# Optimizing Efficiency in Grid-Connected Photovoltaic-Battery Energy Storage Systems through Nonlinear Control and Energy Management

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## Abstract:

This study investigates a nonlinear control strategy for managing power flow in a grid-connected hybrid renewable energy system that integrates solar power and battery storage to serve a nonlinear load. The intermittent nature of photovoltaic (PV) energy and frequent load fluctuations can have a negative effect on battery life and load performance. To address these challenges, we developed a nonlinear controller and energy management system that creates multiple energy flow scenarios to balance energy distribution between the load and sources. This approach aims to stabilize the microgrid and optimize energy use, reducing dependence on grid purchases while ensuring a reliable energy supply. A unidirectional DC-DC boost converter and a bidirectional back boost converter connect the PV module and battery storage to the DC bus, while a three-phase voltage source inverter connects the AC side to the grid via an inductive filter. The control goals are: i) maximize PV power output under varying weather conditions; ii) maintain a constant DC link voltage to balance power between the DC and AC sides; iii) control active power by injecting surplus energy into the grid; iv) develop an energy management strategy to optimize consumption from solar sources, the grid, and battery storage.

The design of the proposed AC/DC microgrid system is illustrated in Figure 1.

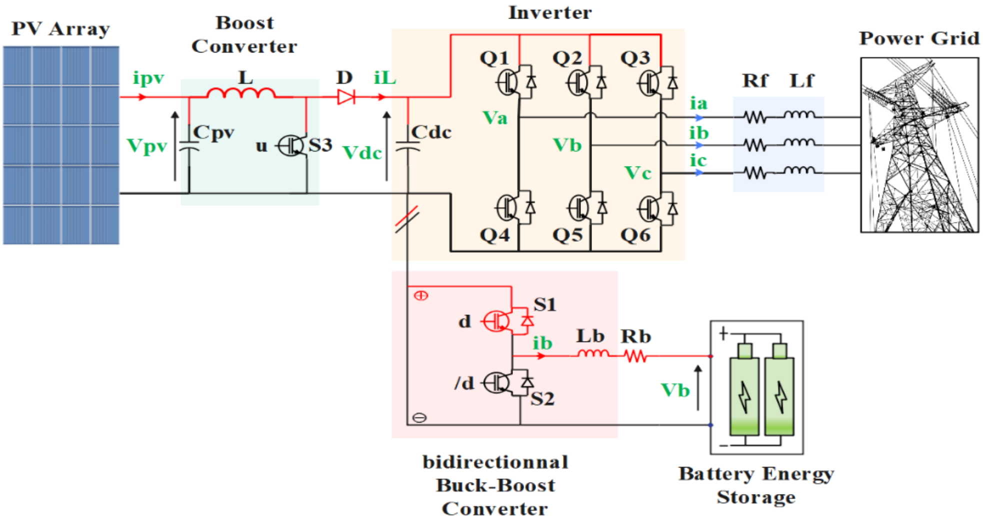


**Figure 1.** Detailed design of the proposed grid-connected photovoltaic system with battery storage.

A simulation model was developed using MATLAB/Simulink to evaluate the proposed controllers under various operating conditions, parameter variations, and load disturbances. The results demonstrate the improved dynamic performance of the microgrid, including reduced voltage overshot, shorter settling time on the DC bus, and lower Total Harmonic Distortion (THD) in grid current compared to existing controllers. Additionally, tests were conducted to assess the controller's efficiency in maintaining power balance during irradiation distortion and non-linear load imbalances validating the proposed energy management strategy's improved performance.

**Keywords:**

renewable energy system, robust control, Energy storage system, energy management, Buck-boost converter.