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Intelligent forecasting of residential heating demand for the District Heating System based on the monthly overall natural gas consumption

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ABSTRACT

In this study, the residential heating demand of a case study (Baharestan town, Karaj) in Iran was forecasted based on the monthly natural gas consumption data and monthly average of the ambient temperature. Three various methods containing Extreme Learning Machine (ELM), artificial neural networks (ANNs) and genetic programming (GP) were employed to forecast residential heating demand of the case study and the results of these methods were compared after validating via real data. Actually, the main goal of the current study is to obtain the most accurate technique among these 3 common methods in this context. Validation of the forecasting results reveals that the important progress can be achieved in terms of accuracy by the ELM method in comparison with ANN and GP. Moreover, obtained results indicate that developed ELM models can be used with confidence for further work on formulating novel model predictive strategy for residential heating demand for the DHS. The outputs reveal that the new procedure can have a suitable performance in major cases and can be learned more rapid compare with other common learning algorithms.

1. Introduction

The world demand of the natural gas for the heating (especially in residential sector) has increased considerably during the recent decades. Because of using the older technology and therefore higher energy intensity, the natural gas consumption growth in developing country is dramatically higher than developed country. Iran as a developing country has the second most natural gas storage in the world; however the consumption of the natural gas especially in the cold months of the year is higher than the supply. In Iran about one-fifth of the overall natural gas demand is related to the residential sector containing heating and domestic demand (hot water for shower, gas for cooking and etc.) [1], hence modern heat generating technologies, such as District Heating System (DHS) have positive influence on the lower consumption of the natural resource and less Green House Gases (GHG) emission.

The DHS encompasses several important advantages, for example high efficiency, less fuel consumption, less CO_2 emission, reduction in the maintenance costs, and also safety, thus the DHS technology can be considered as an alternative to generate thermal energy for dwellings in various regions in Iran. Generally, the DHS consists of three distinct parts containing supply, transmission (distribution pipeline) and demand sections. The primary investment of the DHS is considerably higher than common heat generating tools, so this system should be designed in optimum scale to make it economically comparable with common methods. In this study, the demand side of a DHS is considered to design an optimum system for meeting residential heat demand for a town (Baharestan) in Iran. For this purpose, three various strong predicting methods containing ELM, ANNs and GP are applied and their results are compared to achieve the best forecasting results for this town by using the monthly residential gas consumption and monthly outdoor temperature of the case study. In fact, the aim of our forecasting model is to acquire medium-term future amount of heating demand by using the most suitable soft computing approach, so all

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the three methods are employed and compared with each other. The results of the current study can be employed to design a DHS as an alternative for natural gas consumption and satisfying heating demand for the case study.

Nowadays, application of modern computational approach in solving the real problems and determining the optimal values and functions are receiving enormous attention by researchers in different scientific disciplines. Neural network (NN), as a major computational approach, has been recently introduced and applied in different engineering fields. In contrast to the typical parametric approaches, NN is capable of solving complex non-linear problems and also has been applied widely in terms of demand forecasting. As an example Wojdyga et al. [2] proposed ANN method for the short-term prediction of the heat demand to obtain the accurate forecasting results. The network type of the ANN (the Radial Base Functions (RBF) and the back-propagation (BP) type have been investigated), its construction, size and sort of the data have been introduced as the main issues which affect the accuracy. The results of this study indicate that three to five percent error which according to the author it is appropriate for obtaining the scale of the heat source.

Another research has been done by Tae Chang Park et al. [3] using three various forecasting methods including ANN, partial least square (PLS) and support vector regression (SVR) to predict short-term (one week) demand of heat consumption. The short-term forecasting has been done by applying two series of data containing outdoor temperature and heat demand of a case study (Suseo area-South Korea) within two months and the forecasting results have been used as a constraint of DHS designing. Although the ANN is generally the best tool for the short-term forecasting [4], results of this study indicate that SVR is the best forecasting model among these three methods because of the structure, number and type of the input data. In addition, a comparison study among two different forecasting procedures has been proposed by Neto and Fiorelli [5] to obtain the energy demand of a University building as a case study. The first procedure was constructed based on the ANN approach and the second was formed according to physical principle (EnergyPlus). The results of this study indicate that both methods were appropriate to predict energy consumption of the case study. Ekici and Aksoy [6] have employed FORTRAN and MATLAB software to calculate and to predict energy demand respectively.

The most important objective of this research is to forecast energy demands of building with helping transparency ratio, thickness of insulation and orientation via ANN. A back propagation NN was chosen and the normalized data have been employed at the network. Besides, three different exemplary buildings with altered form factors (FF) have been chosen and it was presumed that different insulations (0, 2.5, 5, 10 and 15 cm) have been exploited for each type of these buildings. For different samples, range of the orientation of the angles is between 0 and 80 and rate of transparency have been selected as 15, 25 and 25 percent. For energy demand calculation, a code was written by the FORTRAN and the forecasting part has been also done via MATLAB (ANN toolbox). In conclusion, the comparison between calculated values and outputs of ANN procedure reveal some acceptable results (the deviation is 3.43% and rate of forecasting is between 94.8 and 98.5%).

On the other hand, thanks to the seasonal fluctuation and changing in amount of demand, the forecasting of the natural gas consumption is non-linear and multifaceted; hence, this issue has been investigated by various authors who employed several forecasting tools such as ANN and GP methods. For instances, the multilayer perceptron model (MLP) ANN have been applied by Szoplik et al. [7] to forecast natural gas demand of Szczecin in Poland by using the real natural gas consumption data and the factors having influence on them (i.e. ambient temperature). In this study, the forecasting results of the MLP-ANN were compared for different size of the data set in training procedure and various numbers of neurons in the hidden layers. Then, the best method has been selected to predict natural gas demand for each day of the year and also any hour of day. In 2014, Miha Kovacic and Bozidar Sarler [8] used the GP model for forecasting the consumption of natural gas in a steel company. The most important goal of the current research was to obtain the forecasting method with the highest accuracy, because the balance between quantity of the daily order and actual supply is so vital for the company. Results of the proposed model validation (via real data) show the most accuracy and it also works about two times more favourably.

There are many algorithms for training NN such as BP, hidden Markov model (HMM) and support vector machine (SVM); however the shortcoming of NN is its learning time requirement. Firstly, the ELM algorithm has been introduced by Huang et al. [9] to obtain more accurate single layer feed forward neural network (SLFN). This algorithm has capability of solving problems which are made by methods with gradient descent based like BP which is employed in ANNs. The ELM is able to decrease the required time for training a NN. This technique has simple structure and it boosts up learning process, as well as generating robust performance [10]. Accordingly, a number of investigations related to application of ELM algorithm have been carried out successfully for solving the problems in various scientific fields [11–16]. As an example, Xinying Wang and Min Han [17] have employed the ELM method for online sequential forecasting of the multivariate time-series. Comparison between results of this predicting method and real data indicated that this procedure can be used as an appropriate online forecasting tool.

In general, ELM is a powerful algorithm with higher learning speed and more appropriate performance compared with regular techniques like BP. This method is employed to have the most possible smallest training error and norm of weights, besides it is an appropriate and modern computational method [18]. As mentioned, a predictive model of overall monthly natural gas consumption as a residential heating demand side of the DHS is developed by using ELM method in this research. The ELM results were also compared with ANN results and genetic programing (GP). An attempt is made to retrieve correlation for the two outputs: months of the year and average temperature in each month. This system should be able to forecast roughness of the surface in regards to the four inputs.

2. Methodology

2.1. Experimental setup

In the current study, meteorological data and previous monthly natural gas consumption of a case study in IRAN (BAHARESTAN town the latitude and longitude are 35.885413967° and 50.891565703° respectively) have been considered to collect data to construct the model. The location of case study is indicated by Fig. 1.

The total area of the case study is about 1,700,000 (m^2) and consists of different units with residential and industrial usage of the natural gas. Indeed, each user received separate bills for residential and industrial consumption of the natural gas, so the summation of monthly residential bill of the units has been considered for 72 months since January 2006. Fig. 2 illustrates the monthly residential consumption of the natural gas where each monthly data represents the whole residential consumption of the units per month.

Clearly, the monthly average outdoor temperature of the case study affects the residential natural gas consumption in terms of the heating (but domestic consumption is approximately same within the cold and hot seasons of the year), so monthly average of the daily ambient temperature data which is gathered by the nearest