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Appraisal of the support vector machine to forecast residential heating demand for the District Heating System based on the monthly overall natural gas consumption

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ABSTRACT

DHS (District Heating System) is one of the most efficient technologies which has been used to meet residential thermal demand. In this study, the most accurate forecasting of the residential heating demand is investigated via soft computing method. The objective of this study is to obtain the most accurate prediction of the residential heating consumption to employ forecasting result for designing optimum DHS system as a possible substitute of a pipeline natural gas in BAHARESTAN Town. For this purpose, three Support Vector Machine (SVM) models namely SVM coupled with the discrete wavelet transform (SVM-Wavelet), the firefly algorithm (SVM-FFA) and using the radial basis function (SVM-RBF) were analyzed. The estimation and prediction results of these models were compared with two other soft computing methods (ANN (Artificial Neural Network) and GP (Genetic programming)) by using three statistical indicators i.e. RMSE (root means square error), coefficient of determination (R^2) and Pearson coefficient (r). Based on the experimental outputs, the SVM-Wavelet method can lead to slightly accurate forecasting of the monthly overall natural gas demand.

1. Introduction

Nowadays, residential heating demand including heating and domestic hot water is an important section of the total natural gas consumption in the world. In Iran, the proportion of the residential heat demand is about 20 percent of the overall natural gas consumption [1], and it is also about four times higher than the global average of the residential natural gas consumption. Therefore, finding the alternatives for generating residential heating demands is to replace the national grid of natural gas. DHS (District Heating System) is one of this alternatives for producing residential heat demand which includes several important benefits such as high efficiency (savings energy up to 30%), cost-effective, clean (Co_2 emission reduction) and compatible in terms of environment. For designing DHS, the first step is to forecast residential heating demand of the case study, because a more accurate forecasting of the DHS demand can lead to more precise DHS simulation and design.

So far several authors have investigated demand forecasting as a crucial part of optimizing the DHS. Ma et al. [2] have proposed a methodology which considers time and type of the buildings as two key factors of the energy consumption patterns. Based on this method, a Gaussian mixture model has been developed to scrutinize the influence of the time and type of the buildings on the heat consumption patterns and then the procedure has been validated by data measuring and a real DHS. The results of this study indicate that in contradiction with time factor, building classification is the effective key factor in the heat consumption patterns. Another study has been accomplished by Park et al. [3] who have applied three forecasting techniques to predict heat demand during one week (short period) for effective management of the DHS. Two months heat consumption and ambient temperature data have been employed to forecast short term data by using Support Vector Regression (SVR), Partial Least Squares (PLS), and Artificial Neural

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Network (ANN), and further the prediction of heat consumption was compared with real data for validating models. In the same year, an online short-term prediction technique has been proposed by Grosswindhager et al. [4] to forecast heat load for the DHS. In this research, the SARIMA (Seasonal Autoregressive Integrated Moving Average) has been applied for the short-term forecasting and then the accuracy of this method was validated by the standard regression diagnostics. Other factors such as ambient temperature and social component were also simulated by the SARIMA. Results of this research show that the proposed method can be applied as an appropriate procedure for the online short-term forecasting.

In the context of natural gas demand forecasting, an accurate short demand forecasting model via a new procedure has been introduced by Lai et al. [5]. In that study, a combination of the SVM-Wavelet and Genetic Algorithm (GA) named (GA Wv-SVM) has been applied to predict gas demand, and GA was applied to obtain the Wv-SVM parameters. The outcome of this proposed model demonstrates that this model is more accurate than ANN and Wv-SVM. The wavelet transform has been also combined with other soft computing methods to predict future demand of energy, as an example, wavelet transform, evolutionary algorithm and neural network was combined by N. Amjady et al. [6] to obtain short-term (hourly) forecasting of the load in the power system. Furthermore, some other soft computing algorithms have been employed to obtain the accurate forecasting of the natural gas consumption in various fields, for example, Miha Kovacic et al. [7].

The dependency of the daily gas demand and ambient temperature has been investigated by Jinsoo Park [8]. For this purpose, two forecasting natural gas demand methods including an improved autoregressive model and a model based on the changing in the ambient temperature were proposed in the first step. In the second step relation between temperatures and heating demand was studied to forecast the daily gas demand. However, the proposed models did not meet the constraints; therefore the weighted average model including combination of these models has been proposed to obtain the daily demand forecasting. In addition, this relevance of gas demand and ambient temperature has been investigated in another research by Jolanta Szoplik et al. [9] that used Multilayer Perceptron of the Artificial Neural Networks (MLP-ANNs) to obtain the accurate forecasting for the natural gas consumption in a case study. In this research, calendar parameters and ambient temperature have been considered and used as two factors which affect the natural gas demand. The results show the accuracy of the forecasting demand is influenced by changing the number of neurons in the hidden layer, so more neurons lead to higher accuracy in the forecasting result. The MLP-ANNs was also employed by Taspinar et al. [10] to obtain short-term demand forecasting with time series approach and four years meteorological data (such as temperature, moisture and etc.). The outcomes of this study indicate that the forecasting method has adequate accuracy.

Three various AI (Artificial Intelligence) including ARIMA (Autoregressive Integrated Moving Average), ANFIS (Adaptive Neuro Fuzzy Inference System) (which combines ANN and Fuzzy Inference System), and MLP-ANN and Radial Basis Function Network ANN (RBFN-ANN) were used to predict weekly natural gas demand [11]. A comparison between validation results of these models indicates that ANFIS and MLP-ANN are the most accurate techniques among these models respectively.

In summary, it can be seen from the previous studies that soft computing methods are usually employed to obtain the short-term (weekly, daily, hourly or even less than hour) prediction of the natural gas consumption. This issue has been considered for the sake of the change in the different weather data (especially ambient temperature) which leads to change in the heat and thermal power demand amount. In the current study, the fluctuations of the average monthly outdoor temperature have been considered as a part of the forecasting methods and the relation between natural gas consumption and ambient temperature has been practiced.

There is a requisite for putting developed procedure for estimating the residential heating via previous natural gas demand data of the case study. This procedure should be simpler and more accurate than conventional approaches. Consequently, soft computing methods such as SVM are potential to be applied to forecast an overall monthly natural gas consumption model as a residential heating demand of the DHS. The SVM is a novel learning algorithm which was broadly applied in the various areas [12–15] and for various purposes such as the pattern recognition, forecasting, categorization and regression analysis [16–18]. The nature of the experimental data affects the adoption of the kernel function, but the main employed kernels contain linear, polynomial inner product functions and the RBF (Radial Basis Function) [19].

Biological inspired metaheuristic optimization algorithms like GA (Genetic Algorithm), ACO (Ant Colony Optimization), and PSO (Particle Swarm Optimization) have been extensively used in different fields of science [20–31]. These techniques are obtained from the approach of adopting the most suitable characteristics in biological systems. The latest methods in biology provoked from metaheuristic optimization techniques are FFA (Firefly Algorithm) (FFA) which has been described by Yang [32]. Among the biological based optimization methods, the FFA is one of the most practical and appropriate methods which can be applied to find local and global optimum comparison [32–40]. The prediction accuracy of the SVM model highly depends on the definition of the suitable model parameters, therefore, selecting procedure and arrangement of the model parameters are two requirements for the model construction, and hence the FFA is used for determination of SVM parameters.

In the current study, the SVM was coupled with DWT (Discrete Wavelet Transform) which has many useful basic functions to select from depending on the signal that is being analyzed. The input of the SVM method is obtained by using Wavelet analysis which decomposes the data time series into its different elements. Over the past few years, this technique has received great interest for engineering applications [41,42]. The objectives of the current study are to construct, develop and appraise the results of Wavelet, the firefly algorithm and the radial basis function of SVM (called SVM-Wavelet, SVM-FFA and SVM-RBF respectively) for predicting monthly natural gas consumption. An attempt is made to retrieve correlation for the two outputs: months of the year and average temperature in each month.

2. Methodology

2.1. Experimental setup

In this study, BAHARESTAN Town (located in the HALJROOD area of KAMALSHAHR in the north east of KARAJ city along the KARAJ-QAZVIN highway) is adopted as a case study. The main portion of the natural gas demand of this town is the industrial demand consumed by several factories located in this location, while this location was chosen based on some reasons which have been listed as below:

- ➢ Heating resource for generating thermal energy is required for the town which would be based on the DHS system. This place is located near some power plants that their thermal energy waste can be employed as a source of thermal energy production of the DHS. Clearly, the distance of the supply side and demand side in the DHS should be near in order to reduce pipeline costs and waste of energy.