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Application of the autocorrelation function to working-day calculation in power management

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ABSTRACT

Strategic planning of electricity generation and dispatch is crucial to providing a stable power supply for industrial users. Among the factors involved in such planning, the users' working and non-working days have an especially significant impact on peak and off-peak power distribution. A case in point is the incentive plan for customers' scheduled load curtailment program that the power company often adopts to avoid power outage or restrictions at peak times. In the process of negotiating with prospective industrial partners, the power company needs to make suggestions on the dates and methods of load curtailment, not only based on the nature of the users' operations, but specifically in terms of the number of working days per week. Using data mining techniques to perform working-day calculation, therefore, becomes a key step in power reduction initiatives. This study adopted the autocorrelation function (ACF) to conduct rapid and automatic detection of power consumption cycles, and then employed the regression analysis to predict power demand trends, thereby automatically estimating the working days in each operating cycle. Applied to the empirical data of 200 industrial electricity users, the proposed method proved to be highly accurate in working-day estimates, which could be extracted quickly for the reference of the power company.

1. Introduction

Ever-improving living standards and rapid industrial development have resulted in increased average electric power consumption. In addition to the escalating demand for industrial power, there is usually a steep surge of household demand in the summer. Consequently, the power company often suspends power supply or imposes restrictions during peak demand periods, which could have negative impact on residential, commercial, and industrial users alike. To maintain a stable power supply, an effective power management system needs to conduct electrical load analysis so that it could take measures corresponding to the unique needs of different industries.

A prevalent example of such energy-saving measures is the incentive plan for customers' scheduled load curtailment program during high load periods. By offering discount incentives, the program prompts users to shift operations that are automated or can be temporarily discontinued to off-peak demand time, thereby considerably reducing peak power load. When contacting prospective industrial partners, the power company must first understand the nature of the operation, and then propose the dates and ways of load curtailment in terms of working days per week. Take the incentive, "Minus Eight Days Per Month", for example. The manufacturer is required to choose eight days per month (agreed upon by both sides), ranging from Monday to Friday (excluding peak days), to reduce power consumption from 10:00 a.m. to 5:00 p.m., i.e., in a total of seven hours per day. To help manufacturers select the eight days properly, the power company needs to identify electricity usage patterns before recommending working-day adjustments. Given the large number of industrial users in Taiwan, performing working-day calculation with data mining techniques is an important initial step in electric energy saving initiatives.

This study proposed a novel method to estimate electricity users' working days with great precision. Firstly, the autocorrelation function (ACF) was used to perform rapid and automatic work-cycle correlation analysis. Secondly, the regression analysis was adopted to capture power demand trends, so as to determine the users' operating cycles. Finally, the mode was further used to determine the working days of the users in each cycle. In an empirical study conducted on the data of approximately 200 industrial electricity users, the screening method was shown to be effective in facilitating work-cycle estimation and working-day calculation.

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The proposed method will thus enable the power company to derive a user's consumption pattern quickly, and then, based on the pattern, make more accurate demand management decisions that optimize power dispatch.

2. Literature review

This study adopted the Autocorrelation function to find cycle correlation in electricity users' consumption data, and then explored the operation and non-operation days in each cycle, in order to provide reference for the power company in power management and rate adjustments.

2.1. Autocorrelation function

The purpose and nature of electricity usage vary greatly from one user to another. The wide range of variations created a problem for work-cycle estimation. To solve this problem, this study conducted research into ACF applications in many other fields. In current financial market studies, researchers used the ACF to analyze fluctuations of stocks' values, and built dynamic models to estimate changes at different times in the financial market [1]. The artificial neural network can also be combined with the ACF. Using actual parameters, the combination was confirmed to enhance accuracy of estimation results [2,3]. Additionally, the ACF was applied to forecast the fluctuations of oil prices. With international crude oil prices as sample data, ACF was used to identify price cycles and predict, with improved accuracy, the time of the rise and fall of oil prices [4]. Given the vast information available online, the iGeneration (i.e., Internet Generation) is faced with the dramatic increase in the demand of network traffic. The ACF was thus employed to estimate the constant online traffic in each period, reduce cache traffic, and avoid congestion [5]. Furthermore, the ACF has been used to analyze natural phenomena, such as time series of sea-level change [6]. Moreover, ACF was applied to earthquake data collected at different observation stations to determine if they have long-term correlation values [7]. The ACF was also adopted in fuzzy system models to select input variables that predict electricity demand [8]. Other scholars used the ACF in conjunction with neural networks to attain higher precision in electricity load prediction [9]. Despite the wide-ranging ACF applications in electricity demand forecasting, the algorithm has not been used to detect electricity users' operation cycles.

2.2. Power management

Electric power is an indispensable part of daily life. Economic development is often associated with, among other things, a country's increased electricity demands. How to construct a power management system that helps to maintain reliable and sufficient power supply, especially for the industrial and economic sectors, has been a growing concern for many countries [10,11]. Power load management can be conducted in various ways, with a view to reducing power demand during peak usage times and improving the load factor of the power system. For instance, the regression analysis was adopted to calculate time-of-use rates that reflect the cost of power supply [12]. Further, the regression analysis was used to make medium- and long-term power load estimates, which helped to establish multi-parameter regression prediction models that effectively took into account economic factors affecting power consumption [13]. Short-, medium- and long-term projection of power load demand could also be made by applying the regression analysis, in combination with the adaptive network-based fuzzy inference system (ANFIS). Annual electricity load, for instance, has been forecasted this way with higher accuracy [14].

While power management systems now boast effective ways to monitor and control domestic power consumption in Taiwan, the designs tend to be rather complicated or somewhat incomplete, and thus not very practical. To solve the problem, a power management architecture was constructed based on the dispatching algorithm for the embedded system [15]. In terms of power maintenance, the Taiwan Power Company (Taipower) employed the fuzzy analytical hierarchy process to test and repair equipment. The impact of power failure was then taken as reference for operations scheduling [16]. Moreover, with power load forecasting lying at the core of power management, the wavelet transform was integrated with the artificial neural network to perform short-term load prediction [17].

2.3. Data mining

The digital age has witnessed the proliferation of data, none the least of which are the administrative and management records in all fields. Data mining and statistical analysis have been combined to explore correlations in medical records, the results of which serve as reference for disease prevention and treatment, as well as health management [18,19]. Analysis of customer relationships could help a business to improve customer service by having a better understanding of customers' preferences and needs [20]. For instance, textile manufacturers conducted an attribute analysis on the transaction time, purchase frequency, currency values, and customer relationships. The cluster analysis of attributes yielded valuable information that helped to devise marketing strategies targeting specific customers [21]. In view of the tremendous demand of electric power at present, greater interest has been shown in the prospect of generating electricity based on customer classification. Via cluster analysis, electricity customers were segmented based on common attributes such as region, population, and amount of power consumption [22]. Within each customer group, customers were further characterized by voltage level, residential and non-residential area, and so on. The K-Means cluster analysis was then applied to obtain the best results [23]. In power management, data mining techniques have also been widely applied to electric power system control and cost reduction [24]. To satisfy present-day electricity demands, power consumption cycles were identified to forecast demand: first, by adopting dynamic optimization methods to predict the curve of daily residential power load, and then, by making demand estimates based on the daily consumption cycle from the peak to off-peak load periods [25,26]. Finally, to conserve energy and electricity, green architecture is all the rage today. Data mining techniques have been used to construct an energy consumption prediction system to help optimize structural design [27,28].

In sum, as the literature review above indicates, power load management currently concentrates on enhancing hardware efficiency and developing the optimal power dispatch approaches, both of which are nevertheless passive management methods. To have higher power efficiency, the power company needs to take the initiative and promote scheduled power curtailment by offering discount incentives for peak power load reduction. While negotiating with prospective industrial partners, the power company has to understand their power consumption patterns and operation cycles to achieve best results. Data mining techniques have been widely applied to cluster analysis, which, coupled with the autocorrelation function, could detect operation cycles quickly. Therefore, this study used the demarcation points identified by the autocorrelation function to estimate the industrial electricity users' working days per week. The information will serve to facilitate negotiations between the electric power company and industrial partners in load curtailment programs.