Optimization of a Natural Gas Distribution Pipeline Network in a Village of Kurdistan, Iran

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Abstract: - In Recent years gas distribution networks of some cold regions of Iran have faced pressure drop and accordingly gas cut off in winters. Most of time, increasing consumption has been stated as the main reason of this problem while the author believes that this is not the only reason. Non-optimized gas distribution network is another important reason that can cause pressure drop and gas cut off. For this purpose, a gas distribution network in a village called Bawariz, near the Sanandaj city, Iran, is optimized using a developed optimization algorithm. The results reveal that most of pipe sizes (more than 90%) are over designed. Non-optimized network increases cost of network implementation and also influences gas distribution and as a result gas delivery in the network.

Key-Words: - Gas distribution network, Optimization, Bawariz, Gas cut off, Pressure drop

1 Introduction
In recent years, gas cut off and pressure drop in gas distribution networks of some cold regions of Iran, has become a serious problem and needs to be studied carefully. Ordinary reasons like high consumption are presented usually as the main reason of this problem, while more important reasons can be low efficiency heaters that consume natural gas as fuel. Increasing each percent of efficiency in these heaters, means saving great amount of energy and producing less air pollutants. The efficiency of these heaters is usually under 70% and a great part of energy just wastes from the chimney. Furthermore, most of houses use separate or independent heating system instead of central heating systems. Using central heating system decreases fuel consumption about 12% as Z. Moradi and M. Ebrahimi [5], calculated. This paper is not going to study heaters or heating systems. But it focuses on the gas distribution network design to find out if there is a problem about the network itself or not. Author believes, in addition to the reasons described above, non-optimized pipe diameter in gas distribution network is another reason that affects gas delivery and capital cost of network. To study this matter, different optimizations of natural gas networks have been studied. For instam, Andrzej J. Osiadacz, Marcin Gorecki[1], have used a developed optimization algorithm to optimize two gas distribution networks. One is a low pressure network containing 108 pipes, 83 nodes and two sources, the other is a medium pressure gas network comprises 39 pipes, 36 nodes and one source. Optimization of the first network gives total profits equal 44603.0USD and the second optimized network which was smaller and much better designed, gives only 2900.0USD saving. Stanisław Nagy, Andrzej Olajossy, and Jakub Siemek [3] carried out the analysis of two dense gas distribution networks by means of griding technique. The main advantages of their work are possibility the calculation of pressure gradient map, flow velocity map, pressure depression map, the Reynolds number map using simple mathematical grid transformation. The necessary condition to perform such analysis is full description of local coordinates (GIS) in the calculated network. B.V. Babu, Rakesh Angira, Pallavi G. Chakole, and J.H. Syed Mubeen [4] have used a differential evolution method to optimize the design of a gas transmission network. The optimum gas transmission network results in $7.289 \times 10^6$ saving per year. According to the above examples we can see that optimization of gas distribution and transmission networks may result in considerable saving. For this purpose, a gas distribution network in a village called Bawariz, near the Sanandaj city is considered to be optimized. This network comprises 87 pipes, 82 nodes and one source. Inlet pressure to the village network is 60psi and gas enters homes with 0.25psi pressure. About 400 consumers are fed...
by this network, and based on NIGS standards each consumer needs a gas flow rate of 2.2 m³/hr. After using a developed optimization algorithm it is shown that most of pipe sizes are over designed. In the following the algorithm applied to the Bawariz network is presented.

2 Optimization Algorithm

In order to optimize a gas network design, a function that connects cost of gas pipeline to the network parameters like pipe diameter, pipe length, etc. is defined as below:[1]

$$f(D) = 2.05 \left[ L_1, L_2, K, L_m \right]^{T}$$

(1)

In which L is the pipe length, K is a weighting factor related to the cost of pipeline, M is the number of pipes and D is the diameter of pipe. The optimization process involves minimizing the cost function of $f(D)$ by considering some other constraints which are mentioned below. Kirchhoff’s first and second laws must be applied to any network. The Kirchhoff’s first law is stated as below:

$$A \cdot D = M$$

(2)

In which $A = A_{n,m}$ is the nodal-branch incidence matrix, and n and m are the number of nodes and pipes respectively, and $d = d_{con}$ is the loads vector. Elements of matrix A are defined as below:

$$a_{ij} = \begin{cases} \alpha_j, & \text{if branch } j \text{ enters node } i \\ -\alpha_i, & \text{if branch } j \text{ leaves node } i \\ 0, & \text{if branch } j \text{ is not connected to node } i \end{cases}$$

(3)

And the second low of Kirchhoff is as below:

$$B \cdot D = 0$$

(4)

Where $B = B_{u,m}$ is the loop-branch incidence matrix and in which u is the number of independent loops, and $\gamma$ is the general flow equation exponent. Elements of matrix $B$ are defined as below:

$$b_{ij} = \begin{cases} \beta_j, & \text{if branch } j \text{ has the same direction as loop } i \\ -\beta_j, & \text{if branch } j \text{ has opposite direction to loop } i \\ 0, & \text{if branch } j \text{ is not in loop } i \end{cases}$$

(5)

Pressure at each node $p_i$, should obey the following inequality:

$$p_i - p_{min} \geq 0$$

(6)

Where $p_{min}$, is the minimum allowable pressure at nodes and can be considered as the minimum required pressure of gas consumer facilities. Another constraint that is applied to the network is as below:

$$v_{min} \leq v_j \leq v_{max}$$

(7)

Where, $v_j$ is the gas velocity in each pipe. The problem is to minimize $f(x)$ considering two following cost constraints applied to each pipe.

$$c_j(x) = 0, \quad i = 1, 2, K, m'$$

$$c_j(x) \geq 0, \quad i = m' + 1, K, m$$

Where $f(x)$ and $c_j(x)$, $(i = 1, 2, \ldots m)$ are real and differentiable. The vector $d = d_k$ is determined by minimizing the quadratic function of Q which is mentioned below:

$$Q(d) = f(x_k) + d^{T} \cdot \nabla f(x_k) + \frac{1}{2} d^{T} \cdot B_{x_k} \cdot d$$

(9)

Two constraints that should be applied to the above functions are as below:

$$c_j(x_k) + d^{T} \cdot \nabla c_j(x_k) = 0, \quad i = 1, 2, K, m'$$

$$c_j(x_k) + d^{T} \cdot \nabla c_j(x_k) \geq 0, \quad i = m' + 1, K, m$$

(10)

Finally, the optimized parameter, $x$ which can be the diameter of pipes, is determined as below:

$$x_{k+1} = x_k + \alpha_k \cdot d_k$$

(11)

In which $\alpha_k$ is a positive length step.

3 Simulation and results

A gas distribution network in a village called Bawariz, near the Sanandaj city is considered to be optimized. This network comprises 87 pipes, 82 nodes and one source. Gas enters the network with 60 psi pressure and enters homes with 0.25 psi pressure. About 400 consumers are fed by this network, and based on NIGC standards each
consumer needs a gas flow rate of 2.2 m³/hr. The map of gas pipeline of Bawariz is depicted in fig. 1. To calculate gas flow (Q) in the pipes the Pole’s equation is used[2]:

\[\Delta P = 5.117 \times 10^{-13} \times L \times Q / D^3\]  (12)

Where \(\Delta P\) is the pressure gradient, and the optimization parameters are as below:

\[Q_i = \alpha_i \cdot D_i^2, \quad (cu. ft / hr)\]

\[\alpha_i = 19.6354 \times v_i\]

\[D_i (inch)\]

\[v_i (ft / s)\]

And also we have:

\[\Delta p_i = \beta_i \cdot D_i^{-4}, (lb / in^2)\]  (14)

\[\beta_i = 1.391 \times 10^{-6} \times L_i \times v_i^2\]

\[L_i (ft)\]

\[v_i (ft / s)\]

In which, \(\gamma = 1\) , and the velocity constraint for each pipe is as below:

\[16.4 (ft / s) \leq v_i \leq 32.8 (ft / s)\]  (16)

And pressure constraint for each node is as following:

\[p_i \geq 0.25 (lb / in^2)\]  (17)

The results of optimization are presented in table 1, and figure 2. In table 1, n is the pipe number, Bn and En are the nodes representing two ends of a pipe, L is the length of pipe, Q is the flow rate, Old-D is the designed diameter, New- D is the optimized diameter and DD is Old-D minus New- D.

According to the results, most of pipe diameters (more than 90%) are over designed, which could be smaller. In more than 40% of pipes the difference between designed diameter and optimized diameter is more than 1(in). Such over designing means wasting a lot of money and additionally this network can influence gas distribution in the network and cause pressure drop and gas cut off locally.

4 Conclusion

Non-optimized gas distribution network is one of the main reasons to increase cost of network. As it is shown most of pipes (more than 90%) are over designed and in more than 40% of pipes the difference between optimum pipe diameter and designed pipe diameter is considerable. Such a network influences gas distribution and as a result gas delivery in the network and may cause gas cut off in critical times. To avoid such problems it is better to optimize the designed network before executing it.

References:
Table 1: Calculations sample and comparison between designed diameter and optimum diameter of pipes

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<th>En</th>
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<th>Q(ft³/min)</th>
<th>OD= Old- D(in)</th>
<th>ND= New- D(in)</th>
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Fig 2: The difference between designed diameter and optimized diameter of pipes (DD) versus pipe number (n)