Expert Systems with Applications 36 (2009) 8799–8806

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Rough set theory with discriminant analysis in analyzing electricity loads

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ARTICLE INFO

Keywords:
Electricity loads
Rough set theory
Discriminant analysis

ABSTRACT

With the ability to deal with both numeric and nominal information, rough set theory (RST), which can express knowledge in a rule-based form, has been one of the most important techniques in data analysis. However, applications of rough set theory for analyzing electricity loads are not widely discussed. Thus, this investigation employs rough set theory to analyze electricity loads. Additionally, to reduce the time generating reducts by rough set theory, linear discriminant analysis (LDA) is used to generate a reduct for rough set model. Therefore, this study designs a hybrid discriminant analysis and rough set model (DARST) to provide decision rules representing relations in an electric load information system. In this investigation, nine condition factors and variations of electricity loads are employed to examine the feasibility of the hybrid model. Experimental results reveal that the proposed model can efficiently and accurately analyze the relation between condition variables and variations of electricity loads. Consequently, the proposed model is a promising alternative for developing an electric load information system and offers decision rules base for the utility management as well as operations staff.

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1. Introduction

Due to increased population, industrialization, and temperature, electrical consumption is rising rapidly and has became one of the most concerned problems worldwide. To help resolve this problem, accurate load analysis can provide decision makers with more information on electricity production, distribution and maintenance of reliable power systems. Goh, Ong, and Lee (1985) compared the performance of the double exponential smoothing approach, Winters' method, autoregressive integrated moving average (ARIMA) model and a proposed hybrid model for forecasting peak power demand. Simulation results showed that the hybrid model could achieve smaller forecasting error than the other approaches. Pappalexopoulos and Hestergerg (1990) designed a linear regression-based model to predict short-term loads, and claimed that the proposed model which considers temperature and holidays as variables is very robust and can achieve accurate forecasting results. A statistical decision model containing clustering techniques and linear discriminant functions was developed by Hubele and Cheng (1990) to predict short-term loads. The proposed model requires less off-line activity and can be conducted on a spreadsheet. Park, Park, and Lee (1991) presented a composite model decomposing data into three components to predict hourly electric load. Load data from a six month period were employed to examine the forecasting accuracy of the composite model; and it was reported that the proposed model is comparable with other models in the literature. Batainch, Anbuky, and Aqtash (1995) applied fuzzy logic systems which consider environmental factors to analyze hourly load demand. The fuzzy logic model is particular useful in forecasting electricity loads when the historical data are represented by linguistic terms. Novak (1995) used the radial basis function (RBF) neural networks to forecast electricity loads, and the empirical results showed that the RBF is at least 11 times faster and more reliable than the backpropagation neural networks. Lee, Lee, and Chang (1997) employed a genetic programming model to forecast long-term electric power demand, finding that the genetic programming model can provide more accurate results than the regression model. Kermanshahi (1998) used recurrent neural networks that consider twelve economic factors to forecast next 10 years load in Japan, and concluded that the recurrent neural network is suitable for long-term forecasting. Saab, Badr, and Nasr (2001) developed a hybrid model to forecast monthly electric consumption in Lebanon. Analytic results indicated that the designed hybrid model outperformed both the autoregressive approach and the ARIMA method. Hsu and Chen (2003a, 2003b) designed a hybrid gray and artificial neural network model to forecast electric load demand, and reported that the proposed model is a powerful forecasting model when the number of observations is not large. Taylor and Buizza (2003) developed a weather ensemble model to predict electricity demand with lead times from 1 to 10 days ahead. The experiment includes 51 scenarios for a weather variable and simulation results concluded that the weather ensemble model is superior to the conventional weather forecasting model in terms of forecasting accuracy. Hsu and Chen (2003a, 2003b) applied a backpropagation neural network to predict regional loads, and analytic results

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doi:10.1016/j.eswa.2008.11.012

showed that the backpropagation neural network techniques can provide more accurate results than the regression models. A fuzzy linear regression model was presented by Al-Kandari, Soliman, and El-Hawary (2004) to forecast electricity loads in summer and winter seasons. Numerical results indicated that the proposed fuzzy model can provide reliable operations to electric power systems. Pai and Hong (2005) designed a support vector regression model to predict electricity loads, using simulated annealing algorithms to determine parameters for support vector regression model. Simulation results showed that the proposed model can provide better forecast than ARIMA model and general regression neural networks based on the same data set.

In this investigation, a hybrid model that combines linear discriminant analysis technique and rough set concept is designed to analyze variations of electricity loads. Chen (2001) pointed out that reduct computation is a time-consuming problem when the problem size increases. Therefore, the linear discriminant analysis is used as an auxiliary tool to determine significant condition variables in the analysis of electric load problem. Then, the selected significant condition attributes serve as a reduct of the RST model to decrease the computation time generating reducts by conventional rough set theory. The rest of this study is organized as follows. Section 2 introduces concepts of linear discriminant analysis and rough set theory. Section 3 illustrates the proposed model and its application in an example of electricity loads. The analytic results are provided in Section 3 to evaluate the efficiency and accuracy of the proposed model. Finally, conclusions are addressed in Section 4.

2. Linear discriminant analysis and rough set theory

2.1. Linear discriminant analysis

With the ability to pursue a low-dimensional space that best discriminates samples from different classes, linear discriminant analysis (Duda & Hart, 1973; Fisher, 1936; Fukunaga, 1990) is one of the most popular techniques for classification and feature selection problems. LDA has been applied in many fields, such as face recognition (Zhang & Jia, 2007), medicine (Yang, Dai, & Yan, 2006), civil engineering (Carroll, Goonetilleke, Al-Shiekh, & Frost, 2006), network traffic modeling (Zhang, Sun, Bian, & Zhang, 2006), network intrusion detection (Katos, 2007), biology (Ginoris, Amaral, Nicolau, Coelho, & Ferreira, 2007), and feature extraction (Chen, Zhu, Zhang, & Yang, 2005). Based on attributes of independent variables and dependent variable, linear discriminant analysis attempts to decide the best linear combination of independent variables to categorize objects investigated into two or more groups. The goal of LDA is to find a transformation matrix A that maximizes the ratio of the between-class scatter S_b against the within-class scatter S_w (Duda & Hart, 1973). The ratio of the between-class scatter to the within-class scatter or the criterion function is illustrated as

$$J(A) = \frac{A^T S_b A}{A^T S_w A} \tag{1}$$

The between-class scatter matrix and within-class scatter are defined as Eqs. (2) and (3), respectively,

$$S_b = \sum_{i=1}^{c} P_i(\mu_i - \mu)(\mu_i - \mu)^T \tag{2}$$

$$S_w = \sum_{i=1}^{c} P_i \sum_{j=1}^{n_i} (x_j^i - \mu_i)(x_j^i - \mu_i)^T \tag{3}$$

where C represents the total number of classes, n_i denotes the number of samples in class i, P_i is the prior probability of class i, x_j^i is the jth training sample vector of class i, and μ_i is the mean of class i, μ is the mean of all samples. The transformation matrix A can be determined by solving the following generalized eigenvalue problem of S_b and S_w,

$$S_w^{-1} S_b A = \lambda A \tag{4}$$

where λ is a generalized eigenvalue. Since the rank of the matrix S_b is $C-1$, there are only $C-1$ nonzero eigenvalues associated with Eq. (4).

2.2. Rough set theory

Introduced by Pawlak (1982), rough set theory assumes that every objective within the universe of discourse is associated with some information, and this indiscernibility relation formed the mathematical foundation of rough set theory. RST has been successfully devoted to problems with vagueness and uncertainty of information and it has provided many exciting resulting results in a considerably wide range of fields, such as location services (Sikder & Gangopadhyay, 2007), analysis of customer complaints (Yang, Liu, & Lin, 2007), and finance (Sanchis, Segovia, Gil, Heras, & Vilar, 2007), travel modeling (Witlox & Tindemans, 2004), medicine (Tsumoto, 2000). However, reduct generation of RST is very time-consuming (Wang, Yang, Jensen, & Liu, 2006). Therefore, in this study, LDA is used to determine an essential reduct for the RST model. Basically, four essential concepts are included in the RST. The indiscernibility of objects is the first concept of RST. RST uses information systems to represent knowledge and deal with vague data. An information system is represented as

$$S = \langle U, \Omega, V, f \rangle \tag{5}$$

where U is a nonempty finite set (namely the universe) with n objectives $\{p_1, p_2, \ldots, p_n\}$, Ω is a nonempty finite set with m attributes $\{q_1, q_2, \ldots, q_m\}$, V is called the domain of Ω, and $f: U \times \Omega \to V$ is an information function such that $f(p,q) \in V$ for every $p \in U$, $q \in \Omega$. Furthermore, let $Q \subseteq \Omega$ and $(x,y) \in U$. The indiscernibility relation of x and y in terms of Q is defined as follows:

$$IND(Q) = \{(x,y) \in U \times U : f(x,q) = f(y,q) \forall q \in Q\} \tag{6}$$

This indiscernibility relation partitions the universe U into a family of equivalence classes. The equivalence classes of the relation $IND(Q)$ is called Q-elementary sets in S and $[x]_{IND(P)}$ denotes the Q-elementary set containing the objective $x \in U$. In the rough sets theory, knowledge about objectives is presented in a decision table. Rows and columns of the decision table are labeled by objectives and attributes correspondingly. Two types of attributes, namely condition attributes and decision attributes, are contained in the decision table. Lower and upper approximation is the second basic concept of RST. Lower and upper approximation plays a crucial role in RST. Let $Q \subseteq \Omega$ and $X \subseteq U$. Then the Q-lower approximation of $X(QL)$ and the Q-upper approximation of $X(QU)$ are defined, respectively, as Eqs. (7) and (8),

$$X(QL) = \{x \in U : [x]_{IND(P)} \subseteq X\} \tag{7}$$

$$X(QU) = \{x \in U : [x]_{IND(P)} \cap X \neq \phi\} \tag{8}$$

The third concept of RST is the attribute reduction. The reduct, denoted by *RED(Q)*, and core, expressed by *CORE(Q)*, are two basic RST concepts employed for knowledge reduction. The reduction of attributes is to eliminate some irrelevant or redundant attributes without decreasing the quality of approximation of an information system as the original set of attributes. The indiscernibility relation of a set of attributes Q remains unchanged when redundant attributes are removed. A reduct is basic part of an information table and the core is the intersection of all reducts. The relation between reducts and the core can be represented as

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