Electricity Price and Load Forecasting Using Intelligent Home Energy Management System

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***Abstract*—This paper proposed a complete system design of an Intelligent Home Energy Management System without changing the conventional energy meter with a CNN-LSTM-RNN-based ensemble model for electricity load and price forecasting. A grid search optimization approach was proposed to modify the hyperparameters to increase the efficiency and performance of the proposed Model. Further Autoencoder technique was proposed to identify anomalies in electricity usage, and by using the expected results of the forecast model and autoencoder, a database-driven demand curve flattening method was proposed to reduce individual home electricity usage in peak hours.**

Keywords— HEMS, CNN, LSTM, RNN, Electricity Price forecasting, Electricity Load Forecasting, Electricity Demand

I. Introduction

With the development of technology, many fields of the world have been changed and upgraded. Though Sri Lanka developed in some areas, the Whole electricity generation, distribution, and consumption management systems still have not changed. These systems still follow manual techniques yet. For instance, due to supply and grid imbalances today, most Sri Lankans experience lengthy power outages. Currently, the government is struggling to give sustainable solutions to resolve this issue.

To solve the above issue, as a country, we need to utilize the newest technologies and forecasting models to be ready to face future problems. Though there are previous works on electricity load and price forecasting, all the research papers state their final results based on old datasets without considering weather features. As a result, these proposed models do not meet the accuracy when used in the real world. On the other hand, Most of the Research topics on demand side management also have the same practical issue.

II. Related Works

Currently, there are very few researchers focused on weather features for forecasting. The paper [1] Load forecasting model was proposed based on Long Short Memory (LSTM) recurrent neural network with weather features as input. According to paper [3], most previous research and their proposed Methodologies on load and price forecasting have different drawbacks. Some are high computational time, some proposed models are complex, unstable, and inaccurate, and some methodologies are not functioning for larger datasets. Therefore, maintaining better performance and higher accuracy in models is much needed in load and price forecasting. They proposed a mix of machine-learning and deep-learning-based Models to solve these issues. The ensemble learner used hyperparameter optimization to achieve optimum precision and used feature engineering techniques to improve the Model's performance in the model-building process.

The Paper [4] add a value flow in the smart grid using innovative services, market mechanism, and information flow. They sketch a conceptual framework of the Cyber-Physical-Power-System (CPPS) by interrogating with Power Internet of Things (PIoT). Using CPPS, they propose a robust smart grid with global information interaction, intelligent decision-making, and real-time agile control. Finally, they conducted a case study regarding Home Energy Management Systems (HEMS) for illustration purposes. In paper [2], a solution for HEMS was proposed with direct current (DC) Power management. In their HEMS, smart DC sockets with load-shedding algorithms were used to control home devices with priority. The home devices were turned on or off by smart sockets only according to the energy consumption threshold at each sampling period.

Based on the above background, this study proposed an intelligent Home Energy Management System. The proposed HEMS makes the following contributions.

- Using both edge computing and cloud computing technologies and client-server architecture were prioritized in the HEMS design. The proposed HEMS architecture can be used with the current one-way grid system while maintaining our manual meter system
- Through our HEMS, every appliance is monitored individually in real-time and captures the data into a relational database running on the edge server
- A CNN-RNN-LSTM Ensemble learner-based grid search hyperparameter optimization was proposed to predict future energy usage and cost in real-time.
- A method to use an auto-encoder to detect anomalies in energy usage patterns and find the starting and ending times of peak-demand hours according to individual usage.
- A database-driven method to flatten the demand curve of an individual consumer using forecasted results and a threshold value. It will be beneficial to both consumers and suppliers to save money.

III. Methodology

In this research, the main algorithm consists of 2 main parts.

1. Load and price prediction for long-term and short-term purposes using an ensemble model.
2. Use LSTM auto-encoder for anomaly detection on the observed dataset.

1) Forecast Model

The following step was proposed to predict the energy load and price forecasting.

- Load data (The HEMS Server's Database)
- Feature selection Using RF and XG-Boost
- Feature Extraction Using RFE
- Splitting of data into training and testing.
- Load the RNN, LSTM, and CNN layers and parameters.
- Tunning the RNN, LSTM, and CNN parameters using the Grid search optimization algorithm
- Predict Price and load daily, weekly and monthly
- Performance evaluation

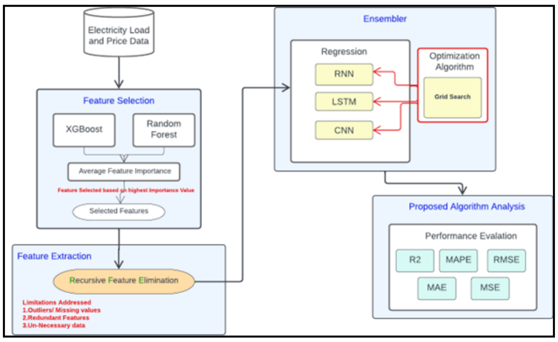

Fig. 1. Proposed Model for Electricity Load and Price Forecasting

2) Autoencoder Model

An Autoencoder(AE) is composed of two different networks in a series. The encoder part compresses the input into a lower dimensional space, and the decoder part attempts to reconstruct the input from the encoded representation.[6] In the beginning, the AE trained with the optimal inputs. At this time, AE will be tuned its parameters to reconstruct the input from the encoded representation. Then when we fed some time series data that had anomalies, the AE failed to reconstruct the input as it is. There might be high values in the loss function and some error matrices like Mean Square Erro(MSE) and Mean Absolute Error(MAE).

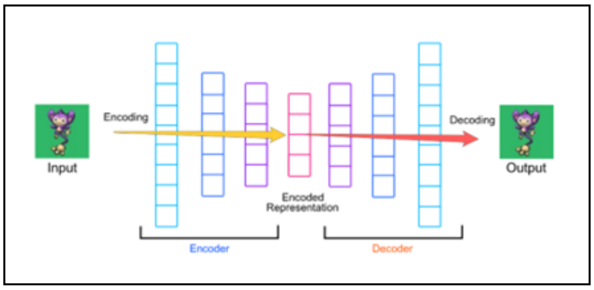

Fig. 2. Internal structure of an Autoencoder

IV. Proposed Designs

1) Network design

This research proposed a modified HEMS consisting of four main layers, each focusing on different activities. Those are-

I. Physical layer – data collection
II. Network layer – data transmission
III. Edge layer- data management
IV. Cloud layer – value creation

The physical layer comprises household electric appliances, sensors, data collection devices, and actuators. The data collected from the physical layer are transmitted to the network layer using Wi-Fi or ZigBee communication technologies.

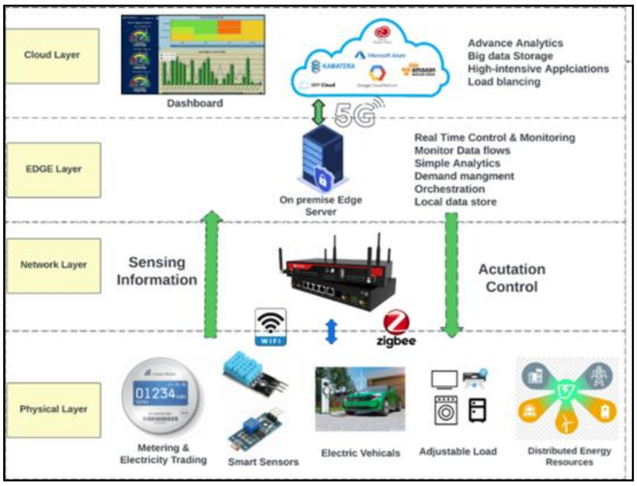

Fig. 3. Architecture of an intelligent home energy management system

After that network layer forwards the environmental and energy consumption data to the edge layer. In the edge layer, all the data is stored in a database, which is used for load and price forecasting. According to the forecast results, several optimization algorithms will be executed and send the final control instructions to actuators from server to client to perform energy management for optimal energy consumption, cost, and user satisfaction. The edge layer is connected to the cloud layer. Using the cloud layer, the electricity service provider connected with the HEMS.

2) Hardware design

This research entirely focused on HEMS and its functions. However, these designs can be used in any place or building according to the situation. HEMS optimizes home appliances' energy usage and helps consumers incorporate other Demand Side Management activities. To build an Intelligent HEMS, all the devices have measured individual consumption, and we must maintain the client-server architecture. In the proposed HEMS, the server

(Raspberry pi) can send commands to their clients (Node MCUs) and control the devices connected to each node Microcontroller Unit using a relay module. While keeping the old meter, the individual equipment was measured using the sensors with the help of modified intelligent HEMS, as shown in Fig. 4. The Pzem sensors are fitted inside the distribution board, and One bedroom monitors its inside temperature and controls its devices.

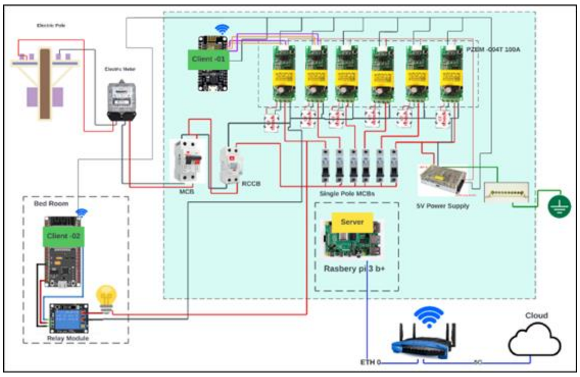

Fig. 4. Proposed design for placing hardware items and sensors in HEMS

3) Database design

The data obtained from the sensors are kept in relevant tables in the Database. Since the Database is running inside the raspberry pi module, we need to reduce the database size. Therefore, all the variable sizes are optimally need to be used while creating the database.

V. Expected Results

Online publicly available PJM Hourly Energy Consumption Dataset was used to build load forecasting models for LSTM, RNN, and CNN. LSTM, RNN, and CNN models achieve 0.93, 0.94, and 0.97 r2 score values, respectively. Finally, using the ensemble model, the r2 score value will lie between 0.93 and 0.97. On the other hand, adding the weather feature model will predict more accurate values. Another expected result is using load forecasted values the peak demand hours for individual houses are identified and we can manulally and automatically shift unnecessary aplliances for off-peak hours.

VI. Future Directions

- Test the proposed ensemble learning model with more Algorithms to obtain higher accuracy and precision.
- Improve the security features such as authentication, authorization, intrusion detection, and privacy in the newly added security layer[5].
- Implement more practical solutions for Individual house Demand curve Flatting using the proposed HEMS design

VII. Conclusion

This paper proposed a complete architecture of an intelligent HEMS with a unique load and price forecasting technique. The main objective of this approach is to improve the precision of the electricity load and price forecasting model. The proposed forecasting model was an ensemble learner-based, CNN-RNN-LSTM hybrid model with a novel optimization technique grid search. Only the LSTM model experiments on a publicly available dataset for residential buildings and developed the LSTM Autoencoder model to identify anomalies in the dataset.

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