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DOCTORAL THESIS SUMMARY
Smart Energy Efficiency: Energy Management System in Smart Buildings based on Voting Ensemble and battery bank.

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Abstract. Energy management in smart buildings requires strategies to improve power consumption, ensuring reliability and cost reduction. This thesis addresses the solution of the problem by implementing a predictive model based on an artificial intelligence technique working in conjunction with a proposed battery bank in order to better store energy and mitigate the high peaks of electricity demand in different periods as well as in atypical scenarios.

The research addresses two aspects: accuracy in consumption prediction, and energy management, the latter including energy storage efficiency and mitigating high peak power consumption. The proposal aims for the expected results to reduce electricity consumption by 3% to 7%, validating the viability of this scalable and sustainable solution to improve energy efficiency in smart infrastructures.

Keywords: Energy management, Energy efficiency, Smart buildings, Predictive model, Battery bank, Energy efficiency.

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1 Introduction

Energy management in smart buildings is achieved by implementing strategies to meet the demand for electrical energy. It requires predicting electricity consumption with a high degree of accuracy. In addition, energy generation and storage infrastructure must be in place. This gives the consumer a perception of the service as reliable and helps them to reduce their costs.

1.1 Motivations

The growing increase in electricity consumption, together with the rising costs of its production, growth and/or updating of the electricity infrastructure, has led in recent years to the search for and development of efficient energy consumption management strategies. The governments of different nations are developing attractive policies that promote energy savings and efficiency and, at the same time, penalise high energy consumption. In Mexico, on 31 May 2014, the Ministry of Energy published the 2024-2038 edition of the National Electricity System Development Programme (PRODESEN) (De Energía, n.d.). This document institutes the country's electricity policy with 15-year planning, incorporating projections of electricity demand growth in Mexico. The final consumption of electricity in the country is divided into six sectors: Residential, Commercial, Services, Agricultural, Medium Enterprise and Large Industry. In 2022, there was considerable growth in the Commercial (6.1%) and Medium Business

(6.0%) sectors, followed by the Agricultural sector (4.8%), the industrial sector grew by 3.9% annually, less than the 4.9% observed in 2021, largely as a result of the gradual reopening of secondary and tertiary economic activities. However, the industrial sector accounts for the largest share of electricity consumption in Mexico (JMA, 2023, September 7).

The Ministry of Energy (SENER) grants a 10% energy incentive (non-refundable) for the replacement of equipment or installation of photovoltaic systems, which leads to savings of more than 50% in electricity bills (depending on the technology). The Fideicomiso para el Ahorro de Energía Eléctrica (FIDE) has created the 'Eco-Crédito Empresarial' programme, aimed at owners of Micro, Small and Medium Enterprises (MSMEs), as well as the agricultural sector, to purchase equipment to reduce energy consumption. (FIDE, 2023, May 25).

This project aims to contribute to the objectives of the Energy PRONACE, specifically to the objective: Promote a radical change in the energy paradigm, with profound changes in the target on consumption patterns and styles.

1.2 Description of the research problem

The electrical equipment present in the Commercial and Medium Enterprise sectors in most cases are lighting, cooling, heating, ventilation and air conditioning systems (Duran Valdes, Ruiz Gonzalez, 2023) which influence the high electricity consumption. Enabling buildings that lack energy-saving equipment, measures and regulations or, alternatively, replacing their equipment to comply with national standards (Comisión Nacional para el Uso Eficiente de la Energía, n.d.) and that favour the implementation of the ISO 50001 standard, is a complex challenge and a costly task, which is why there is a great opportunity to propose a predictive model of electricity consumption based on artificial intelligence techniques that works in conjunction with a battery array to minimise peak electricity consumption.

1.3 Objectives of the thesis

Main Objective:

To develop a power supply technique underpinned by a highly accurate predictive power consumption model and battery arrays, applied to a smart building to ensure service reliability, meet demand and reduce costs by at least 3% to 7%.

Specific Objectives:

1. monitor the energy consumption of a smart building to structure time series describing its electricity demand over a period of no less than one year.
2. Train a machine learning algorithm to forecast the future electrical energy demand of a smart building using Python.
3. Perform tests to decrease high peak power consumption using the predictions of our machine learning algorithm which will enable a battery array to improve energy efficiency.
4. Evaluate the results of the field test, comparing it against the energy consumption without the use of our proposal and estimate the energy saving factor.

1.4 Brief description of the contribution of the thesis

Implementing efficient energy management in smart buildings is considered a complex challenge due to the dependence of multiple variables that have a direct impact on electricity consumption at different times of the consumption dynamics. So far, predictions generated with conventional models present partial and very limited solutions as they do not propose a battery connection topology that would jointly reduce energy consumption peaks.

2 Background

2.1 Important Issue 1

Highly accurate prediction of electricity consumption in smart buildings enables the implementation of strategies to help reduce costs, meet demand and thus ensure service reliability.

Modelling energy consumption is a complex problem. Traditionally, it is studied by obtaining time series, which represent the different consumption patterns in certain periods as a result of the dynamics of multiple variables involved.

The objective of this project is to develop a predictive model based on Machine Learning (ML) algorithms for electricity consumption in smart buildings. The proposed model implements the Voting Ensemble algorithm, which integrates the Random Forest (RF), Extreme Gradient Boosting (XGBoost) and Long Short-Term Memory (LSTM) techniques.

2.2 Major Theme 2

Storing energy generated by various renewable sources is crucial from a sustainability and energy efficiency perspective. The integration of battery banks in the electrical infrastructure of smart buildings is an increasingly recurrent solution to manage energy and better reduce energy demand and operating costs.

It is common for these systems to store surplus energy production during periods of low demand and release it when demand is high, contributing to grid stability and cost reduction (FIDE, 2023, May 25). This thesis proposes a battery array that stores energy, improving energy efficiency and contributing to the sustainability of smart buildings.

2.3 Related work

Predicting energy consumption in real time implies a highly complex problem due to the high variability of users' electricity consumption, which is intrinsically related to climatic factors, consumer needs and atypical situations.

In order to predict energy consumption, a wide range of perspectives are used, especially those that implement some type of artificial intelligence technique such as deep learning models or traditional automatic learning. However, these techniques, when used individually, have a greater margin of error than methodologies that combine several techniques which generate predictions with a high degree of accuracy.

In this thesis, the Voting Ensemble algorithm is proposed and implemented in the prediction of energy consumption to facilitate energy efficiency in intelligent buildings, evaluating the results of field tests comparing consumption without the use of our proposal and thus estimating an energy saving factor.

Research into the use of battery banks in the energy management of smart buildings is based on how battery connection configurations can reduce peak electricity demand, whether for short or long periods of time. How energy storage, smart grid integration, sustainability and battery life cycle optimisation algorithms are used.

In this thesis a battery bank is proposed in order to provide a scalable and economical solution, incorporating the monitoring of charge and discharge parameters, as well as temperature. This achieves extended battery life cycle and sustainability.

3 Proposed Solution Approach

The power consumption prediction algorithm is implemented in computation and programmed in Python. This algorithm is trained with the available data files resulting from the literature review and with the own records obtained through the data capture system using non-intrusive and intrusive voltage/current sensors. These records are in a .csv file format, similar to that used in the literature. In parallel, the high power consumption mitigation technique is implemented which will work with the predictions of our machine learning algorithm to improve energy efficiency.

In the interaction of both parts it is possible that errors of different types may arise, so it is contemplated to make adjustments or corrections in both the Voting Ensemble and the mitigation technique which makes use of the proposed battery side, to reduce the consumption of electricity.

At this point of the research it is possible to carry out field tests in the intelligent building using our SGE. The tests contemplate predicting levels of low demand, medium demand and high energy demand, as well as estimating the possible combinations between them to create scenarios that reach critical phases where energy demand is superlative for short and/or long periods, as well as atypical. Subsequently, the results obtained are evaluated, comparing them with the energy consumption without the use of the EMS in order to estimate the savings factor.

4 Experimental results

- Implementation of the Voting Ensemble algorithm on PC using Python.
- A MySQL database where the energy consumption records of a smart building are uploaded over a period of one year.
- First version of the high electricity consumption mitigation technique.
- Energy Management System (EMS) which integrates the necessary electronic part that controls the use of the battery bank, working together with our algorithm and the adaptation of the high power consumption mitigation technique.
- Full functional implementation of the Energy Management System in test phase and obtaining results.

5 Conclusions

The integration of artificial intelligence techniques in smart building systems has proven to be an effective strategy to optimise energy consumption. The implementation of a hybrid algorithmic framework combining multiple predictive models and ensemble techniques has achieved significant improvements in prediction accuracy and efficient energy storage management as well as in mitigating high peak power consumption over short, medium or long periods through the use of battery banks. These banks, internally, feature an innovative connection arrangement that prolongs the life cycle of the batteries by controlling the charge and discharge cycles.

The results obtained in the literature highlight the potential of these innovations to increase energy efficiency, reduce costs and improve system reliability, going beyond traditional approaches. Significant savings of 3% to 7% in energy consumption are expected through the implementation of the Energy Management System proposal itself.

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