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A review of the decomposition methodology for extracting and identifying the fluctuation characteristics in electricity demand forecasting

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ABSTRACT

Electricity consumption data is regarded as nonlinear, non-stationary series, and is often made up by a superposition of several distinct frequencies. Thus most of the conventional approaches currently employed for the modeling and forecasting involve great complexity and uncertainty. Recently, fluctuation characteristic analysis has increasingly become essential step in the application of electricity demand forecasting, yet the implementation of this analysis is an inherently difficult task. To obtain reasonable accuracy and stability in the modeling, there has been the tendency to accommodate multidimensional attributes of the consumption demands with decomposition based approach in terms of more advanced and hybrid form. And the decomposition can be achieved through utilization of two different procedures, namely component model-based and frequency domain analysis-based decomposition. Consequently, a comprehensive review and summarization of decomposition based approach for the prediction is conducted in this paper. More specifically, the issues of demand forecasting classification, the dependency between the electricity demand and external indicators, features of various decomposition approach, as well as the unique fluctuation characteristic of electricity demand at different time scales are discussed. In addition, future research directions of the decomposition based prediction approach are outlined.

1. Introduction

Demand side management (DSM) is a central aspect of managing the modern electric power systems. The primary content of DSM involves some different aspects such as load control and management (LCM) [1,2], automatic meter reading (AMR) [3,4], and so on. As an indispensable part of DSM, modeling and predicting electricity demand have been the subject of long-lasting topic. The nonlinear, multi-dimensional nature of the electricity demand poses a number of challenges for the researcher and electric power planner. Moreover, many unpredictable factors exist in electricity demand modeling [5–7], including external indicators selection, the assumption of data distribution, estimates of the model parameters, etc. From a data mining perspective, a critical mission of electricity demand forecasting is to reduce those uncertainties. Thus, to measure the uncertainties and increase the effectiveness of demand forecasting, various kind of approaches have been proposed and implemented in the real applications, involving diverse type of background (i.e. residential [8,9], industrial [10,11], total electricity demand [12,13], etc.) and different prediction horizons (short term [14,15], medium term [16–18] and long term [19,20], etc).

Electricity demand forecasting procedure might consists of processes choosing appropriate model, selecting affecting variables, and evaluating prediction accuracy, all of which are operated based on identification of the fluctuation characteristic. Due to the significant difference and complexity in identifying the fluctuation patterns of various consumption demands, there has been a tendency to accommodate such conditions with models in terms of more advanced form (i.e. improved versions of conventional methods [21], hybrid methods [22,23], combined methods [24,25]). Over the past decades, researchers have considered vast numbers of approaches (i.e. time series models [26–28], statistical regression models [29–31], and machine learning method [32–34]) to investigate the mechanism of electricity demand variation at different time period and space scales. The common motivation to employ these methodologies is that they may excellently characterize the consumption demand on some specific scales by adopting the relevant historical data. However, most of the existing methodologies to fulfill the modeling tasks rely on some assumptions regarding time series properties of the data, such as the stability of the demand fluctuation, time series correlation, and so on.

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To some extent, the requirement of electric power planning to obtain both desired flexibility (by altering the model structure to suit the actual situation) and information processing capacity (precise estimation of the model structure under the initial assumption) makes the forecasting procedure difficult to accomplish.

More recently, the above problem has gained greater prominence due to the fast advance in sensor technology, computer networks technology, as well as the development in smart grid technologies. One of the primary task that must be completed before the establishment of simulation model for the prediction is to take into consideration of the inherent characteristics of the consumption data. To handle the increasingly complex consumption data, targeted method should be taken to provide more effective way for reducing the dimension of consumption data and capturing those changes in intrinsic pattern of the consumption fluctuation. For this reason, decomposition based methodologies have gained more and more popularity in electricity demand modeling and forecasting. At present, numerous publications have concentrated on the application of decomposition approach in the power system analysis covering a wide range of topics: demand forecasting [35], co-feature analysis [36], load dispatching [37], component estimation [38], energy-related gas emission [39], energy efficiency trend monitoring [40–42], and so on. From current trend of predicting the electricity demand, although many progress have been made in recognizing the variation rule of the demand, we can see that, the conventional method is far from comprehensive and mature. Moreover, there is lack of meticulous review concerning the feature of the decomposition approaches employed in forecasting the electricity demand. In this respect, there is an urgent need to provide a comprehensive and updated insight on the decomposition methodology, by covering the aspects of classification, application area, and superiority.

This paper is organized as follows: Section 2 classifies the electricity demand forecasting from a time scale perspective and briefly reviews the relevant example applications from the literature. In Section 3, component model-based decomposition approach proposed in the literature are classified and reviewed. Its features and limits are also discussed in this section. In Section 4, frequency domain analysis-based decomposition approach proposed in the literature are classified and reviewed. This section also discusses some of the features and limits. Section 5 draws conclusions.

2. Overview of the feature of energy demand forecasting over different time scales

Over the past decades, a vast amount of approaches have been proposed to address the problem of complex trend analysis and forecasting of electricity demand. As noted previously, the major intuition behind these approaches is to capture the intrinsic characteristic of fluctuation pattern of the demand. Thus, it will be necessary to consider, not only a review of the presented forecasting approaches, but also a briefly summary of the basic feature of demand forecasting. There are various perspectives to classify the procedure of electricity demand forecasting. From the perspective at various time-length scales (represent different fluctuation characteristic), electricity demand forecasting can be classified into at least three subgroups: short term, medium and long term forecast. Despite their similarity, these time scales forecasting differ in several important respects.

2.1. Short-term electricity demand forecasting

There has been a tremendous amount of research to be studied on the field of short term demand forecasting, where the recognition of fluctuation pattern also has long been a central concern of the researchers. The object and main contents of short term demand forecasting are discussed from many aspects, most of the existing literatures mainly focused on the prediction of hourly, daily demand. Typically, the research is carried out in an attempt to analyze and evaluate the influence of external factors on the demand fluctuation. Among various kinds of factors, meteorological variables are regarded as the fundamental elements of short electricity demand forecasting. Rahman and Bhatnagar [14] investigated the applicability of expert systems adopting meteorological variables, namely relative humidity, drybulb and wetbulb temperatures to the short term load forecasting. Ren et al. [43] compared the performance of artificial neural network (ANN) and support vector regression (SVR) based hybrid approaches for the short term wind speed forecasting, the results suggested that the Empirical mode decomposition (EMD) enhance the accuracy of SVR based method significantly but marginally on ANN based method. Taylor and Buizza [44] investigated the use of weather ensemble predictions in electricity demand forecasting for lead times from 1 to 10 days ahead. Fan and Chen [45] established a novel method which adopts a non-stationary model with two-stage adaptive hybrid architecture: day type, humidity, and wind speed are only used in the first stage, temperature data is used for the SVMs in the second stage. Goude et al. [46] developed a semiparametric approach based on generalized additive models theory to estimate the relationship between load and the explanatory variables: temperatures, calendar variables, etc.

Apart from the impact of meteorological variable, there are many factors can be attributed to the fluctuation of electricity demand, such as calendar inputs, economic development, and so on. Engle et al. [47] investigated the application of bivariate models incorporating deterministic influences such as holidays, stochastic influences to the hourly peak electricity demand prediction. The load curves of holidays are dissimilar to those of normal weekdays, Song et al. [48] employed the concept of fuzzy regression analysis in the short-term load forecasting problem. Based on weather and calendar inputs, Pielow et al. [49] specified and estimated the state-level models of short-term electricity demand in the United States. López et al. [50] considered the influence of meteorological factor, economic growth on the daily and intra-daily load of the Spanish electricity market. Based on the fact that working days and weekends have very different electricity demand patterns, Aneiros et al. [51] considered different scenarios for the residual demand forecasting. To respond to sudden changes in the economy, Lin and Chou [52] proposed a novel, economy-reflecting, short-term load forecasting approach based on theories of moving average line of stock index and machine learning.

Fluctuation pattern analysis in short term demand forecasting, on the other hand, can be categorized as modeling the inherent characteristics (to some extent, it is hidden within original series) of the demand series or measuring the functional dependency between the inherent characteristic and external factors. Peng et al. [53] investigated the application of load decomposition using digital filters with different passband frequencies to one-week ahead load forecasting. Based on neural weather compensation, Chow and Leung [54] presented a nonlinear generalization of Box and Jenkins approach to the non-stationary time-series prediction. To capture the seasonality of the online electricity demand, Taylor [55] adopted the Holt-Winters exponential smoothing formulation. Considering the intermittent and uncertain characteristic of the electrical load, Kavousi-Fard et al. [56] proposed a hybrid prediction algorithm comprised of support vector regression and modified firefly algorithm to provide the short term electrical load forecast. Quan et al. [57] developed a framework for probabilistic forecasting of electricity load demands which allows the analyst to construct PIs (prediction intervals) for uncertainty quantification. Kouhi et al. [58] introduced a robust forecast method based on chaotic feature selection algorithm and hybrid neuro-evolutionary algorithm. To improve the effectiveness of processing the nonlinear signal with time dependent behavior, Kouhi and Keynia [59] utilized a new hybrid forecast strategy based on cascaded neural network. To overcome the shortage of conventional method in modeling anomalous load, Arora and Taylor [60] adopted a rule-based approach which