

INTISARI

Konsumsi energi listrik rumah tangga yang terus meningkat mendorong perlunya sistem yang mampu memprediksi penggunaan daya secara presisi. Penelitian ini bertujuan untuk mengimplementasikan *Tiny Machine Learning* (TinyML) berbasis algoritma *deep learning* dengan arsitektur *Vanilla Long Short-Term Memory* (LSTM) pada mikrokontroler ESP32-S3 untuk prediksi beban listrik secara *real-time*. Mikrokontroler tersebut diintegrasikan dengan sensor PZEM-004T sebagai perangkat *edge* untuk membaca daya aktif kelistrikan secara mandiri. Mengatasi keterbatasan memori pada ESP32-S3, model LSTM dilatih terlebih dahulu di komputer menggunakan dataset deret waktu 7 hari, kemudian bobot parameternya dikompresi menjadi format 8-bit (*Integer Quantization*) melalui *TinyML pipeline*. Hasil pengujian perangkat keras menunjukkan tingkat *error* kalibrasi bacaan sebesar 2,23%. Selanjutnya, pengujian inferensi langsung di lapangan selama 24 jam membuktikan bahwa mikrokontroler sanggup mengeksekusi arsitektur model tanpa kendala *Out-Of-Memory*. Model LSTM terkuantisasi tersebut berhasil melacak tren fluktuasi beban listrik dengan nilai *Mean Absolute Error* (MAE) pada rentang 52 hingga 65 Watt. Penelitian ini menegaskan bahwa algoritma *deep learning* yang direduksi via TinyML sangat layak diimplementasikan pada mikrokontroler berspesifikasi rendah untuk menunjang *Smart Energy Monitoring*.

Kata kunci: *Internet of Things* (IoT), *Smart Energy Monitoring*, ESP32-S3, PZEM-004T, *Long Short-Term Memory* (LSTM), Prediksi Beban Listrik.

ABSTRACT

The continuous increase in household electrical energy consumption drives the need for systems capable of precisely predicting power usage. This study aims to implement Tiny Machine Learning (TinyML) based on a deep learning algorithm with a Vanilla Long Short-Term Memory (LSTM) architecture on an ESP32-S3 microcontroller for real-time electrical load prediction. The microcontroller is integrated with a PZEM-004T sensor as an edge device to independently read active power. To overcome the memory constraints of the ESP32-S3, the deep learning LSTM model was pre-trained on a computer using a 7-day time-series dataset, and its parameter weights were subsequently compressed into an 8-bit format (Integer Quantization) via a TinyML pipeline. Hardware test results show an average calibration reading error of 2.23%. Furthermore, 24-hour real-world inference testing proves that the microcontroller is capable of executing the model architecture without Out-Of-Memory issues. The quantized LSTM model successfully tracked load fluctuation trends with a Mean Absolute Error (MAE) ranging from 52 to 65 Watts. This research confirms that deep learning algorithms reduced via TinyML are highly viable for implementation on low-specification microcontrollers to support Smart Energy Monitoring.

Key words: *Internet of Things (IoT), Smart Energy Monitoring, ESP32-S3, PZEM-004T, Long Short-Term Memory (LSTM), Load Forecasting.*