ABSTRAK

Penelitian ini membahas pengembangan *Energy Management System* (EMS) pada *Solar Mobile Power* berbasis panel surya 1,5 kWp, baterai $LiFePO_4$ 10 kWh, dan inverter 6,6 kW sebagai sumber suplai daya darurat. Sistem ini dikembangkan untuk menjawab kebutuhan pemantauan energi dan pengelolaan beban ketika ketersediaan energi terbatas, khususnya pada kondisi darurat bencana atau pemadaman listrik berskala besar. EMS dirancang sebagai sistem eksternal agar proses monitoring dan pengendalian tidak bergantung pada protokol komunikasi internal inverter. Metode yang digunakan meliputi perancangan dan implementasi perangkat monitoring berbasis ESP32, sensor PZEM-017 pada sisi baterai, sensor PZEM-004T pada sisi keluaran AC, relay sebagai aktuator outlet, komunikasi MQTT, dan dashboard Node-RED. Estimasi *State of Charge* (SoC) dilakukan menggunakan metode *Coulomb Counting*, sedangkan estimasi *Energy Time-to-Empty* (TTE) digunakan untuk memperkirakan sisa waktu operasi berdasarkan energi baterai dan daya beban. Pengelolaan beban dilakukan menggunakan metode *Adaptive Priority Matrix Load Shedding* (APMLS), yaitu metode berbasis prioritas yang mengevaluasi kondisi SoC, TTE, daya PV, daya beban, daya tersedia, serta tingkat prioritas outlet sebelum menentukan status relay. Hasil pengujian menunjukkan bahwa sistem monitoring mampu membaca parameter operasi baterai, PV, dan keluaran AC secara *real-time*. Hasil evaluasi akurasi menunjukkan rata-rata MAPE keseluruhan sebesar 5,55% atau akurasi relatif 94,45%. Akurasi relatif tertinggi diperoleh pada pembacaan tegangan baterai sebesar 99,63%, sedangkan akurasi relatif terendah diperoleh pada pembacaan arus PV sebesar 83,66%. Estimasi SoC menunjukkan kecenderungan meningkat saat pengisian dan menurun saat pengosongan. Estimasi TTE menunjukkan bahwa waktu operasi dipengaruhi oleh kombinasi SoC dan daya beban, dengan hasil 7,8 jam pada pembebanan tinggi, 10,3 jam pada pembebanan menengah, dan 9,3 jam pada pembebanan rendah. Pengujian APMLS menunjukkan bahwa outlet prioritas tinggi tetap dipertahankan pada mode NORMAL, SAVE, dan CRITICAL, sedangkan outlet berprioritas lebih rendah diputus lebih dahulu ketika energi sistem menurun. Dengan demikian, EMS yang dikembangkan mampu mengintegrasikan monitoring, estimasi kondisi energi, dan pengelolaan beban adaptif untuk mempertahankan kontinuitas suplai pada beban prioritas.

Kata kunci: *Energy Management System*, *Solar Mobile Power*, *Coulomb Counting*, *Energy Time-to-Empty*, *Adaptive Priority Matrix Load Shedding*

ABSTRACT

This research discusses the development of an Energy Management System (EMS) for a Solar Mobile Power unit based on a 1.5 kWp photovoltaic panel, a 10 kWh $LiFePO_4$ battery, and a 6.6 kW inverter as an emergency power supply. The system was developed to address the need for energy monitoring and load management under limited energy availability, particularly during disaster emergencies or large-scale power outages. The EMS was designed as an external system so that monitoring and control processes do not depend on the inverter internal communication protocol. The method includes the design and implementation of an ESP32-based monitoring device, a PZEM-017 sensor on the battery side, PZEM-004T sensors on the AC output side, relays as outlet actuators, MQTT communication, and a Node-RED dashboard. State of Charge (SoC) estimation was performed using the Coulomb Counting method, while Energy Time-to-Empty (TTE) estimation was used to estimate the remaining operating time based on battery energy and load power. Load management was carried out using the Adaptive Priority Matrix Load Shedding (APMLS) method, a priority-based method that evaluates SoC, TTE, photovoltaic power, load power, available power, and outlet priority level before determining the relay status. The test results show that the monitoring system can read battery, photovoltaic, and AC output operating parameters in real time. The accuracy evaluation showed an overall average MAPE of 5.55%, equivalent to a relative accuracy of 94.45%. The highest relative accuracy was obtained from the battery voltage reading at 99.63%, while the lowest relative accuracy was obtained from the photovoltaic current reading at 83.66%. The SoC estimation showed an increasing trend during charging and a decreasing trend during discharging. The TTE estimation showed that operating time was affected by the combination of SoC and load power, with results of 7.8 hours under high load, 10.3 hours under medium load, and 9.3 hours under low load. APMLS testing showed that the high-priority outlet remained supplied in NORMAL, SAVE, and CRITICAL modes, while lower-priority outlets were disconnected first when the system energy decreased. Therefore, the developed EMS can integrate monitoring, energy condition estimation, and adaptive load management to maintain supply continuity for priority loads.

Keywords: Energy Management System, Solar Mobile Power, Coulomb Counting, Energy Time-to-Empty, Adaptive Priority Matrix Load Shedding