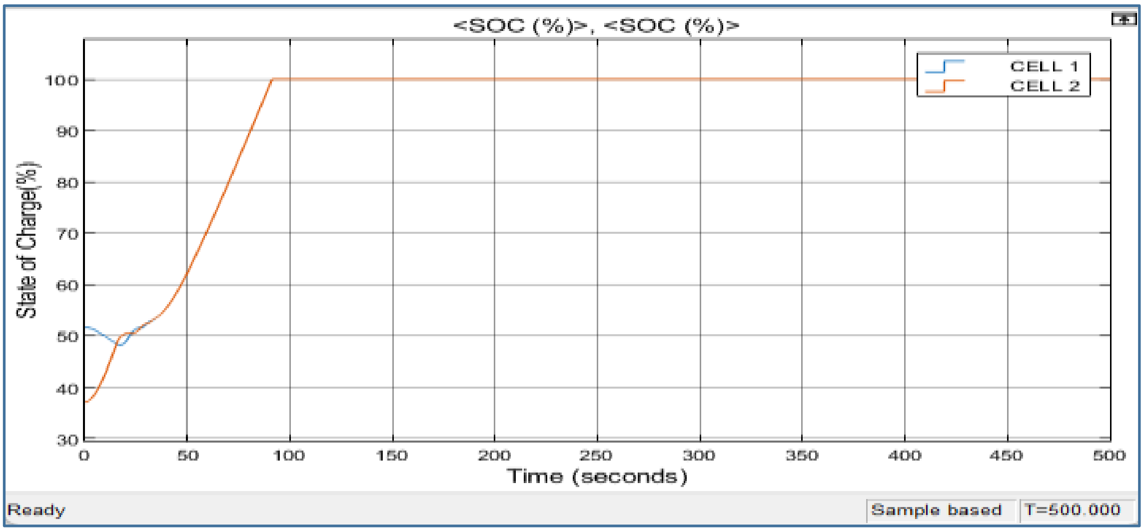

Figure 2: State of Charge Vs Time Charging State

For Cell 1 (the blue line), the SOC starts off at about 40%. During charging, the SOC increases continuously and reaches 100% around 100 seconds. Once Cell 1 has been charged to capacity, it is maintained at a constant SOC of 100% for the remainder of the timeframe. InCell2 (orange trace), the starting SOC begins around 35%. Nonetheless, Cell2 Charges Faster and reaches 100% SOC after around 50 seconds, faster than Cell1. Following this, Cell 2 also maintains a fully charged state at 100% for the remainder of the charging process. This difference in charging rates shows that Cell 2 has a lower internal resistance or is charged with a greater charging current, enabling it to charge faster than Cell 1. The different charging rates between the two cells are significant in understanding their performance profiles and the necessity for effective balancing to allow both cells to achieve a full and balanced charge without overcharging.

5.2 DischargingStateAnalysis:

The graph shows the discharge profiles of Cell1 and Cell2 over time, with time (0 to 500 s) on the x-axis and state of charge (15% to 55%) on the y-axis. The curve shows the effectiveness of the smart cell management system, which equalizes energy evenly distributed between the cells during discharge. Both cells exhibit an initial steep SOC decline that gradually transitions to a sustained, controlled drop. This consistent drop indicates effective energy utilization and demonstrates a balanced operation during the discharge process, reflecting the system's ability to maintain balance between the two cells throughout the process

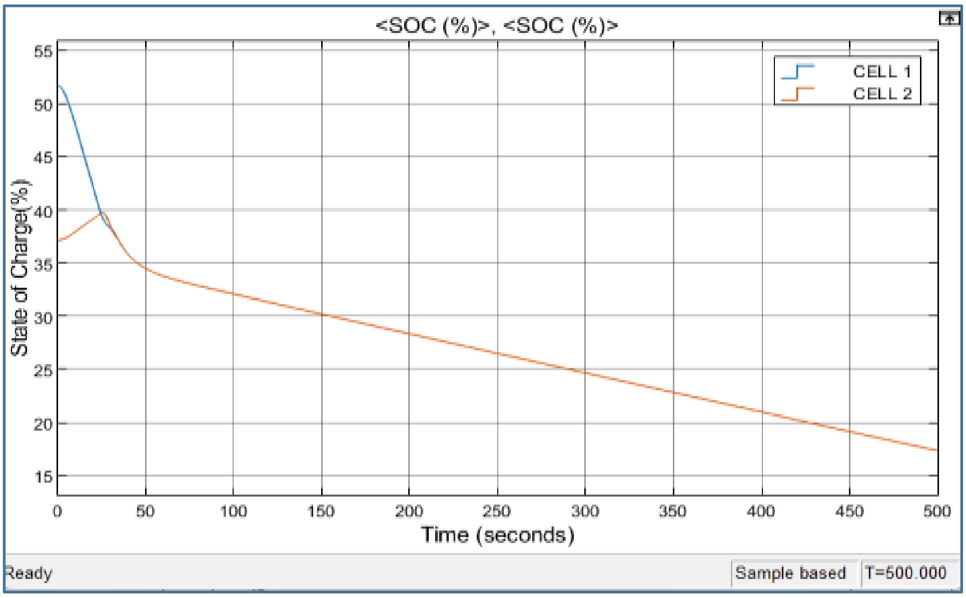

Figure 3: State Of Charge Vs Time Discharging State

For Cell1 (reflected by the blue line), the initial SOC is around 52%. Within the first 50 seconds, SOC falls rapidly to around 38%. After this initial dip, the discharge rate decreases. Bytheend ofthe500-second mark, theSOCofCell1 isaround28%. For Cell2 (the orange line), the initial SOC is a little lower, around 50%. Cell2 discharges the current at a slower rate than Cell1 for the first 50 seconds. Then, Cell 2 also follows the same slow-release trend, with a SOC of around 26% at 500 seconds. The equal discharge rates of the two cells after the initial period indicate that the active balancing system has been effective in managing energy supply, as the two cells discharge current evenly and effectively. This supports the extended lifespan and reliability of the battery pack by preventing overdischarge of individual cells.

6. Conclusions

This work delves into simulating a photovoltaic solar-powered power bank with active cell balancing as a valuable milestone in battery technology management. This work explores the simulation of a photovoltaic solar-powered power bank with active cell balancing, a significant milestone in battery technology management. Submerging a photovoltaic (PV) array beneficially taps solar energy and converts it into electrical energy to recharge cells of a battery with a minimum dependency on conventional charging, providing a cleaner and more rapid transition initially, and the equilibrium state later on, demonstrating the dynamic response of the balancing mechanism, resulting in efficient and balanced charging. This balanced SOC prolongs battery life by preventing overcharging and undercharging, improves efficiency by reducing energy waste, and ensures maximum power delivery reliability. All these advantages demonstrate the potential of an active cell-balanced solar-powered power bank as a valuable, green, and dependable device for energy storage. An alternative to portable energy storage. The cell-balancing capability actively maintains even discharge and charge rates for each battery to deliver the best overall battery performance. By actively balancing the charge state across all cells, energy loss is kept to a minimum while solar energy utilisation is optimised. The MATLAB/Simulink model demonstrates the functionality of the active cell management circuit, which rapidly balances charge levels to bring initially unbalanced cells to equilibrium. The initial fast dynamics, followed by equilibrium, demonstrate the balancing mechanism's dynamic behaviour, allowing homogeneous and effective charging. Such ongoing SOC balancing enhances battery life by avoiding overcharge and undercharge, increases efficiency by reducing energy waste, and improves power delivery reliability. These advantages illustrate the possibility of an active cell-balanced solar power bank as an effective, environmentally friendly, and dependable power storage device.

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Conflict of Interest

"The authors declare no conflict of interest.".

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