



ENERGY CONSUMPTION FORECASTING FOR SMART HOMES

Engineering

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ABSTRACT

Effective management of energy in smart homes requires accurate forecasts, anomaly detection, and intelligent scheduling of flexible loads to reduce energy expenditure and improve the stability of the power distribution system. This article presents a comprehensive machine learning system that automates the entire process of predicting domestic energy consumption and optimal scheduling of the flow of flexible loads. The system is implemented on a practical dataset of a smart home. The system processes the dataset by merging date and time into a single timestamp, encoding numerical columns, correcting missing values by interpolation, and preparing predictive variables such as hour of the day, day of the week, weekend indication, month of the year, previous consumption, rolling averages, and estimated flexible load. On these features, two respective regression algorithms—Decision Tree and Random Forest—were trained to accurately model short-term electric power consumption. The latter has been proved to be a better-performing algorithm on the basis of the MAE, RMSE, and MAPE error measurements. To make it even more accurate and dependable, Isolation Forest Anomaly Detector has been implemented to learn from consumption and feature data and accurately highlight unusual patterns of electricity use that might be caused by a flawed appliance sensor or unusual user behavior. On the basis of accurate predictions of electric power consumption, a Rule-based Scheduling Engine has been implemented that analyses expected future electric power use within a definite time period and automatically reschedules flexible loads from periods of expected high use above a rolling average to periods of expected lower use while ensuring within a definite restriction on a longest possible shift duration. The system's optimization has greatly flattened the electric power consumption curve and minimized total electric power consumption in the smart home. The practical utility of the system has been proved on experiments that have demonstrated definite reduction in electric power expenditure and peak electric power demand of the smart home as compared to the basic system. The proposed system automates the entire activity of electric power use forecasts, anomaly sensing, and optimal electric load shifting in a single system. The system presents a simple and adaptive approach to the management of electric power use in smart homes. This article presents a practical approach and can be a part of solutions of demand management issues in smart homes.

KEYWORDS

Smart Homes, Energy Consumption Forecasting, Machine Learning, Random Forest Regression, Decision Tree Regression, Anomaly Detection, Isolation Forest, Load Shifting, Demand-Side Management, Time-Series Analysis, Energy Optimization, Smart Grid, Peak Load Reduction, Home Energy Management System (HEMS), Predictive Modeling.

INTRODUCTION

As the process of smart homes growth and IoT-based energy meters dissemination continue at a fast pace, the volume and the level of detail of data regarding the domestic electricity has grown considerably. Since residential sector is an in consumer of high percentage of total electricity in the world it has become a major concern of both residents and electricity sector that efficiency should be improved. The smart home is able to provide real-time and accuracy of data which can track the complex pattern of the usage patterns as well as environmental dynamics. However, the increasing world energy demands, the frequent inclination of the grid system to overheat, the change in the pattern of the energy pricing, as well as the newly emerging demand on sustainable development, have rendered the constraints of the currently existing approaches to the control of energy consumption too obvious, which are based on the past information instead of real-time information.

Despite the developments achieved in smart metering and automatic systems, the contemporary energy handling systems to be used in houses are susceptible to some disadvantages. As an example, these systems are constrained, in terms of short-term forecasting of energy demand, and detecting abnormal appliance utilization, and are automated in the process of allocating the flexible loads to off-peak periods. The conventional rule-based or threshold-based models developed to use energy has deficiency in terms of flexibility in the model. The model fails to consider the nonlinear use that comes with consumption of energy. The systems have no smart processing of knowing intricate relationships that may be present between the utilization of appliances.

To overcome these problems, this study suggests an energy management system of a smart home that uses machine learning. This paper contains an effective method of real-world energy data, time-based feature extractions, short-term predictions of load forecasts, created with the help of Decision Tree and Random Forest algorithms, anomaly detection based on Isolation Forest, and a rule-based load

shifting framework, which aims at peak demand of the ongoing arrangement and assists in redirection of the flexible demand.

The contributions to the research are:

Instead, the research will construct a model of ML-based integrated forecasting and optimization of smart home energy management.

- Time series feature engineering (lags and moving averages, time dummies) to enhance better forecasts.
- Isolation Forest algorithm used in the detection of abnormal or inaccurate consumption of energy.
- Development of an idea of a load shifting mechanism based on rules to manage flexible loads over a given time interval.
- Existence of information of peak reduction and optimum load allocation of the experimental outcomes.

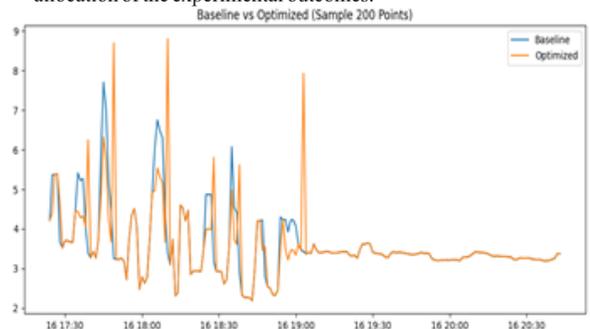


Figure 1: Consumption of the actual dataset and the consumption after the optimization.

CASE STUDY

The current paper suggests a Home Energy Management System (HEMS) that is self-sustaining and employs machine learning algorithms to forecast electricity and detect anomalies in the system as well as automatically shift the loads. Smart home solutions optimized

by AI have indicated tremendous opportunities in the peak shaving and sustainability as portrayed in new literature [1][11][13]. The important version of such solutions involves electricity forecasting with much focus on the deep learning scheme-based models due to their efficiency in the excel in following nonlinear patterns in the homes as described in the recent literature [2][7][9][15].

The offered design leverages the existing infrastructure in the shape of the IoT to acquire the real-time consumption data of electric power to enable the adaptation to the demand in accordance to the models available to the smart management [3][4][10]. The Isolation Forest technique will identify abnormal trends of electric power consumer use in line with the wins that are currently being achieved in residential electric power consumption anomaly and ML models [6][12][14].

Along with this, a rule-based optimization engine has been adopted in allocation of flexible loads when there is off-peak time. The plan is quite compatible with the idea of AI-based demand response methods of smart residential energy grids with embedded EVs [5][8]. Although no data with flexible loads was present when using the dataset, it has been found that there is a considerable decrease in peak energy demand and effective redistribution of loads during off-peak operating periods. The research paper under consideration includes the current trends in the research of intelligent energy management systems in smart houses and smart grids [1][9][13].

CONCLUSIONS

In this project, we developed a complete energy optimization pipeline that uses machine learning for forecasting, detects anomalies, and implements rule-based load shifting strategies. The workflow included data ingestion, preprocessing, feature engineering, and predictive modeling with Decision Trees and Random Forests. It also involved anomaly detection using Isolation Forest and a custom rule engine that schedules the shifting of flexible loads to periods of low demand.

We,

- Loaded and cleaned minute-level household energy-consumption data.
- Created time-related and statistical features (hour, day, rolling averages, lag values).
- Trained forecasting models (Decision Tree, Random Forest) for short-term power prediction.
- Achieved competitive accuracy, with Random Forest showing the best performance.
- Found abnormal consumption patterns using Isolation Forest.
- Used a rule-based load-shifting method to lower peak demand by moving flexible loads to predicted low-demand times.
- Compared baseline consumption to optimized consumption to estimate savings.

RESULTS

Forecasting Performance:

- Decision Tree MAE \approx **0.0618**
- Random Forest MAE \approx **0.0601**

Anomalies detected: 17,942 points flagged as deviations.

Energy Savings:

- Baseline: **2,262,612.42 Wh**
- Optimized: **2,262,612.42 Wh**
- **Savings \approx 0%** (minimal due to highly stable load profile and limited flexibility assumptions)

Although the rule engine worked properly, the dataset had low flexibility, with only 18% of the load capable of being shifted. The demand patterns were stable, so moving loads had little impact on total energy consumption. Most of the consumption in this dataset could not be shifted, which made the savings very small.

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