Adaptive Genetic Algorithm for Steady-State Operation Optimization in Natural Gas Networks

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***Abstract*—Natural gas is normally transported through a vast network of pipelines. A pipeline network is generally established to connect gas wells with gas processing fields (gathering network) or to transmit gas at high pressure from gas sources to regional demand points (trunk network) or to distribute gas to consumers at low pressure from regional demand points (distribution network). The problems involved in optimizing the operation conditions of networks to promote benefit belong to a class of non-liner optimization problems. The operation benefit of gas network is combined with the purchase and sale prices of gas, the quantity bought and sold of gas and the management costs. Aimed at the maximum operation benefit, the paper proposes an operation optimization model of gas network with consideration of quantity input (output) constraints of each node, operation pressure constraints of pipelines, compressor constraints, valve constraints and hydraulic constraints of the pipeline system. The model adapts to all kinds of pipeline structures, followed with our presentation of a global approach, which is based on the method of adaptive genetic algorithm, to the optimization model. Afterwards, computer software is developed to optimize the operation conditions of gas trunk networks, gas gathering and distribution networks. Finally, an application example is demonstrated.**

***Index Terms*—gas pipeline network, operation optimization, mathematical model, adaptive genetic algorithm**

I. Introduction

After produced from the gas wells in fields, gas is gathered and treated before its long-distance transmission in trunk lines. Finally, gas is distributed to end-users through distribution network of each city. These pipeline networks are established in order to connect gas wells with gas fields (gathering network) or to transmit gas at high pressure from natural gas processing plant to regional demand points (trunk network) or to distribute gas to consumers at low pressure from regional demand points (distribution network). All the stages of gas transmission construct a unified and airtight pipeline network system.

The consumption of natural gas in China has increased steadily over the decades. Its clean-combustion characteristic and its ease of transmission through justify its wide use. As the demand for natural gas increases, gas pipeline networks have evolved into a complex system. Therefore, new challenges are being imposed on decision makers. Efforts are needed to intensify the development of an appropriate network capable of satisfying the demand for natural gas while still maximizing the operation benefits of the networks. The combination of a comprehensive method and a mathematic model cable of simulating pressure and the mass flow rate of the pipeline network under different operation conditions would greatly facilitate the evaluation of new operation schemes [1]. Nevertheless, the optimal scheme is confined to limited schemes obtained from simulation. Thus, the global optimization of operations is not able to be gotten. But, it is estimated that the global optimization of operations can enhance at least 15% of the network operation benefit [2]. Hence, the problem of maximizing the network operation benefit based on global optimal algorithm is of tremendous importance.

There is a wide range of literature on this subject .The United States and Europe started to study operation optimization of gas system in 60s of 20 century and it very started in 1961 when an American transmission company and IBM Corporation made a co-operative research on this issue [3-4].

With the development of optimization technology and simulation model of gas pipelines, the study on operation optimization had a further improvement. In 1983, Goldberg David introduced genetic algorithm to the study in order to obtain the optimum solution of the optimization model which aimed on minimum energy consumption. This new achievement drove a further research on applications of intelligent optimization algorithms for long-distance pipelines. During the year of 1984 and 1997, many scholars such as V.B. Mantri, Z. Renji, Bhaduri, Anglard Wilson, Bill Kay and Chi-Ki Sun continued to improve the optimization model and its solutions of gas pipelines and Richard Carter had an important breakthrough in 1998. According to application examples, he found that the convergence speed of dynamic programming algorithm is faster than simulated annealing algorithm and genetic algorithm.

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The pipeline networks were gradually formed with the construction of gas pipelines in the United States and North Europe. Therefore the study issue turned into optimization of pipeline networks based on the study achievements of gas trunk lines. Seamands Patrickaaron, Suming Wu and Kim Seong Bae made their dissertation about minimum energy consumption of gas pipeline network by operation optimization. By the end of 20^{th} century, the optimization model (including discrete variables, objective function aimed on minimum energy consumption) and its simulation methods of pipeline network had been developing rapidly and were accepted by the academic community [5-13].

Nevertheless, a much further study is still necessary because a huge number of complex influence factors are introduced into the optimization model by the larger scale of gas pipeline networks. In Sect.2, aimed at the maximum operation benefit, an operation optimization model of gas pipeline networks is presented with consideration of quantity input (output) constraints of each node, operation pressure constraints of pipelines, compressor constraints, valve constraints and hydraulic constraints of the pipelines system. Thus, the model adapts to all kinds of pipeline structures. In order to obtain the global optimal scheme, we provide the approach of adaptive genetic algorithm to solve the model in Sect.3. Based on achievements above, a computer program is developed to optimize the operation conditions of gas trunk lines, gas gathering and distribution network based on MS VC++. In Sect.4 an application example is given. We end this paper in Sect.5 with the conclusions and directions for future work.

II. Optimization Model of GAS Transmission Pipeline Networks

In this section, the paper focus on the pipeline networks operation benefit maximization problem. We first present the problem description, and then we provide the objective function and constraints of the optimization problem mathematic model.

Operation optimization of gas pipeline networks is developing gas distribution and transmission scheme to maximize the benefit of operation companies. The scheme must consider gas supply conditions, gas demand conditions, transmission pipeline conditions and different purchase and sale prices of gas.

A. Objective Function

The maximum operation benefit is set as objective function which can be obtained by the sales minus cost of purchase costs of gas, pipeline operation and management costs, compressor running costs. It is expressed as follow:

$$\max F = \sum_{i=1}^{N_n} S_i Q_{ni} - \sum_{i=1}^{N_e} R_i f\left(P_i, Q_i, L_i\right) - \sum_{i=1}^{N_c} C_i N_i \quad (1)$$

In which, Q_{ni} is inflow or outflow rate of gas at node i, inflow rate is set as positive value and outflow rate is negative, the value is 0 if there is not inflow and outflow rate, m^3; S_i is purchase or sale cost coefficient of gas at node i, dollars/$10^4 m^3$; N_i is the power of compressor station i, kW; f is a function of management and operation, it dependents on pressure, flow rate and pipeline length; R_i is management and operation cost coefficient of pipeline section i, dollars/km; P_i is maximum operation pressure of pipeline section i; Q_i is flow rate of pipeline section i; R_i is length of pipeline section i; C_i is cost coefficients of compressors station i, dollars/km; N_n is amount of nodes in pipeline system; N_e is amount of pipeline sections; N_c is amount of compressors stations.

It should be noted that natural gas exploration and development costs, natural gas processing costs can be reflected by the gas purchase coefficient; Pipeline design, construction costs can be presented by the gas sale coefficient; pipeline operation and management costs can either be illustrated by the second in (1) or by discounting the gas sale prices to get coefficient S_i, and then the second term in (1) can be neglected.

B. Constraints

The maximization proceeds subject to a number of constraints which involve the mass flow rate and pressure limits at each node, basic gas flow equations through each pipeline, mass flow balance equation at each node, power limits of compressors, characteristic equations of non-pipeline elements such as various types of compressors and valves. The rest of this section will express the constraints in detail.

1) Constraint of outflow and inflow rate

The gas must be provided at the demand nodes at a minimal mass flow rate which is requested by the consumers. At supply nodes, the mass flow rate is bounded above by the maximum mass flow rate that the gas wells can produce. In general, these two mass flow rate can be summarized in the following form:

$$Q_{i\min} \le Q_i \le Q_{i\max} \;.\;\; i = 1, 2, \cdots N_n \quad (2)$$

Where, Q_i is inflow or outflow rate of gas at node i, m^3; Q_{imin} is the minimum allowable inflow or outflow rate at node i, m^3; Q_{imax} is the maximum allowable inflow or outflow rate at node i, m^3.

2) Constraint of outflow and inflow pressure

Similar to mass flow rate constraint at each node, the pressure at each node must also satisfy the following constraint:

$$P_{i\min} \le P_i \le P_{i\max} \quad i = 1, 2, \cdots, N_n \quad (3)$$

Where, P_i is pressure at node i, MPa; P_{imin} is minimum allowable pressure at node i, MPa; P_{imax} is maximum allowable pressure at node i, MPa.

3) Constraint of pipeline strength

For safety reasons, and then P_k which is pressure in pipeline k must less than maximum allowable operation pressure P_{kmax}, that is:

$$P_k \le P_{k\max} \qquad \left(k = 1, 2, \cdots, N_p\right) \quad (4)$$

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. In which, N_p is amount of pipeline; P_k is maximum actual pressure in pipeline k, MPa; P_{kmax} maximum allowable pressure in pipeline k, MPa.

4) Pressure drop equation of pipelines

The pressure drop equation which is used to describe the relationship between gas flow rate in the pipeline and pressures at both ends of the pipeline takes the following form:

$$M = \frac{\pi}{4}\sqrt{\frac{\left[P_Q^2\left(1-C_1\Delta h\right)-P_Z^2\right]D^5}{\lambda ZRTL\left(1-\frac{C_1\Delta h}{2}\right)}} \tag{5}$$

In which, P_Q is pressure at starting point of the pipeline, MPa; P_Z is pressure at end point of the pipeline, MPa; M is mass flow rate in the pipeline, kg; T is average temperature of gas, K; L is pipeline length, km; D is pipeline internal diameter, mm; Δh is elevation difference between the starting and end point of pipeline, m; Z is compressibility factor, it is can be obtain by state equation of BWRS; C_1 is calculation coefficient,; R is gas constant; λ is gas friction factor.

5) Constraint of compressor's power

In order to ensure the feasible operation domain of the compressor, the compressor's power is confined as (6). Otherwise the surge or stonewall condition may occur.

$$N_{i\min} \le N_i \le N_{i\max} \qquad \left(i=1,2,\cdots,N_c\right) \tag{6}$$

Where, N_i is power of compressor i, kW; N_{imin} is minimum allowable power of compressors station i, kW; N_{imax} is maximum allowable power of compressors station i, kW.

6) Equation of Compressor

The compressor stations are constituted of several turbo compressors, which could be stopped or started. The operation power of a compressor as a function of the variables Q_i (flow through the compressor unit) and ε_i (compression ratio) is given by the following equation:

$$N_i = Q_i\left(K_{i1}\varepsilon_i^{K_{i3}} - K_{i2}\right) \tag{7}$$

Where, N_i is power of compressors station i, kw; K_{i1}, K_{i2} are compressor coefficients; K_{i3} is compressor index; ε_i is compression ratio of compressor; Q_i is flow through the compressor unit, m^3.

7) Equation of other non-pipe elements

Besides the compressor, other non-pipe elements include various types of valves, buffer tanks and so on. All the characteristic equation can be expressed as a general model which is given by:

$$F_N(P_{in}, P_{out}, M) = 0 \tag{8}$$

Where, F_N is a general model of non-pipe elements; P_{in} is s of non-pipeline elements, MPa; P_{out} is outlet pressure of non-pipe elements, MPa; M is mass flow rate in non-pipe elements, kg.

8) Mass flow rate balance equations of nodes in network

According to mass conservation law, the algebra of outflow and inflow rate must equal to 0, which is expressed as follow:

$$\sum_{k\in C_i}\alpha_{ik}M_{ik} + Q_i = 0 \tag{9}$$

Where, C_i represents the set of elements connected with node i; M_{ik} is absolute value of inflow (outflow) rate of element k connected with node i, m3; Q_i is exchange flow rate between node i and outside (inflow is set as positive value and outflow is negative value), m^3; a_{ik} is a coefficient, its value is -1when gas in element k flow into node i, the value is 1 when gas in element k flow out of node i.

C. General form of natural gas optimization model

In order to simplify the solution of the problem, it is necessary to transform the variables, objective function and constraints into a general form. According to analysis above, the optimization variables include pressure of nodes in network, inflow and outflow rate at each node, flow rate in elements(pipeline, compressors and so on), power of compressors. x is utilized to summarize all the optimization variables, then:

$$x = \left[P_1, Q_1, P_2, Q_2\cdots, P_{N_n}, Q_{N_n}, M_1, M_2, \cdots, M_{N_e}, N_1, N_2, \cdots, N_{N_C}\right] \tag{10}$$

The general form of optimization problems can be written as:

$$\min_{x\in R} f\left(x\right) \tag{11}$$

$$\text{S.t. } h_i\left(x\right)=0 \quad i=1,2,\cdots,M \tag{12}$$

$$g_i\left(x\right)\le 0 \quad i=1,2,\cdots,L \tag{13}$$

In which, $f(x)$ is general form of objective function (1); $h_i(x)$ is general form of equality constraints (6)-(9); $g_i(x)$ is general form of inequality constraints (2)-(5); M is total of equality constraints, L is total of inequality constraints.

The mathematical model not only contains discrete variables and integer variables such as the number of compressors but also includes continuous variables such as mass flow rate. At the same time, the objective function and some of the constraints are non-liner equation. Hence, the optimization problem is a class of problems belonging to the area of large scale nonlinear discrete-continuous optimization. In order to find the global optimum, the heuristic method, adaptive genetic algorithm, is adopted.

III. Solution of Mathematic Model Based on Adaptive Genetic Agorithm

In this section, we introduce genetic algorithms (GA), and present their theoretical foundations and their application in solving the gas pipeline network optimization model.

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A. Basic Principles of Adaptive Genetic Algorithm

Genetic Algorithm (GA) has been widely used and improved since it proposed by J.Holland in 1975. GAs represents a class of adaptive algorithm whose search methods are based on simulation of natural genetics. They belong to the class of probabilistic algorithms; yet, they are very different from random algorithms as the combine element of directed and stochastic search. For hard optimization problems, they are superior to hill-climbing methods, since at any time Gas provide for both exploitation of the best solution and exploration of the search space. Because of this, Gas are also more robust than existing directed search methods. Another important property of such genetic-based search methods is their domain-independence.

In general, a GA performs a multi-directional search by maintaining a population of potential solutions and encourages information formation and exchange between these directions. This population undergoes a simulated evolution: at each generation the relatively 'good' solutions reproduce, while the relatively 'bad' solutions die. To distinguish between different solutions we need some evaluation function which plays the role of an environment.

As described above, GA is based on nature principle of biological survival of the fittest and the optimal solution or quasi-optimal solution of the optimization problem would be gradually approached by simulating natural selection in biological evolution, crossover and mutation process. Because the basic unit of the solution process is an initial feasible solution of optimization problems, it is not involved in solving the complex issues of non-linear equations; therefore, it is especially suitable for solving this type of highly sub-linear constrained optimization problem such as gas pipeline network optimization.

However, crossover probability and mutation probability of the basic genetic algorithm should be determined by repeated experiments, and it is difficult to find the best value. Fortunately, Srinvivas [15] proposed adaptive genetic algorithm (AGA) in which the crossover probability and mutation probability can adjust dynamically according to the fitness in the new algorithm. In the AGA algorithm, according to the fitness of individuals, the crossover probability and mutation probability adjust linearly between the population average fitness and maximum fitness. The closer the fitness is to the biggest one and the smaller the crossover probability and mutation probability are. If the fitness value close to or equal to the maximum value of the individual, the crossover probability and mutation probability close to or equal to zero. The following papers will introduce the application of AGA in solving the gas pipeline network optimization problem.

B. Procedures of solving operation optimization problems with AGA

Procedures of solving operation optimization model with AGA are as follow:

Step (1): Generate initial populations

Initial populations are sets of initial values of optimization variables which are necessary in AGA and can be obtained by pipeline network simulation .

Step (2): Coding

This paper utilizes real-coded method which encode variables values $X=(x_1, x_2, \ldots, x_n)$ into individuals $x_1, x_2, \cdots, x_n$ and every variable of the individual is a gene.

Step (3): Determine fitness function

Equality constraints and objective function can be integrated into fitness function. Because the types of inequality constraint are lower or upper limits, it requires special treatment. The objective function and constraints can be included in GA algorithm fitness function by using of penalty function method. The AGA algorithm fitness function is obtained as follow:

$$F_c(x) = f(x) + C\left\{\sum_{i=1}^{m}\left[\max\left\{0,\ -g_i\left(x\right)\right\}\right]^2 + \sum_{i=1}^{M}\left|h_i\left(x\right)\right|^2\right\} \tag{14}$$

In which, C is penalty function; $F_c(x)$ is the AGA algorithm fitness, the priority of individuals is determined in accordance with the fitness during selection process.

Step (4): Selection

Assume the size of the population is N, in which the fitness of individual i is F_i, then the selection probability of individual i is P_i which can be obtained as follow:

$$p_i = \frac{F_i}{\sum_{j=1}^{N} F_j} \tag{15}$$

After the individual fitness is obtained, selection of crossover individual can be realized by roulette wheel method. Firstly, the roulette is divided into N division according to the proportion of individual accounts for the total population fitness. Then turn the roulette N times, the pointer individual is the selected corrosive one each time. The process can be achieved through the method of random number generator.

Step (5): Crossover

This paper adopts real number encoding method. Therefore, crossover operator is set as arithmetic crossover operator which means new individual can be generate by linear combination of two father individuals. The new individual generated by linear crossover can be calculated as follow:

$$\begin{cases} X_A^{t+1} = \partial X_B^t + \left(1-\partial\right) X_A^t \\ X_B^{t+1} = \partial X_A^t + \left(1-\partial\right) X_B^t \end{cases} \tag{16}$$

In which ∂ is a parameter, it is a random or constant; X^t_A and X^t_B are two father individual of the generation; X^{t+1}_A and X^{t+1}_B are two new individuals.

The process will be repeated until M new individuals are generated to form a new population.

The improved crossover probability calculation in AGA is expressed as follow:

$$P_c = \begin{cases} P_{c1} & f < f_{avg} \\ P_{c1} - \dfrac{(P_{c1} - P_{c2})(f_{\max} - f')}{f_{\max} - f_{avg}} & f \geq f_{avg} \end{cases} \quad (17)$$

In which, P_{c1}=0.9, P_{c2}=0.6, $f_{\max}$ is the largest fitness value in population; f_{avg} is the average fitness value of population; f' is the bigger one between the two crossover individual's fitness; f is fitness of mutation one.

Step (6): Mutation

Assume X=(x_1, x_2, ... , x_n) is an individual. If x_k is selected as mutation point according to mutation probability and the value range of gene x_k is [U^k_{min}, U^k_{max}], and then the new gene is determined as follow:

$$x'_k = \begin{cases} U^k_{\min} & , \ if \ \text{random}(0,1) = 0 \\ U^k_{\max} & , \ if \ \text{random}(0,1) = 1 \end{cases} \quad (18)$$

In which random (0, 1) express a uniformly distributed random number between 0 and 1 .

Similar to crossover probability, mutation probability of AGA is obtained as follow:

$$P_m = \begin{cases} P_{m1} & f < f_{avg} \\ P_{m1} - \dfrac{(P_{m1} - P_{m2})(f_{\max} - f')}{f_{\max} - f_{avg}} & f \geq f_{avg} \end{cases} . \quad (19)$$

In which P_{m1}=0.1, P_{m2}=0.001, the other symbols has expressed above.

Step (7): Check whether the termination conditions are satisfied, if met, then the outputs are the optimization results. Otherwise, move back to Step (3) and continue the calculation until get the results.

IV. Software Development

Based on the achievements above and the MS Visual C++, the software package PESO (Pipeline Emulation System and Optimization) has been developed for the practical steady state optimization of gas gathering, transmission and distribution pipeline networks. PESO has an input and output interface in the form of text files and figure files. It allows operators to create a network on the software interface; to receive initial values of supplies, demands and gas parameters; to produce and present a graphic output as shown in Fig.1 and Fig.2. The general functions of optimization are: to minimize the expenditure; to select supplies and demands; to maximize the operation benefit; to optimize net work operation.

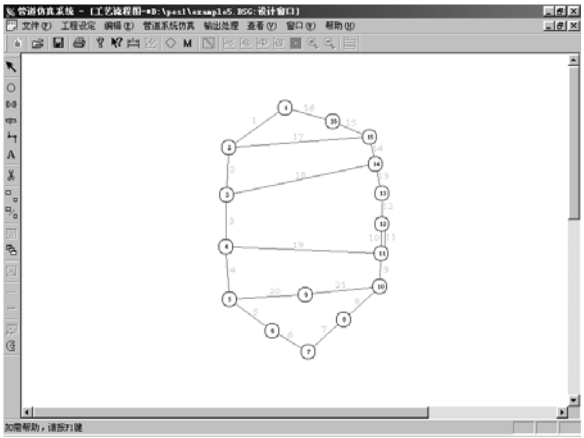

Figure 1. Network creating interface

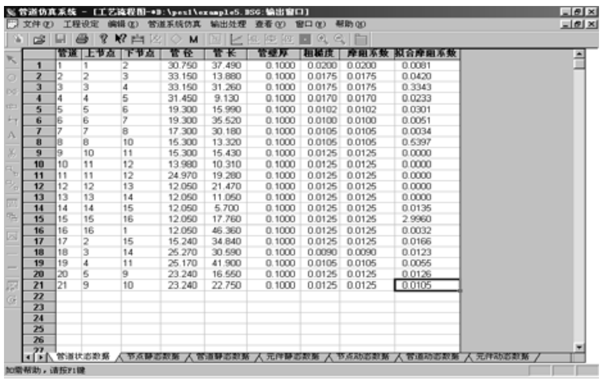

Figure 2. Results output interface

V. Application Example

A pipeline network system constructed as Fig.3 and it is formed by 22 segments of pipelines and 21 nodes. Pipe material is TS-52K and X52. The pressures of the system ranges from 2.0MPa to 3.6MPa. The management fees are obtained according to sale price of gas. The structural factors are shown in TABLE I and the input (output) quantity, quantity constrains and purchasing (sale) price of gas of each node are shown in TABLE II. The negative quantities present the input quantities while the positive ones present the output quantities.

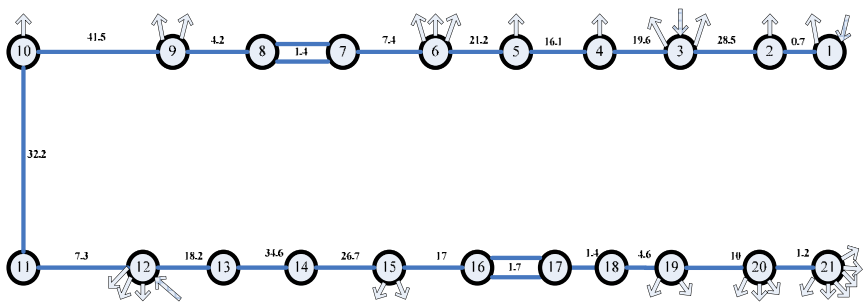

Figure 3. Simplified diagram of basic information of a gas pipeline network

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TABLE I.
BASIC DATA OF EACH SEGMENT

NO.	Description of pipes	Pipeline specification	Length(km)	Fitting friction coefficient
1	1—2	720×8	0.7	0.4
2	2—3	720×8	28.5	0.011
3	3—4	720×8	19.6	0.011
4	4—5	720×8	16.1	0.011
5	5—6	720×8	21.2	0.011
6	6—7	720×8	7.4	0.011
7	7—8	720×9	1.4	0.011
8	7—8	711×11	1.4	0.011
9	8—9	720×8	4.2	0.011
10	9—10	720×8	41.5	0.011
11	10—11	720×8	32.2	0.011
12	11—12	720×8	7.3	0.011
13	12—13	720×8	18.2	0.011
14	13—14	720×8	34.6	0.011
15	14—15	720×8	26.9	0.011
16	15—16	720×8	17	0.011
17	16—17	720×8	1.7	0.011
18	16—17	720×8	1.7	0.011
19	17—18	720×8	1.4	0.011
20	18—19	720×8	4.6	0.03
21	19—20	720×8	10	0.018
22	20—21	529×7	1.2	0.018

TABLE II.
THE OPTIMIZATION DATA OF EACH NODE

NO.	Purchasing (Sale) price (Yuan/m^3)	Gas consumption (10^4m^3/d)	Income (10^4Yuan/d)	Maximum consumption (10^4m^3/d)	Minimum consumption (10^4m^3/d)	Optimization consumption (10^4m^3/d)	Optimization pressure (MPa)	Maximum income (10^4Yuan/d)
1	0.645	-400	-256.0	-400	-400	-400	3.60	-256.0
3	0.645	-80	-51.6	-80	-80	-80	3.535	-51.6
12	0.645	-140	-90.3	-140	-140	-140	3.081	-90.3
1	1.01	3.90	3.939	4.485	3.822	3.822	3.60	3.860
2	1.0525	1.00	1.053	1.05	0.95	1.05	3.598	1.105
3	1.01	17.85	18.029	20.5275	17.493	19.9093	3.535	20.108
3	1.00	0.31	0.31	0.3255	0.2945	0.2945	3.535	0.295
4	1.01	2.60	2.626	2.99	2.548	2.99	3.475	3.020
5	1.01	0.42	0.424	0.441	0.399	0.441	3.425	0.445
6	1.0139	3.60	3.650	4.14	3.528	4.14	3.359	4.198
6	0.872	14.00	12.208	14.28	12.6	12.6	3.359	10.987
6	1	2.40	2.40	2.52	2.28	2.28	3.359	2.280
7		0.0	0.0	0.0	0.0	0.0	3.338	0.0
8		0.0	0.0	0.0	0.0	0.0	3.334	0.0
9	1.0516	2.35	2.471	2.7025	2.303	2.7025	3.321	2.842
9	1	2.00	2.0	2.1	1.9	1.9	3.321	1.900
10	1.0525	0.80	0.842	0.84	0.76	0.84	3.200	0.884
11		0.0	0.0	0.0	0.0	0.0	3.103	0.0
12	1.0523	0.87	0.916	0.8874	0.783	0.8874	3.081	0.934
12	1.0947	1.51	1.653	1.5402	1.359	1.5402	3.081	1.686
12	1.0525	8.35	8.788	8.517	7.515	8.517	3.081	8.964
13		0.0	0.0	0.0	0.0	0.0	2.984	0.0
14		0.0	0.0	0.0	0.0	0.0	2.791	0.0
15	1	4.00	4.0	4.2	3.8	3.8	2.630	3.800
15	1.1609	1.50	1.741	1.575	1.425	1.575	2.630	1.828
16		0.0	0.0	0.0	0.0	0.0	2.525	0.0
17		0.0	0.0	0.0	0.0	0.0	2.514	0.0
18		0.0	0.0	0.0	0.0	0.0	2.505	0.0
19	1.01	1.50	1.515	1.575	1.425	1.51	2.470	1.525
19	1.0943	4.00	4.377	4.2	3.8	4.2	2.470	4.596
20	1.0525	1.19	1.252	1.2495	1.1305	1.2495	2.412	1.315

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20	1.0968	17.00	18.646	17.85	16.15	17.85	2.412	19.578
20	1.0	242.62	242.62	242.62	242.62	242.62	2.412	242.62
21	1.1001	18.00	19.802	18.9	17.1	18.9	2.402	20.792
21	1.0473	5.14	5.383	5.397	4.883	5.397	2.402	5.652
21	1.0884	2.50	2.721	2.625	2.375	2.625	2.402	2.857
21	0.8635	4.00	3.454	4.08	3.6	3.6	2.402	3.109
21	1.1058	1.33	1.471	1.3566	1.197	1.3566	2.402	1.500
21	0.7643	12.00	9.172	12.24	10.8	10.8	2.402	8.254
21	0.8204	140.00	114.856	161	137.2	137.2	2.402	112.559
21	1.1048	3.26	3.602	3.423	3.097	3.423	2.402	3.782
21	1.0	100	100.0	100	100	100	2.402	100.0
Total			198.021					199.375

According to the data in TABLE II, it can be concluded that gas consumption of each node is optimized because of the different sale price. The gas consumption of node 20 whose sale price is 1.0968 Yuan/m^3 was $17 \times 10^4 m^3/d$ before and its optimized consumption is $17.85 \times 10^4 m^3/d$ so that the income increase 0.932×10^4Yuan/d. On the other side, the gas consumption of node 1 whose sale price is 1.01 Yuan/m^3 was $3.9 \times 10^4 m^3/d$ before and its optimized consumption is $3.822 \times 10^4 m^3/d$ so that the income decrease 0.079×10^4Yuan/d. The optimization of other nodes is also based on their price. According to the method that increases the consumption of high price node and decreases it of low price node, the overall income of the system increase 1.354×10^4Yuan/d although the overall consumption remains the same. Hence, Operation optimization has accomplished the results of maximizing operation benefit.

VI. Conclusion

In this paper, we presented the gas pipeline network optimization mathematic model. The objective function of the model is the maximum operation benefit and it is established with consideration of quality input (output) constraints of each node, operation pressure constraints of pipelines, compressor constraints, valve constraints and hydraulic constraints of the pipelines system. In order to obtain the global optimal solution, we utilized the adaptive genetic algorithm to solve the large scale nonlinear discrete-continuous optimization problem. Based on the theory achievements, a gas pipeline network simulation and optimization software (PESO) is developed.

In the application example, a steady state operation optimization problem is solved. The results show the operation benefit is improved with using of AGA.

As a result, AGA is ready for application to other more difficult optimization problems such as the gas network transient optimization. However, the optimal results obtained through AGA should be compared with other heuristic algorithm such as simulated annealing algorithm, artificial neural networks, so that the advantages and disadvantages of AGA can be confirmed.

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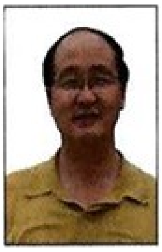

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