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Response of natural gas distribution pipeline networks to ambient temperature variation (unsteady simulation)

Mahmood Farzaneh-Gord, Hamid Reza Rahbari*

The Faculty of Mechanical Engineering, Shahrood University of Technology, Shahrood, Iran

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ABSTRACT

Natural gas is transported through pipeline networks such as transmission and distribution to the final consumers. Local natural gas companies should make the continuous delivery of natural gas under any ambient temperature and demand. Natural gas demand varies due to ambient temperature variation (ATV) in different seasons or even during a day. The continuous supply of natural gas could be achieved only if the response of natural gas pipeline network to ATV is fully studied and understood. This study investigated the response of a typical natural gas distribution pipeline network to ATV. Firstly, a multilayer perceptron neural network model has been developed to forecast natural gas demand at any ambient temperature. Secondly, a new approach has been presented to simulate the natural gas distribution pipeline network in unsteady conditions. This approach is developed to predict the response of the distribution pipeline to ATV. The city of Semnan, Iran, was selected as the case study. Natural gas consumption in 4 coldest days of a year was extracted from the metering points. According to the results, the forecast data for natural gas demand has about 1% division compared with the actual values. Also, the node pressures significantly dropped on the coldest day of the year due to the increase in natural gas demand. In addition, the effect of natural gas composition on node pressure investigated. Results show that the natural gas with higher molecular weight has a lower pressure in all network nodes.

1. Introduction

After being extracted from wells and refined in refineries, natural gas reaches to the final consumers through pipeline networks. The natural gas pipeline networks include pipes, valves, compressors etc. and it is divided into two general categories. The first category is a high pressure natural gas transmission pipeline networks. These networks transfer natural gas to the main gate of cities. The second category is the natural gas distribution pipeline networks in which natural gas flows at medium or low pressure. These networks deliver natural gas to end costumers. Due to the long path and pressure drop in the transmission networks, compressor stations are installed at a distance of 100–150 km apart. These stations consist of a set of compressors which are responsible for increasing natural gas pressure. Natural gas could not be consumed at the pressure level with which it reaches the main gate of cities. Therefore, firstly this pressure is reduced at pressure reduction stations, and then, it is delivered to consumers by distribution networks. The main consumers of natural gas distribution networks could be classified into residential consumers (household hot water, cooking and space heating), commercial consumers (hotels, hospitals, restaurants, cinemas and etc.) and industrial customers (power plants, cement factories and etc.).

In natural gas distribution pipeline networks, the junction of two pipes is commonly called node. In addition, each distribution network is made up of several closed loops. Due to the different rate of consumption of various areas, consumption of natural gas should be specified for each node (usually called node demand). To ensure continuous supply of natural gas in any cases including natural gas consumption variation or sudden natural gas pipeline failure, natural gas distribution pipeline networks should be analyzed in unsteady (transient) conditions. For this purpose, firstly, the pipelines as the most important component of networks should be analyzed in unsteady conditions. Then, natural gas pipeline networks should be studied.

Numerous previous studies have provided algorithms and numerical methods for analyzing the unsteady (transient) flow in natural gas pipelines. These methods were based on computational fluid dynamics (CFD) methods (Greyvenstein, 2002; Ibraheem and Adewumi, 1996; Luongo and others, 1986; Osiadacz, 1983; Wylie and Streeter, 1993; Yow, 1971). Since CFD methods are time-consuming, researchers have developed other algorithms to analyze the unsteady flow in natural gas pipeline networks with simpler procedures. Researchers such as Luongo and others (1986) and Wylie et al. (1971) neglected one term (intertie

* Corresponding author.
E-mail addresses: mgord@shahroodut.ac.ir, mahmood.farzaneh@yahoo.co.uk (M. Farzaneh-Gord), rahbarihamidreza@yahoo.com (H.R. Rahbari).

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term) in the momentum equation to achieve a simpler nonlinear governing equation of natural gas flow by linearization of these equations. Yow (1971) applied the method of characteristics to formulate the unsteady natural gas flow by considering the inertia term in the momentum equation.

Some researchers simulated unsteady natural gas pipeline network in isothermal conditions. For instance, Osiadacz (1987) and Kiuchi (1994) analyzed unsteady natural gas pipeline network by considering all terms in the momentum equation. In other studies, researchers investigated the effect of the non-isothermal condition on unsteady natural gas pipeline networks. They formulated the governing equations by applying the total variation diminishing (TVD) method (Adewumi and Zhou, 1995; Dukhovnaya and Adewumi, 2000). Moreover, Osiadacz and Chaczykowski (Osiadacz and Chaczykowski, 2001) compared the effects of isothermal and non-isothermal conditions on unsteady natural gas pipeline networks.

Tentis et al. (2003) simulated slow and fast transient conditions for natural gas flow in pipelines. Furthermore, Gato and Henriques (Gato and Henriques, 2005) applied the Galerkin method together with Runge–Kuttato simulate unsteady, one-dimensional and compressible flow in natural gas pipelines. The effect of the equation of state on momentum and energy equations in addition to the effect of thermal model on energy equation were investigated by Chaczykowski (Chaczykowski, 2010, 2009). An equation to calculate the unsteady natural gas volumetric flow rate of a pipeline based on the well-known Weymouth equation was also presented by researchers (Adeosun et al., 2009; Olatunde et al., 2012). Ebrahimzadeh et al. (2012) applied a new approach (orthogonal collocation method) to simulate the unsteady transmission pipeline network in isothermal and non-isothermal conditions. Helgaker et al. (2014)applied the GERG 2004 equation of state and simulated natural gas pipelines in unsteady conditions. In addition, Wang et al. (2015) presented four forms of governing equations of unsteady natural gas pipelines and compared the equations in terms of accuracy and efficiency.

A Few studies have been conducted in the field of unsteady natural gas pipeline networks. Electrical circuits are employed to simulate unsteady natural gas pipeline networks in isothermal conditions (Ke and Ti, 2000; Tao and Ti, 1998). Reddy et al. (2006) developed a mathematical method to simulate unsteady natural gas pipeline network and compared it with numerical methods such as finite difference. Some investigators applied MATLAB® Simulink library to simulate natural gas distribution pipeline networks (Herrán-González et al., 2009) and natural gas pipelines (Behbahani-Nejad and Bagheri, 2010). The results show that the suggested method is more accurate and efficient than the previous studies.

In recent years, limited studies have been conducted to expand and present new approaches to simulate unsteady natural gas pipeline networks. For example, Behbahani-Nejad and Shekari (2010) developed a novel method according to corresponding Eigen system to study the governing equations. Alamian et al. (2012) employed control approaches such as state space model. In their study, the proposed model was compared with other methods, e.g. conventional, implicit, and explicit finite difference. Furthermore, Behrooz and Bozorgmehry (2015) solved the governing equations of unsteady and non-isothermal flow inside the transmission natural gas pipeline networks by presenting a new efficient procedure and method.

Literature reviews have indicated that there are three models for forecasting energy and natural gas demand: time series (TS) model, regression model (RM) and artificial neural network (ANN) (Aydinalp-Koksal and Ugursal, 2008; Kavaklioglu et al., 2009). In the TS model, energy demand is forecasted by the future data based on previously observed values. The RM is very useful for forecasting energy demand and could be linear or nonlinear based values. The ANN is new computational method for solving nonlinear problems, optimization, forecasting, etc. The main idea of the ANN is based on the human nervous system. Numerous researchers developed ANN model to forecast natural gas demand. For example, Khotanzad et al. (2000) combined two-stage ANN to forecast natural gas consumption. Potočnik et al. (2014) studied the effect of various ANN methods in forecasting residential natural gas demand in Croatia and concluded that the adaptive linear model is better than the other models. Yu and Xu (2014) developed an optimized genetic algorithm and ANN with back propagation (BP) algorithm to forecast natural gas demand. Also, some researchers from Turkey applied ANNs to forecast natural gas consumption in Ankara Province (Gorucu, 2004) and Istanbul (DEMİREL et al., 2012; Kizilaslan and Karlik, 2009). In one study, a genetic algorithm was developed to forecast natural gas consumption using ANN and for a steel plant (Kovačič and Šarler, 2014). Moreover, multilayer perceptron model (MLP) in different modes was applied by Szoplik (2015) to forecast natural gas consumption in Szczecin. In that particular study, an efficient MLP was proposed using the trial and error method.

Due to the high demand for space heating in low ambient temperatures, natural gas consumption in cities is highly influenced by ambient temperature variation. To ensure a continuous supply of natural gas, it is necessary that local natural gas companies should be able to accurately predict the natural gas consumption rate of their customers. The companies should also know the specific response of natural gas distribution pipeline networks to ATV. This response includes the node pressure at any point of the network. In cold days, the response of distribution pipeline networks to ATV is pressure drop at the nodes due to increase in natural gas demand. If the ambient temperature drop is severe, the pressure drop in the nodes and pipelines is considerable which may be resulted to the natural gas supply operation cut off. Therefore, the response of distribution network to ATV is of special importance.

Thus in this study, firstly a neural network has been developed and presented to forecast natural gas demand in a distribution pipeline network due to ATV. Then, a novel approach has been proposed to analyze the unsteady simulation of the distribution pipeline network. Finally, the response of the distribution pipeline network to ATV has been investigated. Semnan, the capital city of Semnan Province, Iran, has been selected as the case study and the effect of ATV and natural gas compositions on the studied distribution pipeline network are investigated.

2. Problem description

The city gate station (CGS) is a pressure reduction point in transmission pipeline networks with high pressure natural gas (5000–7000 kPa) at its entrance. The natural gas pressure at the CGS exit should be around 1724 kPa (250 psi). This medium pressure natural gas is transferred to the town border station (TBS) using a basic grid pipeline as part of the distribution network. The pipeline, nodes and closed loop are the main components of the distribution pipeline network. Fig. 1 and Table 1 demonstrate the details of natural gas distribution pipeline network for the case under investigation (i.e. Semnan). The natural gas demand at each node is depicted in Table 2. These informations are provided by Semnan Gas Company.

3. Natural gas demand in Semnan as case study

Natural gas consumption is influenced by climatic characteristics, e.g. daily effective temperature, cloudiness, rainfall and wind speed. These parameters, together with average ambient temperature, are usually measured, calculated and reported by local weather organizations. Fig. 2 presents the variation of average ambient temperature versus month for 2011–2013 in Semnan (I.R.OF IRAN Meteorological Organization website).

The number of natural gas consumers for Semnan, between 2011 and 2013, was approximately 45,311. Space heating, domestic hot water and cooking are the important sources of natural gas consumption. The monthly natural gas consumption was measured using