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Using artificial neural network predictive controller optimized with Cuckoo Algorithm for pressure tracking in gas distribution network

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ABSTRACT

In order to model and analyze gas networks, several methods have already been developed and presented. Nevertheless, all these methods have their own specific applications and most of them are very complex and usually contain some errors. In this paper, in an attempt to resolve these problems, an Artificial Neural Network (ANN) has been used to model a gas distribution network. The algorithms utilized for ANN training, such as the gradient descent algorithm, are usually subjected to local minima; in this regard, the new Cuckoo Optimization Algorithm (COA) is used in training the weights of the neural network. However, gas networks are often very large and operate a multitude of distant points, which explains why time delays in these networks are inevitable. Accordingly, in order for all points of the output (pressure) to achieve the desired value, a Model Predictive Controller was used. According to the results achieved, it can be said that the Artificial Neural Network Cuckoo Optimization Algorithm (ANN_COA), in comparison to regular ANN, yields a more suitable performance and is less prone to error. In addition, the MPC controller is faster and suffers from fewer errors compared to the Proportional-Integral-Derivative (PID) controller while also preventing fluctuations in gas system input.

1. Introduction

Pipelines significantly affect daily lives in most parts of the world. Modern people's lives rely on the environment, and energy plays a very important role, of which oil and gas are two major sources. To fulfill oil and gas demands for power generation, recovery processes and other uses, pipelines are utilized to transport the supply from their sources to where they are needed (Mohitpour et al., 2007). Considering the distances and the significant amounts of gas that need to be transferred on a daily basis, pipeline has proven to be one of the best and most reliable current methods of gas transmission (Mokhatab and Poe, 2012). Countries such as the USA and Iran have very wide natural gas transmission and distribution networks, with Russia and Europe also boasting similar systems (Mohitpour et al., 2000).

The economical and proper distribution of natural gas is to a great extent determined by the data (dispatching) and control systems of the gas engineering software utilized. It has been demonstrated that using the factory default specifications for pipelines and gas transmission systems typically leads to significant errors (Hajialiakbari and Behbahani, 2014). Several equations have been documented for natural gas network modeling purposes, most of which are nonlinear and suffer from a number of issues (Mohitpour et al., 2007). These equations are usually reserved for special applications and cannot be used for general purposes, thus making them prone to practical errors (Hajialiakbari and Behbahani, 2014). When a fluid passes through a pipeline at high velocities, it can cause both vibration and erosion in the pipeline, eroding the pipe wall over time. In addition, unforeseen circumstances can also lead to issues in distribution networks. For example, the pipeline and its surrounding temperatures in the coming years cannot be predicted 100% precisely, making it nearly impossible to predict the erosion rate, chemical reactions of the pipes' wall, and variations in the pipes' roughness. Assuming that an equation which can accurately calculate pressure-flow parameters in pipelines existed, its validity would severely degrade in just a few months or years because of these unexpected changes. There are also other factors at play here, like the chemical compound of the gas, which is subject to change as a result of modifying energy policies. For example, as petrochemical industries develop, a large amount of intermediate hydrocarbon will need to be allocated for

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these industries, reducing the amount of gas allocated to home uses. In addition, as time elapses, aging occurs at the reservoirs, particularly those which have been in use for a long time. This can also affect the gas's chemical compound. Consequently, the parameters affecting the equations of gas flow pressure are persistently changing. In other words, the physical characteristics of the pipeline (pipeline aging), the chemical characteristics of the gas and environmental conditions are all variable. Consequently, it is impossible to anticipate future conditions and what will happen in, for example, the next forty years (Hajialiakbari and Behbahani, 2014; Montoya-O et al., 2000; Hanmer and Jackson, 2012). However, identification methods such as Artificial Neural Networks (ANNs) can potentially eliminate a large portion of errors (Yegnanarayana, 2009; Maren et al., 2014).

Neural networks are capable of identifying non-linear and complex systems, making them strong modeling devices. The algorithms utilized for ANN training, such as the gradient descent algorithm, are usually subjected to local minima; in a similar vein, the new Cuckoo Optimization Algorithm is used in training the weights of the neural network. Such an algorithm is a new evolutionary technique grasped from the behavior of a certain type of bird: the cuckoo (Rajabioun, 2011). Among the benefits of this technique, faster convergence, high accuracy, lower possibility of trapping in the local minima, and fast solution of optimization problems with high range dimensions can be mentioned. Such advantages are the main reason why the use of such a technique has become so widespread (Civicioglu and Besdok, 2013; Yang and Deb, 2014). This optimization algorithm is run so as to achieve enhanced identification through exploring the optimized values of the weights of the neural network. As far as the authors are cognizant, this may be the first time that such an identification method is used for a gas distribution network.

Due to the expanse of gas networks and long distances between the input flow and desired pressure points as system outputs, time delays exist in such systems. In order to achieve desired output values despite these time delays, appropriate control methods should be used for gas networks along with artificial neural networks for system identification. Many studies have been done in the field of control systems for gas transmission (Mokhatab and Poe, 2012; Eiber et al., 2004; Sun and Hebbale, 2005). Considering the system complexity, time delays, and large numbers of outputs involved, Model Predictive Controller (MPC) has been used. Model Predictive Control (MPC) is one of the most successful control methodologies having an important influence on industrial control engineering. This strategy involves solving an optimal control problem on-line, enabling the controller to deal explicitly with Multiple Input-Multiple Output (MIMO) plants, time delays and constraints such as state constraints as well as actuator constraints (Camacho and Alba, 2013; Morari et al., 2002; Mayne et al., 2000; Ma et al., 2012; Rossiter, 2013). The system is also easy to tune while also benefiting from high accuracy and simplicity.

Moreover, due to the model's dependence on controlling systems and the fact that gas network parameters vary over time, an Artificial Neural Network (ANN) optimized by Cuckoo Algorithms, as an online identification method, has been used in the current study to improve the performance of the MPC controller.

The proposed technique was applied to a portion of the Iranian gas distribution network and its performance compared with that of the conventional neural network. The results gleaned from the tests carried out show that an optimized Cuckoo Algorithm can play a very effective role in training the Neural Network and continuously improve its performance. On the other hand, the MPC controller can help achieve the desired system outputs faster and more accurately.

The study, in section 2 tries to have an investigation into the common modeling methods in gas network. In sections 3 and 4, artificial neural network and model predictive controller have been studied. Section 5 contains explanations and results on how the proposed methodology has been operated on the studied gas network. In section 6, an overall conclusion is given and the results are presented.

Section 2 provides a look into modeling methods commonly used in gas networks. In sections 3 and 4, the artificial neural network and model predictive controller are described. Section 5 contains explanations about how the proposed methodology was implemented on the gas network investigated and the results obtained. In section 6, the overall results are presented and conclusions are drawn.

2. Gas pipeline

The flow-pressure equation in gas transfer and distribution lines and present effective parameters on gas pressure in a certain point of the gas network are briefly investigated. The general flow equation of natural gas in a pipeline is as follow (Mohitpour et al., 2007):

$$\boldsymbol{Q_b} = \boldsymbol{f}\left(\boldsymbol{P_{in}}, \boldsymbol{P_{out}}, \boldsymbol{T_{ave}}, \boldsymbol{Z_{ave}}, \boldsymbol{P_{ave}}, \boldsymbol{D}, \boldsymbol{G}, \boldsymbol{L}, \boldsymbol{R}, \Delta\boldsymbol{H}, \sqrt{1/\boldsymbol{f}}\right) \tag{1}$$

Where

P_{in}: Inlet gas pressure, psia
P_{out}: Outlet gas pressure, psia
T_{ave}: Average absolute temperature of pipeline
Z_{ave}: Average compressibility factor
P_{ave}: Average pressure, psia
D: Inside diameter of pipe, inches
G: Gas specific gravity, dimensionless
L: Pipe length, miles
R: Gas constant, 10.73, (psia*ft^3/lb moles *°R)
ΔH: Elevation change, ft
f: Moody friction factor
$\sqrt{1/f}$: Transmission factor, dimensionless

Panhandle B, Weymouth, AGA and Colebrook-White are the most accurate and common methods for pressure-flow computation in natural gas transmission industries (Mohitpour et al., 2007; Mokhatab and Poe, 2012). The above equation is not explicit and some parameters of this equation have some ambiguities, so researchers may not be able to achieve a precise theory about them. The physical characteristics of the pipeline, chemical characteristics of the gas and environmental conditions also change over time and adversely affect this equation (Hajialiakbari and Behbahani, 2014; Montoya-O et al., 2000; Hanmer and Jackson, 2012). As a result, artificial neural networks are a good option to rectify the aforementioned problems.

In this study, a small segment of the gas transmission and distribution network in Iran was chosen as a case study. This network is located in Azerbaijan Province, Iran, with a pressure range of about 705–1073 psi. A schematic view of this network is depicted in Fig. 1.

3. System identification

3.1. Artificial neural network

Neural networks are able to estimate a process with various inputs and outputs at any degree of complexity with the required