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A general neural and fuzzy-neural algorithm for natural gas flow prediction in city gate stations

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ABSTRACT

This paper presents an approach to predict the transmission of natural gas (NG) in city gate stations (CGSs) by neural and fuzzy neural networks. The proposed approach constructs a model that is based on a primary station data and uses it to predict the NG transmission of a secondary station. Two stations in Qazvin, Iran, are selected as case study for daily prediction. The artificial neural network (ANN) and adaptive neuro-fuzzy inference system (ANFIS) are optimized for minimum error. Results show that ANFIS is more accurate than ANN and its mean absolute percentage error (MAPE) in primary station (Qazvin no. 2 CGS) is 5.57%. Furthermore, the ANFIS prediction model is used after adaptations for the secondary station (Takestan CGS). The range of NG transmitted volume is different in the secondary station but the results show that the MAPE of prediction in Takestan station is 5.73% which is of the same order as that of the primary station. The effect of errors in the adaptation step for secondary station is investigated. This approach is useful for prediction of transmitted NG in stations with insufficient data but similar consumption and saves the cost of the construction of new prediction model for each station.

1. Introduction

Technological progress over the past decades has increased the energy consumption and at the same time helped manage or reduce consumption in different sectors. NG is one of the most attractive energy sources at present. Prediction of NG demand for different periods and applications is a necessary concern for governments and NG distribution corporations due to its wide areas of application and its rising price. Error in demand prediction causes financial penalties for local distribution companies that buy NG from main pipelines. Also, accurate consumption prediction of different sectors is necessary for appropriate management of any NG network.

There is a large body of literature on forecasting NG consumption in different horizons. Soldo [1] investigates the papers that use different prediction tools for various time periods. Brown et al. [2] and Brown and Matin [3] use ANN to predict NG demand and they compare their model with linear regression. They show ANN prediction models are more accurate than linear regression model. Khotanzad and Elragal [4] and Khotanzad et al. [5] combine ANN with different methods and construct two stage prediction models. They show that different combinations of ANN models improve prediction accuracy. Ozturk et al. [6] use genetic algorithm to predict residential-commercial energy consumption in Turkey. They show that their proposed approach is a viable alternative for available techniques for energy planning policies. Viet and Mańdziuk [7] predict NG consumption in different regions of Poland with neural and fuzzy neural networks. They show their models give superior predictions as compared to linear and quadratic regression models that gas companies use. Musilek et al. [8] use ELVIRA to construct a modular prediction model. They use binary codes to distinguish different days and show by means of feature selection that a larger number of inputs do not necessarily create a more accurate model. Ivezić [9] uses ANN to predict NG demand in Serbia with different prediction error in different months. Sanchez-Ubeda and Berzosa [10] use statistical methods for generating a daily prediction model. Their model has three different components and uses time series prediction. Azadeh et al. [11] predict natural gas demand in the Iranian network with ANFIS. They show that for short term forecasting, ANFIS is more accurate than ANN. They use same day consumption in the previous year as an additional input in addition to other conventional inputs. Sabo et al. [12] construct a mathematical model for prediction of NG consumption in Osijik city in Croatia. They show that most acceptable mathematical predictor models result when natural gas consumption and ambient temperatures are explicitly related. Tavakoli and Montazerin [13] investigate natural gas consumption in residential and commercial buildings in Tehran with probabilistic analysis approach. They employ analytical binomial distribution to predict the probability of average gas consumption in two different cases of

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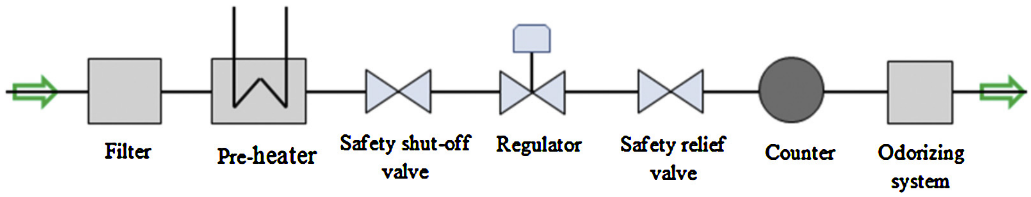

Fig. 1. City gate station parts.

500 and 1000 buildings. Taşpınar et al. [14] use ANN and time series to construct four prediction models in Turkey. They show that the type of ANN and properties of it are significantly effective in accuracy of prediction. Soldo et al. [15] use linear and nonlinear models to predict residential consumptions. They use solar radiation as input and show this variable improve the forecasting models.

The available literature on daily NG consumption shows that the networks based artificial intelligence systems create accurate short term prediction models [16]. These networks can handle complexity, non-linearity and fuzziness of field data and make accurate models from non-accurate data [17,18]. Uncertainty in field data may be from measurement errors or irregular system response. These prediction models are for data from cities or larger regions.

Focus on smaller units in NG transmission networks helps better network management and critical zone distinction. In the present study, NG transmission in a pressure reduction station is predicted. This station feeds the residential or industrial consumers of a region where the transmitted NG of such stations is a function of downstream consumers' consumption pattern.

Applicability and generality of artificial intelligence based prediction models is also very important. Therefore further in this approach, the constructed model for primary station is used to predict the flow of station of a nearby city. This approach is useful in regions that have lack of data or their data is not appropriate for constructing prediction model. This approach eliminates the necessity of construction of a new prediction model for each station and time and cost savings are achieved.

The rest of the paper is organized as follows. In Section 2, the role of pressure reduction stations in the NG transmission network is briefly described. Section 3 gives the methodology of the present study and also gives a brief description on the theory of ANN and ANFIS. Section 4 contains case studies in Qazvin province in Iran which show the applicability of the proposed approach.

2. The role of pressure reduction stations in natural gas transmission networks

NG pressure in the main intercity pipelines is about 4–7 MPa g which is successively reduced to 1.7 kPa g for residential consumption or some intermediate pressure for industrial use. The initial pressure reduction is in the city gate stations (CGS). These stations decrease NG pressure from 4–7 MPa g to 1.7 MPa g. Inlet pressure in CGS may be different depending on the season and the position of a station in network, but outlet pressure is fixed to 1.7 MPa g. Only minor variations occur in the outlet pressure. Further reductions occur in Town Boarder Stations (TBS) which are similar to city gate stations but do not have heaters and sometimes flow rate sensors. Different parts of a city gate station are shown in Fig. 1.

A filter is placed in the incoming line to collect unwanted particles. Natural gas is real gas and therefore a drop in pressure could accompany a corresponding drop in temperature. In order to avoid liquid formation, a preheater raises gas temperature before pressure reduction. Safety shut-off valve and safety relief valve are placed in CGSs and pressure reduction is achieved in the regulator where a counter records the flow rate in each track. NG is odorless and because of safety considerations, it is odorized in CGSs and then enters the city networks.

3. Methodology

The methodology to develop a prediction model from the CGS data and investigating the applicability of model in secondary station is presented in this section. After presenting the main structure of the approach, the prediction tools are briefly introduced.

Main structure of proposed approach is presented in Fig. 2. In the first step, the available data that includes the history of NG flow through the station and weather data are divided into training and test data. 80% of data is used for making the models and the remaining 20% for testing the constructed models. The best available inputs are selected by the ANFIS in the next step. The criterion of selecting inputs is Root Mean Squares Error (RMSE) from Eq. (1).

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{n}^{i=1}(O_i - A_i)^2}{n}} \tag{1}$$

where A_i is the actual transmitted NG of station, O_i is the system output and n is the number of training or test data. Best possible models from selected inputs are constructed with ANN and ANFIS in step 3. In the next step, models' outputs are presented and their performance is surveyed with RMSE and mean absolute percentage

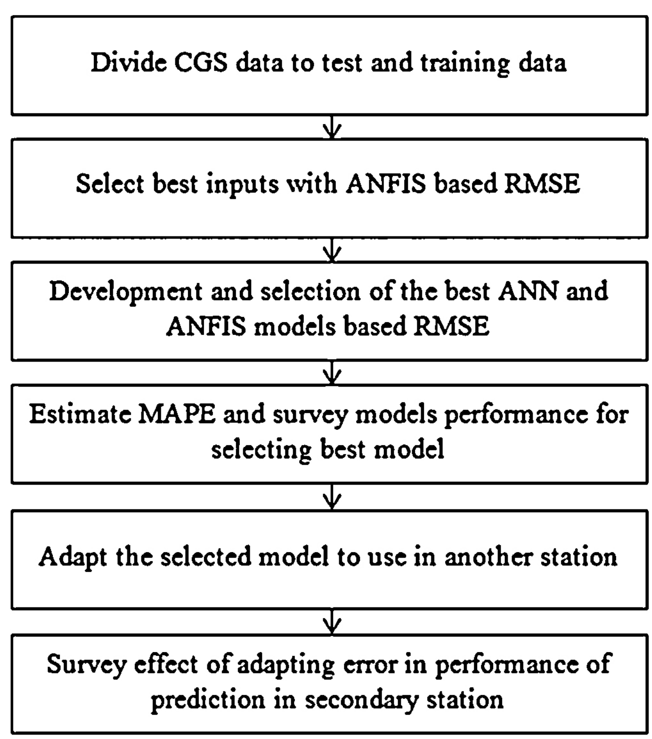

Fig. 2. The main structure of proposed approach.