



Smart Home Energy Management System with Integrated PV and Battery Storage

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A smart residential renewable energy system integrated with a solar photovoltaic (PV) system, a battery energy storage system (BESS), web-based monitoring system, and an advanced home energy management system (HEMS) is presented in this research. The objective of the system is to optimize energy usage, enhance supply reliability, and ensure efficient operation under varying on-grid and off-grid conditions. The existing off-grid PV arrangement was upgraded by developing a structured load integration mechanism and an automated load bank that enabled realistic testing of domestic energy patterns. A key component of this work is the development of a real-time energy management strategy that prioritizes power allocation, protects the battery from deep discharge, and ensures uninterrupted supply to critical loads. Direct communication between the PV inverter, BESS, and microcontroller was established using Modbus TCP and RTU protocols by bypassing the manufacturer-provided apps. Real-time inverter parameter retrieval, real-time measurements, and data transmission to a backend server for storage and visualization were accomplished through an ESP32 microcontroller. The developed HEMS algorithm uses these retrieved battery state of charge, inverter status, and load demand to determine load shedding levels and reconnection thresholds. Real-time visualization of PV output, battery behavior, load currents, and system operating modes is provided through a web interface, enabling remote supervision and improved user awareness. To achieve advanced home energy management, simulation studies were conducted to compare baseline operation with the proposed rule-based HEMS algorithm. The proposed algorithm uses the time-of-use tariff in Sri Lanka. Hence, it is relevant as residential solar PV owners are required to transition from flat tariffs to TOU-based pricing structures. Improved battery utilization, reduced grid dependency, and efficient PV energy distribution among household loads are the results of the study. Therefore, the proposed system provides a smart, sustainable, reliable, and efficient solution for powering a home while improving energy efficiency.

Keywords: Battery Energy Storage System (BESS), Building integrated photovoltaics, Energy management system, Load management, Rule-based systems, Smart homes