Study on Parameter Optimization of Gas Network Based on Reliability

Xuan Wang[1] and Changgui Duan[2]

1 School of Civil and safety Engineering, Dalian Jiaotong University, 794# Huanghe Road, Shahekou District, China, wxosh@163.com
2 School of Municipal and Environmental Engineering, Harbin Institute of Technology, Huanghe Road, Nangang District, China, duancg@sohu.com

ABSTRACT

Entropy is taken as an indirect index to measure the reliability of gas distribution network. The entropy function is set up. According to principle of maximum entropy, the maximum entropy model is established. With the relative entropy which is the ratio of actual entropy and maximum entropy as the reliability constraint, the diameter optimization model is set up and solved by improved genetic algorithm. Through actual engineering example, the optimization model with reliability constraint and optimization arithmetic in this paper can acquire satisfied solutions to engineering project and have certain reference value for diameter optimization design of gas distribution network.

KEYWORDS

Gas distribution network; Reliability; Diameter parameter optimization; Entropy; Genetic algorithm

INTRODUCTION

Gas distribution network optimization is an important problem in civil engineering. The optimization design is to gain the least total investment cost by determining the best diameters under several constraints. Most previous optimization mathematical model of gas distribution network is just from an economic point of view, while neglecting the reliability at the same time. In this paper, entropy is used as an indirect index to solve the problem of reliability-based diameter parameter optimization.

SIGNIFICATION OF INFORMATION ENTROPY

Entropy was from Classical thermodynamics in 19 century and first introduced into information theory by C.E.Shannon in 1948. Thus was the conception of information entropy brought forward to measure the source uncertainty (Jia, 2001).

Events uncertainty can be measured by its appearance probability while events are taken as random variables. Suppose probability space of a random variable X is:

$$\begin{cases} X: x_1\ ,\ x_2\ ;\cdots\ ,\ x_n \\ P(x): p(x_1)\ ,\ p(x_2)\ ;\cdots\ ,\ p(x_n) \end{cases}$$

Where X is the state space of random events; $P(x)$ is probabilistic distribution of random event probable states and $\sum_{i=1}^{n} p(x_i) = 1$.

So the definition of entropy is :

$$H(x) = -\sum_{i=1}^{n} p(x_i) \ln p(x_i)$$

GAS DISTRIBUTION NETWORK ENTROPY FUNCTION

Annular gas distribution network has fine connectivity and can provide gas for one node through several paths, which is called network redundancy. It is just because of the network redundancy that ensures the gas supply capacity and network reliability to some extent in case of the accident when some paths are disconnected owing to internal elements failure. Entropy theory is applied to try to measure the gas distribution network redundancy, indirectly to measure the reliability.

First to define the gas distribution network node entropy: suppose a gas network has N nodes, and there are $n(j)$ upstream nodes directly supplying gas for node j, the flow of pipe ij is q_{ij}, Q_j is the total flow into node j, and $Q_j = \sum_{i=1}^{n(j)} q_{ij}$. Define $p = q_{ij} / Q_j$ as a probability space, so node entropy function is:

$$H_j = -\sum_{i=1}^{n(j)} \left(\frac{q_{ij}}{Q_j}\right) \ln \left(\frac{q_{ij}}{Q_j}\right) \tag{1}$$

The effect of one pipeline failure on the whole network reliability is discussed here when we solve the gas distribution network reliability. Take Q_0 as sum of all pipeline flow and $Q_0 = \sum_{j=1}^{N} Q_j$. Define $p = q_{ij} / Q_0$ as a new probability space, which means the distribution probability of upstream pipeline flow into node j in all pipeline flow. So q_{ij}/Q_j in (1) is replaced by q_{ij}/Q_0:

$$H = -\sum_{j=1}^{N}\left(\sum_{i=1}^{n(j)} \left(\frac{q_{ij}}{Q_0}\right) \ln\left(\frac{q_{ij}}{Q_0}\right) \right) \tag{2}$$

Equation (2) is gas distribution network system entropy function.
According to (1) and (2), gas distribution network system entropy function can be expressed as:

$$H = \sum_{j=1}^{N} \frac{Q_j}{Q_0} H_j - \sum_{j=1}^{N} \frac{Q_j}{Q_0} \ln \frac{Q_j}{Q_0} \tag{3}$$

It shows that gas distribution network system entropy is the function of node entropy.

GAS DISTRIBUTION NETWORK MAXIMUM ENTROPY MODEL

Jaynes advanced principle of maximum entropy on the basis of information entropy in 1957. The principle indicates that internal elements of any physical system are always free in different states except constrained by external conditions. Of all states under certain conditions, the state in which entropy is the maximum or the probability distribution is the most uniform means the system is the most balanced and the maximum entropy value is the only one(Xing, 2001). For gas distribution network system, both node entropy and system entropy become maximum when the flow of each path to any node is equal and that is, achieving the most uniform distribution. For the network system in which node flow is provided with several gas sources, each source together with the nodes it supplies can be taken as one subsystem. So the maximum node entropy function of multi-source gas distribution network could be expressed as follows:

$$H_{j\max} = -\sum_{k\in K_j}\left(\frac{NL_{kj}\cdot\alpha_k\cdot\gamma_k}{\sum_{k\in K_j}\alpha_k\cdot\gamma_k\cdot NL_{kj}}\right)\ln\left(\frac{NL_{kj}\cdot\alpha_k\cdot\gamma_k}{\sum_{k\in K_j}\alpha_k\cdot\gamma_k\cdot NL_{kj}}\right)$$

$$\alpha_k = p_{kj} / p_{1j}$$

$$\gamma_k = Q_k / Q_1 \tag{4}$$

Where NL_{kj} is the path number of node j in the subsystem which is formed from the k-th gas source; α_k is the ratio of path flow probability between source k and reference source 1; p_{kj} is the path flow probability of the k-th source to node j; p_{1j} is the path flow probability of the reference source 1 to node j; γ_k is the ratio of gas supply quantity between the k-th source and the reference source 1.

The maximum system entropy H_{max} of multi-source gas distribution network can be obtained from (3) and (4).

RELIABILITY CONSTRAINT OF GAS DISTRIBUTION NETWORK

According to principle of maximum entropy, the maximum entropy value of a layout-given gas distribution network system is one and only decided. It reflects the gas network reliability to the full extent that is to say the potential maximal reliability of the system. But the hydraulic conditions of gas distribution network are different when adopting various diameters. So the actual system entropy will change with the change of hydraulic conditions caused by diameter parameter.

Taking maximum entropy as a reference value, the ratio of actual system entropy H and maximum entropy H_{max} is defined as system relative entropy which means the extent of achieving the optimal reliability. System relative entropy is proposed to describe the difference between actual reliability and maximum reliability of a layout-given gas network system and is expressed as follows:

$$\zeta_R = \frac{H}{H_{\max}}$$

The extent of achieving the reliability is considered to be greater when ζ_R is approaching nearer to 1 for the same layout-given gas distribution network.

PARAMETER OPTIMIZATION MATHEMATICAL MODEL OF GAS DISTRIBUTION NETWORK

Study on diameter parameter optimization with reliability constraint takes the minimum total investment cost of a gas distribution network as the optimization object. The investment cost can be expressed approximately as continuous function of pipeline diameter and length and so the total investment of gas distribution network is :

$$E = \sum_{l=1}^{M} (b \cdot d_l + c) L_l$$

Annular gas distribution network parameter optimization model with hydraulic and reliability constraints can be expressed as follows:

Minimize $$E = \min \sum_{l=1}^{M} (b \cdot d_l + c) L_l = \min \left(\sum_{l=1}^{M} F(d_l \, , \, L_l) \right)$$

Subject to:

Node equation: $q_i = \sum_{g=1}^{S} Q_{gi}$ $i=1, 2, \cdots, N$

Loop equation: $\sum_{j=1}^{k} \Delta P_j = 0$ $i=1, 2, \cdots, k$

Node pressure constraint: $P_i \geq P_{\min}$ $i=1, 2, \cdots N$

Relative entropy constraint: $\zeta_R = \frac{H}{H_{\max}} \leq \zeta_g$

Diameter class constraint: $D_i \in \overline{D}$

A SOLUTION BASED ON IMPROVED GENETIC ALGORITHM

Proper improvements are adopted to overcome the shortcomings of traditional genetic algorithm (Yan, 2003). The solution can help find optimal pipeline diameters which meet the gas distribution network optimization model. The algorithm improvements include:

Coding. Integer coding scheme is proposed to solve the redundancy problem caused by the fact that binary coding space is larger than parameter space of diameters. Integer coding scheme is using a positive integer g_i to represent a standard diameter and the number series $\{g_1, g_2, \ldots g_m\}$ made of m positive integers thus corresponds to a gas distribution network with m pipelines. For instance, integer genes 1，2，3，4，5，6，7 can be adopted to correspond respectively to standard diameters 100、150、200、300、400、500、600，unit (mm). Then, for a 10-pipeline gas distribution network, one of its diameter schemes {100，150，150，200，400，200，300，150，200，300} can be denoted as integer coding{1，2，2，3，5，3，4，2，3，4}.

Fitness function. Gas distribution network diameter optimization is a constrained optimization problem and needs to be converted to unconstrained optimization. So penalty function is introduced to convert the node pressure constraint and relative entropy constraint into the objective function.
For node pressure constraint, penalty function can be:

$$\phi(P) = \max(P_{\min} - P, 0)$$

For relative entropy constraint, penalty function can be:

$$\psi(\zeta_R) = \max(\zeta_{\min} - \zeta_R \;, 0)$$

Other equality constraints can be achieved if the network hydraulic analysis is right and vice versa. Thus, define:

$$const = \begin{cases} 0 & \textit{the result is right} \\ \text{a large enough positive number} & \textit{the result is wrong} \end{cases}$$

So the objective function is converted to:

$$\min E = \min\left(\sum_{j=1}^{M} F(d_l \;,\; l_l) + P_{FP}\sum_{i-1}^{N}\phi_i(P) + P_{F\zeta}\cdot\psi(\zeta_R) + const\right)$$

So the following fitness function can be built as:

$$f = 1\Big/\min\left(\sum_{j=1}^{M} F(d_l \;,\; l_l) + P_{FP}\sum_{i-1}^{N}\phi_i(P) + P_{F\zeta}\cdot\psi(\zeta_R) + const\right)$$

Where P_{FP} is the penalty factor of node pressure constraint, $P_{F\zeta}$ is the penalty factor of relative entropy constraint.

The following linear fitness-scaling of fitness function is adopted to improve genetic algorithm evolution properties.

$$f^{'} = \alpha\cdot f + \beta$$

$$\alpha = \frac{f_{avg}}{f_{avg} - f_{\min}}\;,\quad \beta = \frac{-f_{avg} f_{\min}}{f_{avg} - f_{\min}}$$

Where f' and f are respective fitness functions after and before the conversion, α, β is linear ratio coefficients, f_{avg} is the average of population fitness, f_{min} is the minimum of population fitness.

So we can obtain the fitness function after linear fitness-scaling:

$$f^{'} = \frac{f_{avg}}{f_{avg} - f_{\min}}(f - f_{\min})$$

Genetic operators: crossover rate P_c and mutation rate P_m. To increase the algorithm self-adaptability, the following crossover rate and mutation rate are adopted to automatically change with fitness:

$$P_c = \begin{cases} \dfrac{k_1(f_{\max} - f^0)}{f_{\max} - f_{avg}} & f \geq f_{avg} \\ k_2 & f < f_{avg} \end{cases}$$

$$P_m = \begin{cases} \dfrac{k_3(f_{\max} - f)}{f_{\max} - f_{avg}} & f \geq f_{avg} \\ k_4 & f < f_{avg} \end{cases}$$

Where f_{max} is the maximum individual fitness among the population, f^0 is the bigger fitness values of the two individuals in crossover, factors k_1, k_2, k_3, k_4 are set values in (0, 1) interval.

The realization process of the improved genetic algorithm is as follows:

1) Import the raw data of the gas distribution network;
2) Generate initial population randomly and store the data in an array;
3) Decode individuals in the initial population, calculate each total investment cost and count the individual fitness according to the fitness function;
4) Carry out selection, crossover and mutation operations to generate offspring population;
5) Judge whether the individuals meet the constraints by hydraulic analysis. Use proper penalty against some individuals which cannot meet the constraints and calculate the offspring population fitness;
6) Repeat 5) until all the individuals fitness fully tend to be consistent;
7) Evolution stops at the maximum genetic generation.

EXPERIMENTAL EXAMPLE

Beijing Yizhuang new district is supplied with natural gas from Ciqu gas station. Three hypo- high pressure regulator stations are planned to be established as gas sources of mid-pressure pipeline network and the design pressure is 0.4MPa. The mid-pressure gas distribution network is ringed arranged combining with the roads planning. The allowable minimum node pressure is 0.05MPa. Three optimal or sub-optimal designs are obtained using the mathematic model and optimization algorithm proposed in this paper based on original design data. And we can have the following results: (1) The total investment cost is almost the same as the original design and the increase is only 0.3279%, 0.7027% and 0.9968% of total amount and can be overlooked compared with the large investment. (2) All of the system relative entropy values of the three optimal schemes meet the set constraints and are no less than the original design values. (3) The reliability of the original design is proved to be in a good condition by the verification of the method in this paper.

CONCLUDING REMARKS

In this paper we approached the problem of finding the optimal diameters of gas distribution networks from a reliability and economy viewpoint. Information entropy is used to measure the reliability of gas network indirectly and models of actual entropy and maximum entropy are built. The system relative entropy is taken as the constraint of a layout-given gas distribution network with different diameter combinations. Once the problem is modeled, we design an approach for obtaining these optimal diameters based on an improved genetic algorithm with a new set of suitable problem-specific genetic operators and fitness functions. The application of actual engineering example proved that the total investment cost is a little larger in the new design scheme based on reliability constraint. But both the economy and reliability of the gas distribution network are overall considered, so the optimal scheme is more close to the practice. The method proposed in this paper can be proved to be practical and useful.

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Study on the Layout and Application of Groundwater Biological Removal of Iron and Manganese System

Xiaodong Duan[1], Hong Yang[2], Shan Wu[3]and Yan Zhang[3]

[1]Doctor, Key Laboratory of Beijing for Water Quality Science and Water Environment Recovery Engineering, Beijing University of Technology, Beijing 100124, dxd231@126.com.
[2]Professor, Key Laboratory of Beijing for Water Quality Science and Water Environment Recovery Engineering, Beijing University of Technology, Beijing 100124.
[3]Assoc. Prof., Key Laboratory of Beijing for Water Quality Science and Water Environment Recovery Engineering, Beijing University of Technology, Beijing 100124.

ABSTRACT

For the difference of iron and manganiferous groundwater qualities and spatial distribution between the groundwater sources and service regions, different layout of groundwater biological removal of iron and manganese system should be adopted. It was one of the conditions to prevent the ferromanganese sediment silting raw water pipelines to ensure the service lives of water pipelines. It was important for the security and stability runing of the entire water supply system. In this paper, the layout relationship between the groundwater biological removal of iron and manganese system and the water supply network were studied. As following recommendations had been made: 1, to minimize the oxygenation opportunity in the process of iron and manganiferous groundwater be taken and delivered; 2, to take into account of removal of iron and manganese water works should be as close as possible to water source during the establishment of the taking water, purification and delivery of water systems, in order to reduce the length of transmission of water line. Use of these recommendations in practice, achieved good results: the groundwater biological removal of iron and manganese treatment plant had a daily handling capacity of 200,000 tons and the effluent iron, manganese all was trace amount and met the Chinese standards for drinking water quality.

KEYWORDS

Groundwater; Biological removal iron and manganese; Water pipeline, layout; Application

INTRODUCTION

It was a worldwide problem that the content of iron and manganese in groundwater was excess. Since the 90s of last century, the theories and techniques of groundwater biological removal of iron and manganese had been established; it had been concerned increasingly by Chinese and foreign researchers for its effective and stable operation, less investment costs, etc. But it was not just a simple bio-filter. This system included the establishment of mechanism, bio-filter training, the system established and operational options, until the entire water supply system and stable operation (Cnmedri, 2001). Base on the characteristics of this system, the difference of iron and manganiferous groundwater qualities and spatial distribution between the sources and service regions, different layout of groundwater biological removal of iron and manganese system should be adopted.

THE MECHANISM OF GROUNDWATER BIOLOGICAL REMOVAL OF IRON AND MANGANESE SYSTEM

Under neutral pH conditions, Fe^{2+} was oxidized to Fe^{3+} by autocatalytic oxidation reaction; the product hydrous iron oxide was the catalyst. While soluble Mn^{2+} in groundwater was removed by the stability ecological systems of iron manganese-oxidizing bacteria growth in the biological filter (Zhang, 1996). Mn^{2+} was oxidized to Mn^{4+} under the catalysis of extracellular enzyme secreted by iron manganese-oxidizing bacteria (Zhang, 1997). So Mn^{4+} was adsorbed to the filter material surface and removed.

Researched on the removal course of Fe^{2+} in the iron manganese bio-filter, the results showed that it was very advantageous for Fe in the form of Fe^{2+} entering the bio-filter to iron, manganese removal (Yang, 2003). In different geographical and different water qualities, the oxidation rate of Fe^{2+} by dissolved oxygen in groundwater was different. In some areas there was a certain amount of time for a large number of Fe^{2+} complete oxidation by dissolved oxygen, while the rate was very fast in some areas. Researched on the biological removal of iron and manganese technology, it also had been proved that the self-catalytic oxidation of Fe^{2+} had participated in metabolism of iron, manganese-oxidizing bacteria. It was very important that Fe^{2+} existence for the balance and stability biological system of iron, manganese-oxidizing bacteria in bio-filter. Therefore, groundwater biological removal of iron and manganese technology required Fe in the form of Fe^{2+} entering the bio-filter to protect the cleaned water quality.

PROCESS AND PROCESS CHARACTERISTICS OF GROUNDWATER BIOLOGICAL REMOVAL OF IRON AND MANGANESE SYSTEM

Base on the groundwater biological removal of iron and manganese technology, and researched on the processing unit and the relationship between iron and manganese in the bio-filter, the following process as shown in Figure 1 was recommended.