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Comparative Performance of Lithium-Ion, Sodium-Ion, and Lead-Acid Batteries in a Solar Photovoltaic System Using MATLAB/Simulink

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Abstract

This study analyzes the performance of lithium-ion, sodium-ion, and lead-acid batteries applied to a solar photovoltaic system using MATLAB/Simulink simulations. The evaluation considers key operational parameters, including voltage range, charging time, current behavior, and state-of-charge (SOC) evolution under identical control conditions, enabling a comparative assessment of their dynamic response when interfaced with a photovoltaic power source.

Lithium-ion batteries demonstrated the best dynamic performance, reaching full charge in approximately 3,900 s, operating within a voltage range of 80–105 V, and exhibiting stable current behavior after initial transient effects, along with a nearly linear SOC evolution. Lead-acid batteries presented a similar charging time but showed higher voltage and current fluctuations during transient operation. Sodium-ion batteries exhibited the longest charging time, a narrower voltage range, and slower SOC evolution, indicating reduced charging dynamics under the same control conditions.

Regarding thermal behavior, lithium-ion batteries require advanced thermal management strategies due to their higher susceptibility to thermal runaway. Sodium-ion batteries exhibit improved thermal stability with a reduced tendency for cascading failure, while lead-acid batteries present lower thermal runaway risk but require proper ventilation due to hydrogen gas generation during overcharging.

The results indicate that all battery technologies are technically viable when supported by appropriate power electronics and charge control strategies. However, significant differences in dynamic behavior were observed under identical operating conditions. In conclusion, lithium-ion batteries provide the most favorable overall performance for solar photovoltaic applications in terms of efficiency, stability, and dynamic response.