DESIGN OF AN ENERGY MANAGEMENT SYSTEM FOR AN OFF-GRID PV POWERED AGRICULTURAL CHARGING STATION

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ABSTRACT

Off-grid solar (PV) systems require an energy management system that monitors energy conditions and regulates loads automatically to keep the power supply stable and prevent excessive battery discharge. At the research site, the existing off-grid PV system had no monitoring or load control based on actual conditions. This study designs and implements a prototype Energy Management System (EMS) for an off-grid PV-powered agricultural charging station using an ESP32 microcontroller. The system integrates a PZEM-017 sensor for DC parameters on the PV and battery sides, a PZEM-004T sensor for AC parameters on the load side, and a DS18B20 sensor for battery temperature, while the State of Charge (SoC) is estimated using the Coulomb Counting method. A Mamdani Fuzzy Logic Controller determines the active load level from three inputs (SoC, PV power, and load power), while the operating mode is set from the power difference between PV and load. Sensor validation shows a maximum error of 0.80% (PZEM-017), 0.84% (PZEM-004T), and 2.74% (DS18B20). The fuzzy decisions vary with energy conditions, producing Level 2 and Level 3 outputs so the system adaptively sheds low-priority loads when the load increases, and the ESP32 implementation was verified against a MATLAB reference model with identical level decisions. Energy analysis shows a total PV energy of 66.68 kWh and a load energy of 20.66 kWh, giving a surplus of 46.02 kWh, indicating that the generation capacity still far exceeds the current load demand. Further development is recommended using a bidirectional current sensor and longer testing under more varied weather and SoC conditions.

Keywords: off-grid PV system, energy management, fuzzy logic, State of Charge, ESP32.