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Building load management using cluster and statistical analyses

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ABSTRACT

Building energy management systems has become very significant to monitor and control loads, mainly due to the tariff and demand side management programs. This technology allows the performance of key energy management functions such as organizing energy use data, identifying energy consumption anomalies, managing energy costs, and automating demand response strategies. Load management techniques allow the energy manager to reshape the building load curve and reduce the peak demand. The synthesis of load shapes is one of the most critical steps in evaluating load management programs. The energy manager should be able to recognize the typical shape of the daily load curve in order to manage the energy use. This paper presents a methodology to perform the synthesis of load shapes. On that purpose, it is essential to identify typical daily load curves as well as the best way to find their representative model. By getting to know the typical load curves of a building, an energy manager may predict load and peak demands. Results have shown the efficiency of clustering technology in the analysis of time series data such as load curves. Using historical data, the total accumulated energy in the end of the day as well as the maximum peak demand of the day may be predicted.

1. Introduction

Load management programs have become increasingly valuable as a result of electricity deregulation and volatile energy prices. The capacity to manage loads, by load reduction or load shifting and minimal interference in the operations of a company may be quite valuable for the energy user [1,2]. The load modelling quality strongly influences the energy management [1–6].

In case the analysis and operation planning for energy and demand in a building is necessary, load modelling becomes very important, as long as it allows the energy manager to predict load shapes in different days. The quality of load modelling influences the system expansion plan and the energy management.

Typically, each building can present different daily load curves and their shapes strongly influence the energy cost. A manager mainly uses expertise and experience in order to better analyse the behavior of the load curve. A load curve is a time series representative of the Building Energy Usage (BEU). A building may or may not work in the same way within a week and the load curve will reflect such behavior. The energy manager should recognize, on historical basis, the load growth during the day and subsequently compare it with the load tendency to allow properly decision-taking actions.

The investigation of load curves is very useful to understand the behavior of BEU. Such analyses can be used to determine the application of special prices proposed by Energy Companies in order to try to have a global consumption that behaves as uniformly as possible.

As observed in literature, cluster techniques are applicable in a large set of curve analyses, so that experts assess a small number of classes instead of a whole set.

This paper presents a methodology that will permit the energy manager to obtain information from measured data and take more appropriate decisions. From such methodology, the energy manager will be able to predict energy and peak power demand besides taking decisions regarding energy management.

A case study has been used in order to show the methodology's capacity. The dataset considered herein comprise a set of several daily load curves corresponding to electric power consumption of a large Brazilian hospital. Hospitals are generally intensive users of energy, both electrical and thermal; furthermore the energy usage in such buildings is distinctive, when compared to other types of commercial buildings, since they comprise typical operating schedules for different functional facilities such as restaurants, laundry, and medical test central office in addition to the variability of occupancy levels throughout the year. These will lead to

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different operating schedules of building service systems and therefore to different energy consumption situations in hospital buildings, when compared to other types of commercial buildings.

2. Literature survey

There are many interesting methodologies projected to forecast power demand in power systems. Load forecasts are usually used in utilities to predict the load for the next day, a week, forthcoming months and even some years ahead. Short-term load forecasts (STLF) usually aim at predicting load up to one week ahead. A very short-term load forecast is frequently used to predict in time-horizon of less than 24 h since it is an important tool in daily operations of utility systems. STLF usually aims at providing the daily, hourly, or half-hourly load and the peak load regardless even smaller time intervals [8]. It is very important on the subject of operations of power systems both in economical and security terms. Load series are generally complex and the load at a given time depends on loads from undetermined number of past hours [9]. An automated energy prediction system is often built on mathematical prediction model consisting of several parameters. The model parameters are estimated using existing data that typically include, for system forecasting, energy demand or consumption and temperature [8].

The use of time series analysis techniques is widespread due to the fact that the history of energy use can be represented by a time series. Time series of loads themselves generally have three seasonal cycles: a daily cycle, a weekly cycle, and a yearly seasonal cycle. The load curve of weekend days, normally different from that of working days, can affect load curves of Mondays and Fridays, therefore the former ones are often separately treated. Models as ARIMA, AR, ARMAX have been used in forecasting; ARMA and AR models work under the assumption that the current value is a linear combination of the previous ones. ARIMA and ARMAX models can handle the changes in a dynamic process, but require the inference of many parameters [10].

Dhar et al. used a Fourier series model to predict the energy demand in an institutional building. When using this model, the energy is considered periodic [11]. The designated time-horizon and data availability determine the input variables. Univariate models are standard for short term forecasts for up to 6 h ahead [8].

Intelligent methods, such as neural networks, fuzzy logic, and expert systems, have started to be applied to STLF [12–21]. Dillon et al. used adaptive pattern recognition and self-organizing techniques for short term load forecasting. Later, he used an adaptive neural network for short term load forecasting [12,13]. The availability of large amounts of historical load and weather data at power utilities has encouraged the use of database machine learning modelling methods such as neural networks [20]. Nevertheless neural networks bear a number of limitations, including difficulty in determining optimum network topology and training parameters [20]. Hippert presents a remarkable review of neural network for short-term load forecasting. Karatasou et al. [20], who presents a modelling for BEU forecast using artificial neural networks, points towards some environmental variables such as ambient temperature and solar radiation as important variables while others, such as wind velocity or humidity can be omitted. Mandal uses Euclidean norm with weighted factors to assess the similarity between the estimated day and the previously investigated days [16]. According to similar day approach, load curve is forecast by using information of the days that are similar to the weather condition of the forecast day. Mandal uses information from one year previous to the involved day and 65 days around it. He uses a neural network to predict the load curve in power systems.

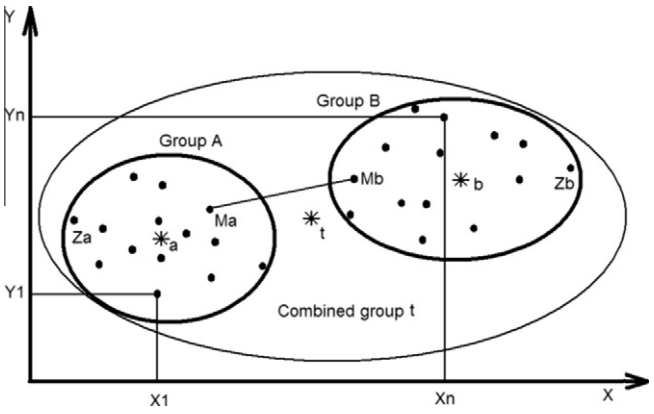

Fig. 1. Similarities measurements.

Regarding the hospital building case study presented in this paper, most equipment usage has no strong correlation with the external temperature, since only a few wards of the hospital possess air conditioning system.

3. The proposed methodology

The methodology herein proposed is divided into four steps. The first one is responsible for analysing the historical load curves and detecting the necessary number of typical load curves to represent the building energy use by means of cluster analysis. In the second step, typical load curves are mathematically modeled. The third one predicts the total accumulated energy in the end of every day. And finally the fourth part predicts the maximum daily demand. Some of the techniques applied are presented below.

The methodology allows historical load data analyses and provides information on them. Firstly, data have to be analysed using classification method to check the necessary number of typical load curves to represent the building behavior. Afterwards, the typical curves are built and modeled. Based on the first hours of the day, the algorithm can forecast the accumulated energy for that day. Based on this value, one can predict the peak power demand for that day. Such methodology has already been used in a large hospital and the results were presented.

4. Classification using cluster analysis

Classification is a systematic arrangement of objects (of any type) into groups or categories according to established criteria [22,23]. The cluster analysis method is used to classify energy consumption, load curves and consumers [20–25].

Cluster analysis is the name given to a group of multivariate techniques whose primary purpose is to identify similar entities from the characteristics they possess. The essence of clustering approaches is the classification according to natural relationships. As such, the primary value of cluster analysis lies in data pre-classification, as suggested by the natural grouping of information itself [22,23]. Cluster analysis has been used to classify time series data in groups.

The nature of cluster analysis is illustrated by means of a graphical presentation for a bivariate example, Fig. 1. The graphic shows two characteristics of the figures. Each point presents one analysed object that has a value for *X* characteristic and another for *Y* characteristic. In problems with more than three dimensions, it is not possible to illustrate the classification by graphical representation. Provided that data are composed of load curves, the characteristic