A Predictive Energy Management Framework for Malaysian Residential Microgrid Using LSTM-Driven Adaptive Rule-Based Control

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Abstract

The rapid increase in global energy demand and the growing emphasis on environmental sustainability have accelerated the integration of renewable energy sources (RES) into modern microgrids. However, the stochastic nature of RES, the unpredictable behavior of load demand, and the variability of utility electricity tariffs under the Time of Use (ToU) pricing mechanism increase the operational complexity of microgrid energy management systems (EMS). To address these challenges, this research focuses on developing and implementing a hybrid EMS that integrates machine learning (ML)-based Long Short-Term Memory (LSTM) predictive models with conventional Rule-based Control (RBC) strategies for tertiary-level control of a centralized, grid-connected residential microgrid. The proposed EMS approach combines one-hour-ahead forecasts of solar Photovoltaic (PV) energy generation and residential load demand with predefined Load Following

(LF) and Cycle Charging (CC) control strategies, enabling the EMS to anticipate future operating conditions while preserving the simplicity of the conventional RBC framework. The main objective of this research is to evaluate whether integrating LSTM predictive models into conventional RBC strategies can reduce the total operating cost of a Malaysian residential microgrid under the applicable ToU electricity tariff and Solar Accelerated Transition Action Program (Solar ATAP) scheme. The microgrid is modeled in MATLAB Simulink as a grid-connected system comprising a solar PV system, battery energy storage system (BESS), and three residential load profiles representing terrace, apartment, and condominium households in Kuala Lumpur, Malaysia. The data used to develop the proposed hybrid EMS are sourced from various trusted platforms, including Tenaga Nasional Berhad (TNB) energy smart meters, Huawei FusionSolar, and Solcast. The simulation results showed that the developed LSTM predictive models achieved higher forecasting accuracy for both solar PV energy generation and residential load demand than the baseline Feedforward Neural Network (FFNN) models. Leveraging these forecasts, the proposed LSTM-RBC-based EMS effectively coordinated the distributed energy resources (DERs) under the ToU electricity tariff and Solar ATAP scheme by strategically scheduling BESS charging and discharging operations and managing grid energy import and export based on economic operating conditions. The proposed hybrid EMS achieved a significant reduction in total operating cost by approximately 30 to 40 compared with conventional RBC strategies under different initial BESS State of Charge (SoC) scenarios. These results demonstrate that integrating ML-based LSTM predictive models into conventional RBC strategies enables more economical microgrid operation, highlighting the potential of predictive control to improve the operational performance of residential microgrids.

Author keywords

Energy Management Systems (EMS); Long Short-Term Memory (LSTM); Machine Learning (ML); Rule-Based Control (RBC); Tertiary-Level Control

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