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Discovering residential electricity consumption patterns through smart-meter data mining: A case study from China

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ABSTRACT

With the increasing penetration of information and communication technologies (ICTs) in energy systems, traditional energy systems are being digitized. Advanced analysis of the energy production and consumption data and data-driven decision support can be combined to promote the formation and development of smart energy systems. Smart grids are a specific application of smart energy systems. Different electricity consumption patterns of residential users can be discovered and extracted by clustering analysis of the electricity consumption data collected by smart meters and other data acquisition terminals in a smart grid. This research explores daily electricity consumption patterns of low-voltage residential users in China. The service architecture of smart power use and the structure of electric energy data acquisition system of the State Grid Corporation of China (SGCC) are introduced and a process model for mining daily electricity consumption data is presented. The analysis is based on the fuzzy c-means (FCM) clustering method and a fuzzy cluster validity index (PBMF). A case study of Kunshan City, Jiangsu Province, China is presented, using the daily electricity consumption data of 1312 low-voltage users within a month.

1. Introduction

Energy systems are increasingly adopting digital information and communication technologies (ICTs), such that large amounts of energy production and consumption data are generated, collected, and stored (Zhou et al., 2016b). This provides the opportunity to implement big-data mining and analysis. Decision support based on advanced data analysis is playing an increasingly important role in the formation, operation, and management of smart energy systems (Zhou et al., 2016a).

Smart grids are a specific application of smart energy systems (Lund et al., 2012). Energy flow, information flow, and business process flow are integrated into smart grids (Zhang et al., 2009; Zhou et al., 2014b). The "smart" of a smart grid means the realization of intelligence for the whole power system, from power generation to power use. Six aspects of this intelligence are smart power generation, smart power transmission, smart power distribution, smart power transformation (at the substation), smart scheduling, and smart power use. As one of the important aspects of smart grids, smart power use aims at the realization of flexible, efficient, and customized electricity consumption using advanced data acquisition equipment, data-analysis techniques, and varied interactive terminals. The energy consumption data in smart grids are mainly collected by the advanced metering infrastructure (AMI) (Bennett and Highfill, 2008). Through the smart meters deployed at the user side, large-scale electricity consumption data of residential users can be collected in real time. For a power distribution network with one million smart meters, meter reading every 15 min will yield 35.04 billion records and 2920 Tb data will be collected in one year (Dunne, 2012).

In recent years, smart grids and smart meters have been widely deployed in China. The State Grid Corporation of China (SGCC) has built the information collection system and promoted the adoption of smart meters since 2009. The electric energy data acquisition system of the SGCC is currently deployed in 27 provinces of China. By the end of 2012, more than 122 million smart meters had been installed by the SGCC, and it is expected that the cumulative number of installed smart meters will reach 340 million by the end

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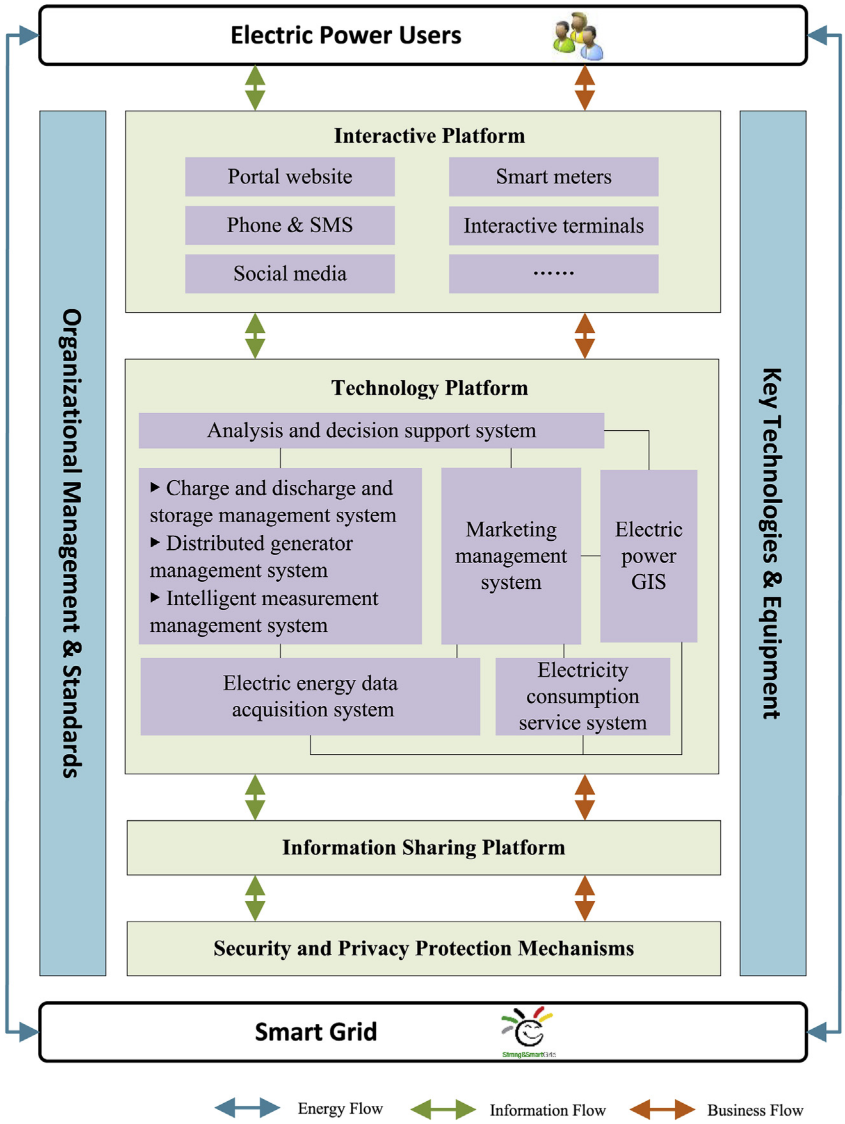

Fig. 1. Service architecture of smart power use of SGCC.

of 2015 (Xinhua, 2013).

Electricity consumption can be represented by univariate time series data. The electricity consumers that have similar electricity consumption profiles are clustered into groups or classes (for example, residential, commercial, and industrial). The data collected from smart meters and other data acquisition terminals can be mined to reveal electricity consumption patterns and user groups can be refined through clustering analysis of these data (an unsupervised learning process). Energy use profiles include minimum, maximum, average, and total energy consumption within specified time periods. Understanding the electricity consumption behavior of users is important for both power companies and users (Zhou and Yang, 2016b). For power companies, more timely, flexible, and customized marketing and demand-management strategies can be developed (He et al., 2013; Zhou and Yang, 2015). Electric power users, through real-time interaction with the power company, can adjust and optimize their electricity consumption, thus reducing household energy costs.

Different types of users have different electricity consumption patterns. Normally, the electricity consumption patterns of commercial users and residential users are significantly different, in terms of the level of instantaneous load, the time of electricity use, and the amount of electricity consumption. The electricity consumption patterns of different types of users are relatively easy to identify. However, electricity consumption patterns can vary significantly within user groups. It is difficult to discover the behavioral characteristics of particular users without advanced data analysis techniques. There has been some research on the grouping of electric power users based on electricity consumption data. Some researchers (Chicco, 2012; Ferreira et al., 2013; Granell et al., 2015; McLoughlin et al., 2015; Verdú et al., 2006) have studied the clustering methods used for load-pattern classification, and the results suggest that no one method is better than the others. Figueiredo et al. (2005) proposed a framework that includes a load profiles clustering module and a classification module, and presented a case study of low-voltage users from Portuguese. For the daily load profiles grouping of large electricity consumers, Tsekouras et al. (2007, 2008) developed a two-stage pattern recognition methodology and applied it to medium voltage users of the Greek power system. Using the hourly measured electricity use data of small customers in Finland, Räsänen et al. (2010) presented a self-organizing maps(SOM) based clustering method for electric

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