Performance Comparison and Analysis of the Genetic Algorithms and Particle Swarm Optimization Methods to Optimize the Pressure-Flow Equations in Gas Transmission and Distribution Networks

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Abstract

One of the most important goals of gas engineering is to optimally distribute gas in gas transmission and distribution networks; however, this process often suffers from some inevitable distribution network problems such as errors caused by inaccurate estimates of pressure at various points in the network. Recently, statistical optimization methods have been proposed to solve this problem. Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) are common methods for this purpose. The purpose of this study is to compare the performances of these two procedures. If similar constraints and computational loads are applied to both methods, PSO can provide more accuracy and speed compared to GA, although repeatability of GA was found to be better.

Keywords: Gas network, optimization, particle swarm optimization, genetic algorithm

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Introduction

After producing natural gas from the underground reservoir, the first process is to transport the natural gas to operation and filtration units. There are a number of options for transporting natural gas from oil and gas fields to market. These include pipelines, liquefied natural gas (LNG), compressed natural gas (CNG), and gas to solids (GTS), i.e., hydrates, gas to power (GTP) and any possible method. If technical and economic hurdles can be overcome, these pipelines can become effective. Pipelining is the method that is preferred. In the last decade, on average, over 12,000 miles per year of new gas pipelines have been completed, most of which are transnational (Mokhatab, S. et al., 2014).

To keep gas flowing in these networks, pressure-boosting stations are installed along the delivery system. The stations use fossil energy or electricity to operate flowing of gas depending on gas volume. The performance of these compressors depends on many factors, the most important of which is gas pressure in the delivery system. In addition, the most important sites along the system are gas delivery points. To estimate pressure, pressure-flow equations are used, and Bernoulli's Equation is one of the most widely used ones for estimating gas pressure in a gas delivery system (Schroeder, 2001). Such equations always show an inevitable degree of error. To tackle this problem a few number of methods have been proposed (Mokhatab, S. et al.,2012; Golshan et al., 2000; Haji Ali Akbari and Reza Mosaiebi Behbahani, 2014).

Recently, researchers have studied the optimization algorithms in a wide variety of fields (Edgar et al., 2001; Rao, 2009). Genetic algorithm (GA) and particle swarm optimization (PSO) are the most popular optimization algorithms, which are called population-based algorithms (Goldberg et al., 1988; Gen et al., 2008; Kennedy and James, 2010; Poli et al., 2007; Haupt, R. L. and Haupt, S. E, 2004). GA was proposed by John Holland in the 1970s based on Darwin's theory of evolution (Holland, J.H, 1975). In GA, the solutions (chromosomes) are evaluated based on fitness values (or objective function values) for a randomly generated initial population. The fitness or objective function values of all solutions are evaluated for reproduction. Thereafter, the population of the new generation is formed based on the selected individual crossover and mutation operations in an iterative manner until maximum number of generations or convergence is reached. Inspired by the social behavior of bird flocking, Kennedy and Eberhart introduced PSO in the 1990s (Eberhard and Kennedy, 1995). The general procedure of PSO is to propagate in the design space the optimal solution over a number of iterations (moves) for an initial population which is randomly generated. In this algorithm, every solution is known as a *particle* which contains three parameters: position, velocity, and the population of solutions (*swarm of particles*). Thereafter, selection is made for reproduction to update velocity, and the position is determined for each individual particle based on fitness values. This process is repeated until the stopping criterion is reached.

In this paper, the performances of GA and PSO for pressure equation tuning in natural gas transmission and distribution networks are compared. To the best of our knowledge, this is the first time that a performance comparison is made between GA and PSO in tuning gas networks. In this study, performance evaluation of the optimization algorithms is practically demonstrated through examining the performance of a natural gas network in Western Azerbaijan Province (as a national site of the Iranian Transmission and Distribution Gas Network).

In recent decades, the optimization algorithms have been studied by the researcher in a wide variety of fields (Rao, 2009; Edgar et al., 1988). Genetic algorithm and particle swarm optimization are the most popular optimization algorithms which are called population based algorithms (Goldberg et al., 1988; Kennedy, 1993; Kennedy and Eberhart, 1995). Genetic algorithm (GA) was defined by John Holland in the 1970s based on the Darwinian theory of evolution applied to biology (Holland, 1992). In GA the solutions (chromosomes) are evaluated based on fitness value (or objective function value) for a randomly generated initial population. For all solutions, fitness or objective function values are evaluated for reproduction. The population of new generation is formed based on the selected individuals crossover and mutation in an iterative manner until maximum number of generations or convergence is reached. Kennedy and Eberhart Particle introduced the swarm optimization (PSO) in the 1990s inspired by the social behavior of birds flocking (Kennedy and Eberhart, 1995; Eberhart and Kennedy, 1995). The general procedure of PSO is to propagate in the design space towards the optimal solution over a number of iterations (moves) for a randomly created initial population. In this algorithm, every solution known as particle contains parameters of position and velocity, and the population of solutions is called a swarm of particles. Thereafter, based on fitness, selection is done on the particles for reproduction to update velocity and position for each individual. This process is repeated until stopping criterion is reached.

In this paper, the performances of GA and PSO for tuning of pressure equation in natural gas transmission and distribution networks are compared. To the best of our knowledge, this is the first time that a performance comparison between GA and PSO for tuning the gas networks is presented. Performance evaluation of the optimization algorithms is practically demonstrated through Western Azerbaijan Province (a part of the Iranian transmission and distribution gas network).

Problem Description

Gas transmission and distribution networks

Gas Network Management

Gas network management means setting the pressure and input equipment's power so that there is no pressure drop or abnormal pressure in the network. The manager tool for this purpose is dispatching, which is a set of tools and software connecting the equipment and engineers. The equipment generally has little specified error value that will be negligible by calibration. But the software is more challenging. This will be discussed below.

General Flow Equation

Based on the assumptions that there is no elevation change in the pipeline and that the condition of flow is isothermal, the integrated Bernoulli's equation is expressed by the following Equation (Schroeder, 2001):

$$Q_{sc} = C\left(\frac{T_b}{P_b}\right) D^{2.5} \left(\frac{{P_1}^2 - {P_2}^2}{f \gamma G T_a Z_a L}\right)^{0.5} E \quad (1)$$

Qsc: standard gas flow rate (measured at base temperature and pressure, ft3/day)
Tb: gas temperature, base conditions, 519.6◦R
Pb: gas pressure, base conditions, 14.7 psia
P1: inlet gas pressure, psia
P2: outlet gas pressure, psia
D: inside diameter of pipe, inches
f: Moody friction factor
E: flow efficiency factor
γ_G: gas specific gravity
Ta: average absolute temperature of pipeline
Za: average compressibility factor
L: pipe length, miles
C: 77.54 (a constant for the specific units used).

Pipelines are usually not horizontal; however, as long as the slope is not too great, a correction for the static head of fluid (Hc) may be incorporated into the following equation (Schroeder, 2001).

$$Q_{sc} = C\left(\frac{T_b}{P_b}\right) D^{2.5} \left(\frac{{P_1}^2 - {P_2}^2 - H_c}{f \gamma G T_a Z_a L}\right)^{0.5} E \quad (2)$$

Where

$$H_c = \frac{0.0375\, g(H_2 - H_1)P_a^2}{Z_a T_a}$$

H1: inlet elevation, ft
H2: outlet elevation, ft
g: gravitational constant, ft/sec2

Error definition

Based on the review of data taken from network measurement system a significant amount of error has been observed.
Error in performed analysis means the difference between the pressure data that has been read from the pressure control station (And outbound of the network) and the predicted quantities from the equations used in the software.

$$E= P_{out}(\text{measurement}) - P_{out}(P,D,z,L,T,\mu,\ldots)$$

This value has been reduced with passage of time by providing newer equations.

Sources of Error

Perhaps the first question that comes to mind is: "Why is it that no equation which provides an accurate answer is available?"
The answer is the condition of pipelines and their performance in the future is ambiguous. For example:

1. Aging of the pipes: This factor is influenced by many parameters (such as temperature tubes per minute, precise amounts of alloy composition, metallurgy metal tube materials, gas ...).
2. Environment: Temperature and weather forecast for the next few days is an approximation so exact temperature and weather forecasting for over than 30 years is impossible.

The only way in this issue is using statistical optimization for fixing the equations which are used in the software.
Such corrections are common in developed countries, for example (in 2012), ATMOS international limited has carried out extensive research on the Subsea Pipeline Models (Hanmer et al., 2012) which leads to better estimates of the hydraulic capacity and the Estimated Time of Arrival will be achieved by tuning the effective roughness and the heat transfer of the pipeline models.

Evolutionary algorithms

All evolutionary algorithms consist of three main components. In the first part, the population is randomly initialized. Possible solutions based on the cost function are evaluated and ranked in the second step. Thereafter, in the last step some of the solutions are selected and new population is generated. As mentioned previously, the purpose of this paper is to compare the PSO and GA in natural gas transmission and distribution networks for tuning of pressure equation. Therefore, the main characteristics and general process of each of these algorithms are described in the following sections.

Genetic Algorithms

There are many ways to implement a genetic algorithm, but the overall process of this algorithm is shown in Fig. 1. The algorithm can be summarized as follows:

- An initial population is randomly generated.
- Objective function values for each solution are calculated (chromosome).
- Better chromosomes are selected (chromosomes with higher objective function values have a higher probability to be chosen).
- A pair of offspring chromosomes are produced by GA parameters such as crossover and mutation.
- New population is created and the process is repeated until stop criterion is satisfied.

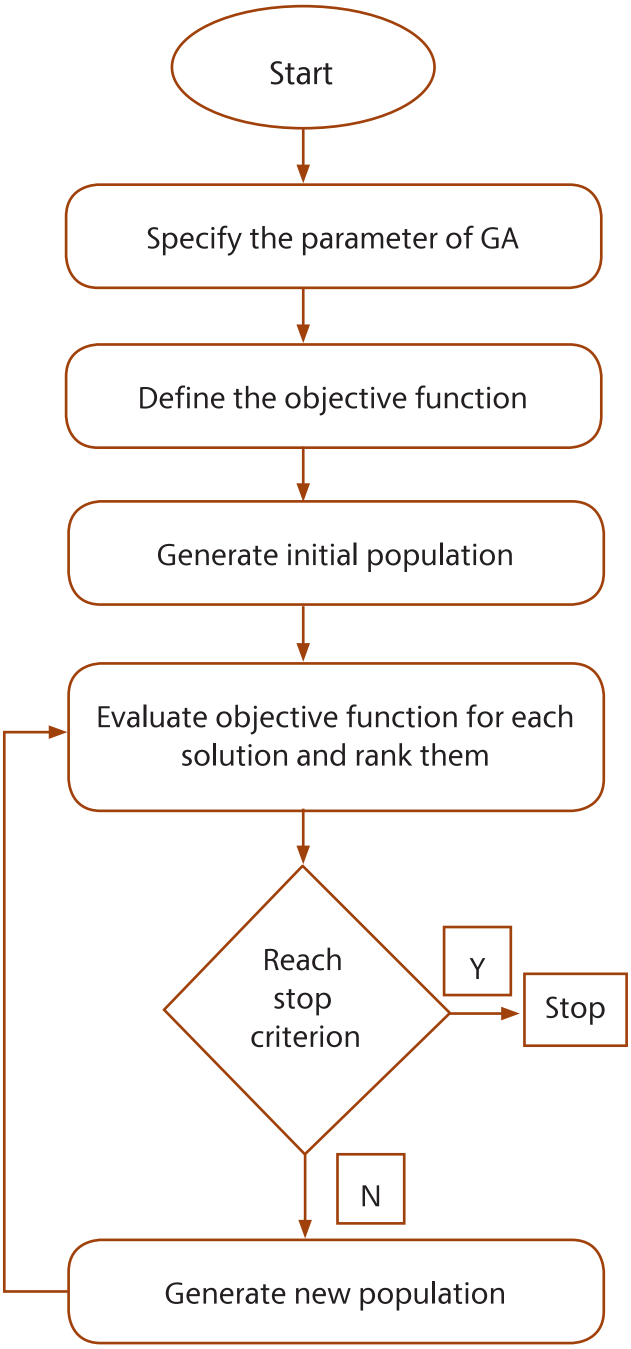

Figure 1. GA flowchart

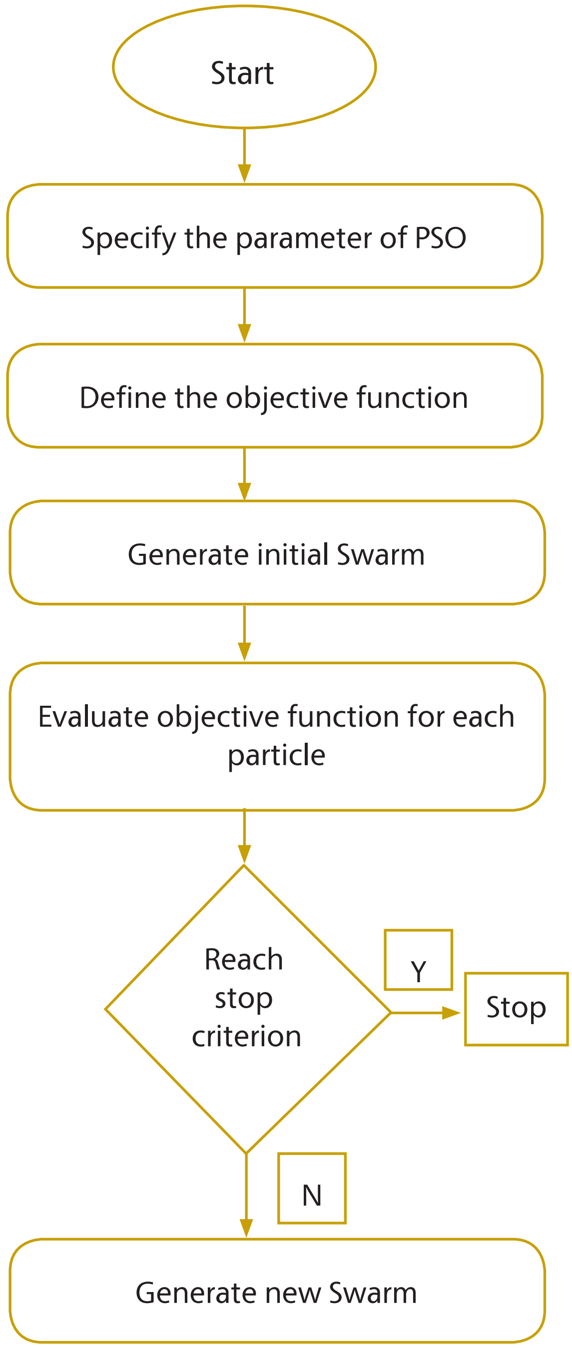

Figure 2. PSO flowchart

Particle Swarm Optimization

One of the drawbacks of previous methods is the lack of data, which limits the search and may even become divergent. In addition, calculation of this method is less. The overall process of the method is shown in Fig. 2. The searching procedure of PSO can be summarized as follows:

- The velocity and position of all particles are randomly initialized.
- Objective function of each particle is evaluated.
- Position and velocity of particles in iteration are updated according to:

(3) $$v_i^k = \omega v_i^{k-1} + c_1 r_{i1}^{k-1}\left(x_B - x_i^{k-1}\right) + c_2 r_{i2}^{k}\left(x_G - x_i^{k-1}\right)$$

(4) $$x_i^k = x_i^{k-1} + v_i^k$$

- When the size of population, inertia weight, and two positive constants called cognitive and social parameters, and random numbers uniformly distributed within the range.
- Personal best and global best are updated by the following:
- The algorithm is repeated until a certain number of iterations is met.

Result and discussion

As mentioned earlier, the results of the gas engineering software (the gas transmission networks) always show an error in predicting pressure in different parts of the network (these default error values are shown in Table 1). To construct a pipeline, from the conventional equation of gas transmission network, AGA is one of the common equations in National Iranian Gas Company's software. The fully turbulent AGA equation has the following formula in Imperial Units (Haji Ali Akbari and Mosaiebi, 2014).

(5) $$Q_b = 38.774\left(\frac{T_b}{P_b}\right)D^{2.5}\left(\frac{{P_1}^2 - {P_2}^2 - E}{GT_{ave}Z_{ave}L}\right)^{0.5}\left(4log\right)$$

where
Qb: gas flow rate at base conditions, SCF/D
Tb: gas temperature, base conditions, 519.6◦R
Pb: gas pressure, base conditions, 14.7 psia
P1: inlet gas pressure, psia
P2: outlet gas pressure, psia
D: inside diameter of pipe, inches
E: flow efficiency factor
Ta: average absolute temperature of pipeline
Za: average compressibility factor
L: pipe length, miles
Ke: roughness

The equation can be rewritten as below (Haji Ali Akbari, 2014; Ahmed, 1989):

(6) $$P_{out} = \sqrt[2]{{P_{in}}^2 - \left[\left(gasdensity * L * T * Z_{ave} * A^2\right) - E\right]}$$

After one year, the data are gathered from this gas network, and accordingly two sets of data can be obtained. As mentioned earlier, the data were gathered from the Iranian Transmission and Distribution Gas Network, Western Azerbaijan Province.

- Series pressures calculated in the software: This series is calculated by physical specifications of the gas network, its volume, properties of the gas, and specifications of the equipment used.
- Series of reports from pressure measurement systems: This series of data is obtained from the real system and is normally used for system performance analysis. In the next section, some criteria for data analysis are introduced.

$$Objective\ function\ for\ default\ value = \sum \left|\mathbf{P_m}^2 - \mathbf{P_{calc}}^2\right|_{\mathbf{i}} = \mathbf{1547273}$$

Therefore, statistical optimization methods are the only way to eliminate the errors in the gas transmission network. In this paper two approaches of genetic algorithm (GA) and Particle Swarm Optimization algorithm (PSO) were applied and evaluated on a small portion of the gas transmission network.

Table 1: The default error values

Exact Value	Default Value	Error	$\lvert P_M{}^2 - P_{CLC}{}^2 \rvert$
1070	1069.127	-0.873	1867.458
1069.65	1030.482	-39.168	82257.97
1069.73	990.6736	-79.0564	162888.1
1069.81	949.197	-120.613	243518.5
1061.82	1059.937	-1.883	3995.268
1061.78	1051.636	-10.144	21438.49
1061.63	1051.33	-10.3	21763.49
1057.62	887.1947	-170.425	331445.6
1045.41	1046.629	1.219	2550.196
1026.49	1031.204	4.714	9699.97
1007.02	1015.033	8.013	16202.71
994.085	1003.845	9.76	19499.8
990.617	893.691	-96.926	182638.4
983.183	763.3859	-219.797	383890.8
986.481	997.5334	11.0524	21928.12
986.948	997.2169	10.2689	20375.19
985.903	996.6532	10.7502	21312.88

PSO

Evaluated network (part of the Iranian transmission and distribution gas network– Western Azerbaijan Province) based on equations AGA and Colebrook-White is modeled and the values of roughness by PSO have been modified so that the error (the difference between the measured pressure and calculated pressure) approaches zero (Figure 3).

As is clear from Figure 3, the objective function value is reduced to about 2,300.

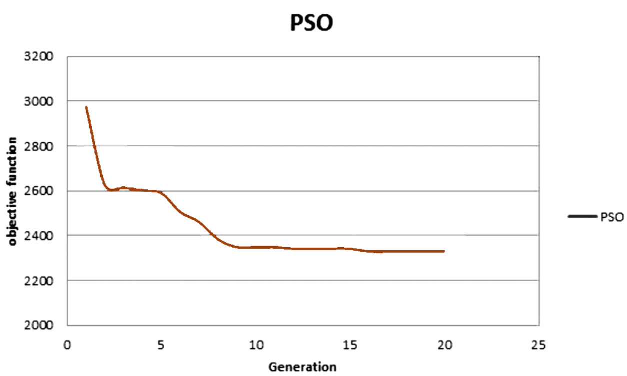

Figure 3. The objective function value per iteration

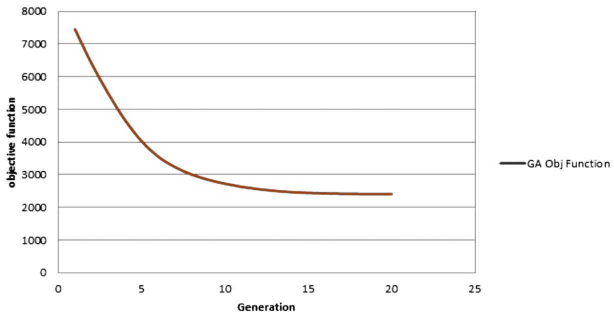

Figure 4 The objective function value per generation

GA

The variation of the objective function according to generations is shown in Figure 4. As shown in Figure 4 an objective function value is reduced to about 2500.

PSO & GA speed and accuracy analysis

In the previous sections, the error rates of the two methods were analyzed. In this section, the speed and accuracy of the methods are analyzed under equal conditions (Table 2).

Table 2: Conditions and constraints of the optimizer

GA	PSO
lower bound=400	lower bound=400
upper bound=500	upper bound=500
population size=3500	swarm size=3500
generation=200	maximum number of iteration=200

Under equal conditions, according to Table 2, both of the methods were tested: the run time needed for GA and PSO were found to be 392 and 223 sec. respectively. As a result, PSO was 76% faster.

In Figs 5-6, roughness values are shown for both GA and PSO methods for the 17 points of the network system. As the values indicate, both of the methods show reasonable degrees, but according to gas engineering analysis, the answers observed in PSO results seem to be more reliable.

Furthermore, the changes in roughness from one point to another were found to be relatively greater in PSO. Yet, in most of the points, the roughness in GA was observed to be less than that of PSO. According to Figs. 5-6, the maximum and minimum roughness rates were obtained in the PSO method. This finding showed that the rate of roughness changes in this method was greater and that in practice the method can problematize roughness changes.

It should be also noted that after about 500 tests on both methods, repeatability of GA was found to be much better than that of PSO. More specifically, the 500 tests on the two methods involved 500 optimization processes conducted on the sample under equal conditions to evaluate repeatability and to verify the performance of the methods. Figs. 6-7 show the variance of the answers based on the results.

As Table 3 shows, variance was used to compare roughness in the two methods. As a result, the degree of changes in PSO was found to be considerably higher (approximately two times greater), which would complicate its implementation. Figs. 6-7 illustrate the pattern of values and their variance for roughness of the two methods. As can be seen, the variance of values for GA is more limited; so one can arrive at the conclusion that the repeatability of roughness values was better in GA than in PSO (Table 3, Figures 5, 6). As mentioned above, the two methods GA and PSO were used to optimize roughness rates in the gas network under study.

Both methods did actually decrease network errors, but to compare them objectively, three criteria were taken into account: error rate, speed, and accuracy. As a result, PSO showed fewer errors and increased the speed and accuracy of the answers.

Yet, at the same time, the degree of point-to-point changes of PSO was found to be high. As a result, users are recommended to first calculate rate of roughness through PSO, and then rely on GA. Through this hybrid process, the results observed will have more speed and accuracy, while they will show fewer changes in answers.

Table 3: Result Variance

Title	PSO	GA
Pipe 1	9637.214	95649.17
Pipe 2	7323317	1822185
Pipe 3	2550420	2546315
Pipe 4	7041421	2469718
Pipe 5	27928.93	57971.79
Pipe 6	1933637	3131380
Pipe 7	7225785	2062032
Pipe 8	342.2096	2175652
Pipe 9	4291376	1086471
Pipe 10	2972490	2106808
Pipe 11	2455181	2058235
Pipe 12	4520820	643426.8
Pipe 13	6774454	1001154
Pipe 14	8326615	1230682
Pipe 15	1619731	1153129
Pipe 16	7659232	4622807
Pipe 17	2588888	2756354
Total	67321276	31019970

Conclusion

Clearly, it is essential to eliminate the errors in gas engineering software in the process of estimating pressure in different parts of gas distribution networks. In line with this, in the present study, PSO and GA algorithms were used to discover degrees of pipe roughness of each point. The results of this study indicated that the PSO method was faster than GA (the process time for GA was 76% more than that of PSO). Moreover, the objective function graphs showed that through reducing the number of generations, PSO could be much more accurate than GA. In other words, in this study, PSO was found to be more accurate than GA in providing answers. Moreover, PSO was found to be slightly faster.

Yet, GA, compared to PSO, showed more reliable answers. In other words, the distribution of PSO answers was found to be relatively higher than that of GA. Given the relative advantage of PSO in terms of speed and accuracy, and the

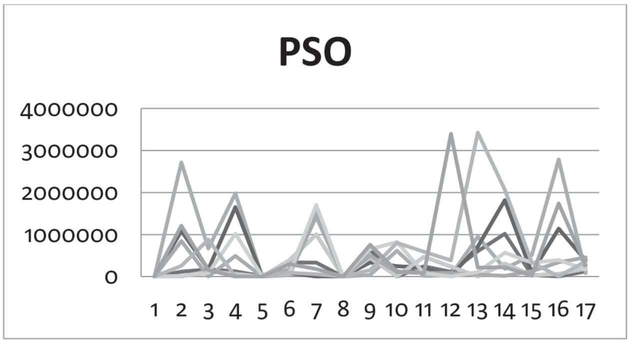

Figure 5: PSO's answers distribution

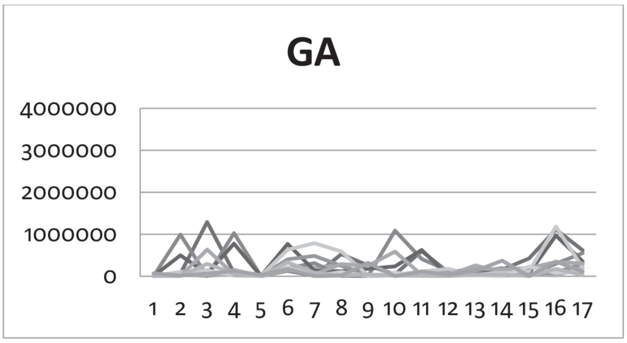

Figure 6.GA's answers distribution

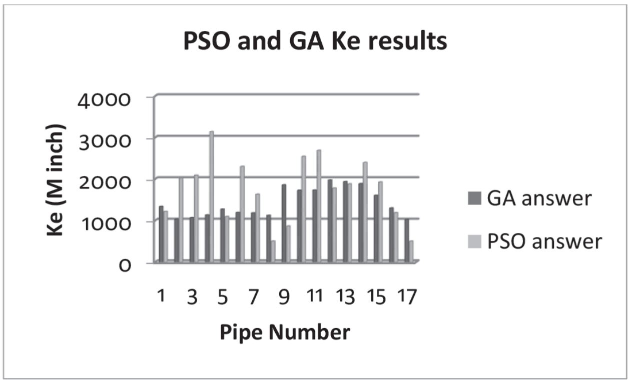

Figure 7. PSO and GA Ke results

slight advantage of GA in the third parameter, one can obtain optimized values by combining the two methods.

The general conclusion of the tuning process is that fuel costs can be cut in the pressure compressor stations, less time is wasted, and it is an exemplar of engineering. In other words, the process involves the design, development, and forecast of the structure, while machines function according to economical and safe goals. Thus, in future studies, an integrated model of GA and PSO can be investigated to provide better roughness values and answers with more accuracy, speed, and distribution.

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مقایسه و آنالیز عملکرد بهینه سازی معادلات Pressure-Flow در شبکه خطوط انتقال و توزیع گاز به دو روش الگوریتم ژنتیک و الگوریتم ازدحام

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چکیـــــــده

یکی از مهمترین اهداف مهندسی گاز، توزیع بهینه گاز در شبکه های انتقال و توزیع گاز است. هرچند که اغلب این فرایند از مسائل غیر قابل اجتنابی مانند وجود خطا در تخمین نادقیق فشار در نقاط مختلف شبکه رنج می برد. اخیرا روشهای بهینه سازی آماری برای حل این مشکل پیشنهاد شده است. روش های ازدحام ذرات و الگوریتم ژنتیک روشهای مرسوم بهینه سازی برای این هدف هستند. هدف از این مطالعه مقایسه عملکرد این دو روش در یک مثال واقعی از شبکه ایران است و با انجام آزمایش ۹۹,۹۹ درصد دقت بدست آمد. در شرایط اعمال محدودیت و بار محاسبات یکسان بر دو روش، عملکرد روش ازدحام ذرات سریعتر و دقیقتر از الگوریتم ژنتیک مشاهده گردید. هر چند که تکرارپذیری روش الگوریتم ژنتیک بهتر از روش ازدحام ذرات بود.

واژگان کلیدی: شبکه انتقال گاز، بهینه سازی، الگوریتم ژنتیک